

PREPARATION OF BIOACTIVE SURFACE VIA GEL OXIDATION ON
TITANIUM FOR BIOMEDICAL APPLICATION (HIP JOINT REPLACEMENT)

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ABSTRACT

Titanium and its alloys are widely used as implant in biomedical applications. They have good mechanical and chemical properties, biocompatibility and biointegration with human body, but they have no ability to bond directly to natural bone. Therefore, alkali and heat treatments (gel oxidation) were introduced to improve the bioactivity of titanium by forming a mixture of sodium titanate and rutile on the surface of titanium. This method enables titanium to possess a bioactive surface which is essential to induce the apatite formation. This study aims to investigate the effects of alkali, sodium removal and heat treatments on *in vitro* bioactivity of titanium. UV light irradiation was used to study the effect on *in vitro* bioactivity of titanium. Alkali-treated titanium subjected to heat treatment in air have shown better overall *in vitro* performance than those treated in argon atmosphere. Therefore, the sodium removal treatment (dilute hydrochloric acid (HCl) treatment) was introduced to convert sodium titanate into anatase to improve the bioactivity of titanium treated in argon atmosphere. Thus, four samples (AT-0.5-HT500R, AT-0.5-HT600R, AT-5-HT500R and AT-5-HT600R) with different ratios of anatase to rutile were produced by varying the concentration of HCl acid treatment and heating temperature in argon atmosphere. It was found that the incorporation of sodium removal treatment has reduced two times the duration of apatite formation as compared with the conventional alkali and heat treatments. In order to further enhance the bioactivity, these samples were subjected to six different conditions of ultraviolet light irradiation and followed by *in vitro* bioactivity test. As a result, AT-5-HT500R (82.2% anatase and 17.8% rutile) was proven to deliver the best performance. It was confirmed that UV light irradiation enhances the bioactivity by removing hydrocarbon, inducing superhydrophilicity and forming OH groups. It was discovered that the duration of apatite formation was shortened to 7 days. Furthermore, the continuous UVA irradiation during *in vitro* test resulted in the acceleration of bonelike apatite formation in 3 days. It can be concluded that the sodium removal treatment and UV light irradiation give very significant

impact to the formation of bonelike apatite on the titanium surfaces for biomedical applications.



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ABSTRAK

Titanium dan aloi merupakan bahan implant yang popular dalam bidang bioperubatan. Titanium mempunyai sifat mekanikal dan kimia yang bagus dan serasi dengan badan manusia. Namun demikian, titanium tidak dapat dilekatkan kepada tulang manusia. Oleh itu, perawatan alkali dan haba (pengoksidaan gel) telah diperkenalkan untuk meningkatkan bioaktiviti dengan pembentukan natrium titanate dan rutil atas permukaan titanium. Cara ini membolehkan titanium memiliki permukaan yang bioaktif yang penting untuk membantu pembentukan apatite dalam ujian *in vitro*. Tujuan kajian ini dijalankan adalah untuk menyiasat kesan-kesan perawatan alkali, penyingkiran natrium dan perawatan haba terhadap bioaktiviti titanium. Kajian ini juga menyiasat kesan radiasi ultra ungu terhadap bioaktiviti *in vitro* titanium. Kajian ini telah membuktikan bahawa titanium yang menjalani perawatan alkali dan haba dalam atmosfera udara adalah lebih baik berbanding dengan atmosfera argon dari segi prestasi *in vitro*. Untuk itu, rawatan penyingkiran natrium (rawatan pencairan asid HCl) diperkenalkan untuk menukarkan natrium titanate kepada anatase untuk meningkatkan bioaktiviti titanium yang menjalani perawatan alkali dan haba dalam atmosfera argon. Oleh itu, empat sampel yang mempunyai nisbah anatase kepada rutil yang berlainan telah dihasilkan, iaitu AT-0.5-HT500R, AT-0.5-HT600R, AT-5-HT500R dan AT-5-HT600R dengan menggunakan kepekatan asid HCl dan suhu perawatan haba dalam atmosfera argon yang berlainan. Penggabungan dengan perawatan penyingkiran natrium telah berjaya memendekkan masa pembentukan apatite sebanyak dua kali ganda berbanding dengan perawatan alkali dan haba yang biasa. Untuk meningkatkan lagi bioaktiviti titanium, sampel telah dipancarkan dengan radiasi ultra ungu dalam enam keadaan yang berbeza dan diikuti dengan ujian bioaktiviti *in vitro*. Hasilnya, AT-5-HT500R (82.2% anatase dan 17.8% rutil) adalah sampel terbaik dalam ujian *in vitro*. Ini telah dibuktikan bahawa radiasi ultra ungu telah berjaya menambah baik prestasi dengan cara penyingkiran hidrokarbon, peningkatan hidrofilik (superhydrophilicity) dan pembentukan kumpulan OH. Ia turut

didapati bahawa masa pembentukan apatite seperti tulang telah dipendekkan lagi kepada 7 hari. Tambahan lagi, radiasi UVA yang berterusan semasa ujian *in vitro* dapat mempercepatkan masa pembentukan apatite seperti tulang kepada 3 hari. Kesimpulannya, perawatan penyingkiran natrium dan radiasi ultra ungu membawa impak yang penting kepada pembentukan apatite atas permukaan titanium untuk bidang bioperubatan.



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REFERENCES

- Aita, H., Hori, N., Takeuchi, M., Suzuki, T., Yamada, M., Anpo, M., & Ogawa, T. (2009a). The effect of ultraviolet functionalization of titanium on integration with bone. *Biomaterials*, 30(6), 1015-1025.
- Aita, H., Att, W., Ueno, T., Yamada, M., Hori, N., Iwasa, F., Tsukimura, N. and Ogawa, T. (2009b). Ultraviolet light-mediated photofunctionalization of titanium to promote human mesenchymal stem cell migration, attachment, proliferation and differentiation. *Acta Biomaterialia*, 5(8), 3247-3257.
- Akpan, U. G., & Hameed, B. H. (2009). Parameters affecting the photocatalytic degradation of dyes using TiO₂-based photocatalysts: A review. *Journal of Hazardous Materials*, 170(2-3), 520–9.
- Alla, R. K., Ginjupalli, K., Upadhya, N., Shamma, M., Krishna, R., & Sekhar, R. (2011). Surface roughness of implants : A review. *Trends in Biomaterials & Artificial Organs*, 25, 112–118.
- Allan, B. (1999). Closer to nature: New biomaterials and tissue engineering in ophthalmology. *British Journal of Ophthalmology*, 83(11), 1235–1240.
- Att, W., Hori, N., Iwasa, F., Yamada, M., Ueno, T., & Ogawa, T. (2009). The effect of UV-photofunctionalization on the time-related bioactivity of titanium and chromium–cobalt alloys. *Biomaterials*, 30(26), 4268-4276.
- Baier, R. E., & Meyer, A. E. (1988). Implant surface preparation. *International Journal of Oral & Maxillofacial Implants*, 3(1), 9-12.
- Bauer, S., Schmuki, P., von der Mark, K., & Park, J. (2013). Engineering biocompatible implant surfaces: Part I: Materials and surfaces. *Progress in Materials Science*, 58(3), 261-326.
- Becker, I., Hofmann, I., & Müller, F. A. (2007). Preparation of bioactive sodium titanate ceramics. *Journal of the European Ceramic Society*, 27, 4547–4553.
- Bhatia, S. K. (2010). *Biomaterials for clinical applications*. Springer Science Business Media, LLC.

- Bico, J., Thiele, U., & Quéré, D. (2002). Wetting of textured surfaces. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 206(1-3), 41-46.
- Blokhuis, T. J., Termaat, M. F., den Boer, F. C., Patka, P., Bakker, F. C., & Haarman, H. J. (2000). Properties of calcium phosphate ceramics in relation to their in vivo behavior. *The Journal of Trauma, Injury, Infection, and Critical Care*, 48(1), 179–186.
- Bojian, L., Shunsuke, F., Masashi, N., Jiro, T. (2003). Histological and mechanical investigation of the bone-bonding ability of anodically oxidized titanium in rabbits. *Biomaterials* 24, 4959-4966.
- Bosco, R., Edreira, E. R. U., Wolke, J. G. C., Leeuwenburgh, S. C. G., van den Beucken, J. J. J. P., & Jansen, J. A. (2013). Instructive coatings for biological guidance of bone implants. *Surface and Coatings Technology*, 233, 91–98.
- Brunette, D. M., Tengvall, P., Textor, M., & Thomsen, P. (Eds.). (2012). *Titanium in medicine: material science, surface science, engineering, biological responses and medical applications*. Springer Science & Business Media.
- C1624-05(2010). Standard test method for adhesion strength and mechanical failure modes of ceramic coatings by quantitative single point scratch testing. Annual Book of ASTM Standards 15.01: ASTM.
- Cai, Y. (2013). *Titanium dioxide photocatalysis in biomaterials applications*. Uppsala University: Ph.D. Thesis.
- Cangiani, G. (2003). *Ab-initio study of the properties of TiO₂ rutile and anatase polytypes*. EPFL.
- Cao, H., & Liu, X. (2013). Activating titanium oxide coatings for orthopedic implants. *Surface and Coatings Technology*, 233, 57–64.
- Carp, O., Huisman, C. L., & Reller, A. (2004). Photoinduced reactivity of titanium dioxide. *Progress in Solid State Chemistry*, 32(1-2), 33–177.
- Chang, K. L., Sekiguchi, K., Wang, Q., & Zhao, F. (2013). Removal of ethylene and secondary organic aerosols using UV-C₂₅₄₊₁₈₅ nm with TiO₂ catalyst. *Aerosol and Air Quality Research*, 13, 618-626.
- Chen, M. F., Zhang, J., & You, C. (2013). Ultraviolet-accelerated formation of bone-like apatite on oxidized Ti-24Nb-4Zr-7.9Sn alloy. *Frontiers of Materials Science*, 7(4), 362-369.

- Chong, M. N., Jin, B., Chow, C. W., & Saint, C. (2010). Recent developments in photocatalytic water treatment technology: a review. *Water Research*, 44(10), 2997-3027.
- Choudhury, B., & Choudhury, A. (2013). Local structure modification and phase transformation of TiO₂ nanoparticles initiated by oxygen defects, grain size, and annealing temperature. *International Nano Letters*, 3(1), 1-9.
- Costantini, A., Luciani, G., Branda, F., Ambrosio, L., Mattogno, G., & Pandolfi, L. (2002). Hydroxyapatite coating of titanium by biomimetic method. *Journal of Materials Science: Materials in Medicine*, 13(9), 891-894.
- Cui, C., Hu, B., Zhao, L., & Liu, S. (2011). Titanium alloy production technology, market prospects and industry development. *Materials & Design*, 32(3), 1684–1691.
- Dai, S., Wu, Y., Sakai, T., Du, Z., Sakai, H., & Abe, M. (2010). Preparation of highly crystalline TiO₂ nanostructures by acid-assisted hydrothermal treatment of hexagonal-structured nanocrystalline titania/cetyltrimethylammonium bromide nanoskeleton. *Nanoscale Research Letters*, 5(11), 1829.
- De Aza, P.N., Guitian, F., De Aza, S. (1997). Bioeutectic: A new ceramic material for human bone replacement. *Biomaterials* 18:1285–1291.
- Dee, K. C., Puleo, D. A., & Bizios, R. (2003). *An introduction to tissue-biomaterial interactions*. John Wiley & Sons.
- Diamanti, M. V., Codeluppi, S., Cordioli, a., & Pedefferri, M. P. (2009). Effect of thermal oxidation on titanium oxides' characteristics. *Journal of Experimental Nanoscience*, 4, 365–372.
- Diebold, U. (2003). The surface science of titanium dioxide. *Surface Science Reports*, 48(5-8), 53–229.
- Dominique, G. P. (2004). *Biomechanics and biomaterials in orthopedics*. Springer-Verlag London Limited.
- Donachie, M. J. (2000). *Titanium: a technical guide*. ASM international.
- Donald, L. W., Debra, J. T., Kai-Uwe, L. (2000). *Biomaterials engineering and devices: Human applications: Volume 2. Orthopedic, dental, and bone graft applications*. Springer Science Business Media, LLC.
- Dowson, D. (1995). A comparative study of the performance of metallic and ceramic femoral head components in total replacement hip joints, *Wear* 190, 171-183.

- Ehrlich, P. Z. (1939) Phasenverhältnisse und magnetisches Verhalten im System Titan/Sauerstoff. *Z. Elektrochem.* 45, 362–370.
- Fatehi, K., Moztafarzadeh, F., & Tahriri, M. (2008). In vitro biomimetic deposition of apatite on alkaline and heat treated Ti6Al4V alloy surface. *Bulletin of Materials Science*, 31(2), 101–108.
- Faure, J., Balamurugan, A., Benhayoune, H., Torres, P., Balossier, G., & Ferreira, J. M. F. (2009). Morphological and chemical characterisation of biomimetic bone like apatite formation on alkali treated Ti6Al4V titanium alloy. *Materials Science and Engineering*, 29, 1252–1257.
- Fawzy, A. S., & Amer, M. A. (2009). An in vitro and in vivo evaluation of bioactive titanium implants following sodium removal treatment. *Dental Materials*, 25(1), 48-57.
- Feng, B., Weng, J., Yang, B. C., Chen, J. Y., Zhao, J. Z., He, L., Qi, S.K. and Zhang, X. D. (2002). Surface characterization of titanium and adsorption of bovine serum albumin. *Materials Characterization*, 49(2), 129-137.
- Ferraris, S., Spriano, S., Pan, G., Venturello, A., Bianchi, C. L., Chiesa, R., Faga, M. G., Maina, G., & Vernè, E. (2011). Surface modification of Ti–6Al–4V Alloy for biomineralization and specific biological response: Part I, Inorganic modification. *Journal of Materials Science: Materials in Medicine*, 22(3), 533-545.
- Francisco, M. S. P., & Mastelaro, V. R. (2002). Inhibition of the anatase-rutile phase transformation with addition of CeO₂ to CuO-TiO₂ system: Raman spectroscopy, X-ray diffraction, and textural studies. *Chemistry of Materials*, 14(6), 2514-2518.
- Fromhold Jr, A. T. (1976). Theory of metal oxidation. Vol. I. Fundamentals. *North Holland Publishing Co., Amsterdam, New York and Oxford*. 1976, 547 p.
- Fujishima, A., Rao, T. N., & Tryk, D. A. (2000). Titanium dioxide photocatalysis. *Journal of Photochemistry and Photobiology C: Photochemistry Reviews*, 1(1), 1-21.
- Gandolfi, M. G., Taddei, P., Siboni, F., Perrotti, V., Iezzi, G., Piattelli, A., & Prati, C. (2015). Micro-topography and reactivity of implant surfaces: an in vitro study in simulated body fluid (SBF). *Microscopy and Microanalysis*, 21(1), 190-203.

- Geetha, M., Singh, A. K., Asokamani, R., & Gogia, A. K. (2009). Ti based biomaterials, the ultimate choice for orthopaedic implants – A review. *Progress in Materials Science*, 54(3), 397–425.
- Gemelli, E., & Camargo, N. H. A. (2007). Oxidation kinetics of commercially pure titanium. *Matéria (Rio de Janeiro)*, 12(3), 525-531.
- Gil, F. J., Padro, A., Manero, J. M., Aparicio, C., Nilsson, M., & Planell, J. A. (2002). Growth of bioactive surfaces on titanium and its alloys for orthopaedic and dental implants. *Materials Science and Engineering*, 22, 53–60.
- Giordano, C., Sandrini, E., Del Curto, B., Signorelli, E., Rondelli, G., & Di Silvio, L. (2004). Titanium for osteointegration: Comparison between a novel biomimetic treatment and commercially exploited surfaces. *Journal of Applied Biomaterials and Biomechanics*, 2(1), 35-44.
- Giordano, N. (2012). *College physics* (Vol. 1). Nelson Education.
- Greenwood, H. L., Singer, P. A., Downey, G. P., Martin, D. K., Thorsteinsdottir, H., & Daar, A. S. (2006). Regenerative medicine and the developing world. *PLoS Medicine*, 3(9), e381.
- Gshalaev, V. S., & Demirchan, A. C. (2012). *Hydroxyapatite: Synthesis, properties, and applications*. Nova Science Publishers.
- Han, Y., Chen, D., Sun, J., Zhang, Y., & Xu, K. (2008). UV-enhanced bioactivity and cell response of micro-arc oxidized titania coatings. *Acta Biomaterialia*, 4, 1518–1529.
- Hamouda, I. M., Enan, E. T., Al-Wakeel, E. E., & Yousef, M. K. M. (2012). Alkali and heat treatment of titanium implant material for bioactivity. *The International Journal of Oral & Maxillofacial Implants*, 27, 776–84.
- Hanaor, D. A. H., & Sorrell, C. C. (2011). Review of the anatase to rutile phase transformation. *Journal of Materials Science*, 46, 855–874.
- Hashimoto, K., Irie, H., & Fujishima, A. (2005). TiO₂ photocatalysis: A historical overview and future prospects. *Japanese Journal of Applied Physics*, 44(12R), 8269.
- Hao, L., Guan, S., Lu, Y., Qiu, W., He, Y., & Liu, J. (2016). Surface topography evolution of TiO₂/SnO₂ coatings during thermal oxidation of Ti/Sn composite coatings. *Surface & Coatings Technology*, 291, 325–333.
- He, Z., Cai, Q., Fang, H., Situ, G., Qiu, J., Song, S., & Chen, J. (2013). Photocatalytic activity of TiO₂ containing anatase nanoparticles and rutile nanoflower



- structure consisting of nanorods. *Journal of Environmental Sciences*, 25(12), 2460-2468.
- Hench, L. L. & Wilson, J. (1993). *An introduction to bioceramics*. World Scientific Publishing Co. Pte. Ltd.
- Hristova, E., Arsov, L., Popov, B. N., & White, R. E. (1997). Ellipsometric and raman spectroscopic study of thermally formed films on titanium. *Journal of the Electrochemical Society*, 144(7), 2318-2323.
- Holzwarth, U., & Cotogno, G. (2012). Total hip arthroplasty—State of the art, challenges and prospects. *Joint Research Centre of the European Commission, Publications Office of the European Union, Luxembourg*.
- Hori, N., Iwasa, F., Tsukimura, N., Sugita, Y., Ueno, T., Kojima, N., & Ogawa, T. (2011). Effects of UV photofunctionalization on the nanotopography enhanced initial bioactivity of titanium. *Acta Biomaterialia*, 7(10), 3679-3691.
- Horkavcová, D., Plesingerova, B., Helebrant, A., Vojtko, M., & Prochazka, V. (2008). Adhesion of the bioactive layer on titanium alloy substrate by tape-test. *Ceramics-Silikaty*, 52(3), 130-138.
- Hsu, H.-C., Wu, S.-C., Fu, C.-L., & Ho, W.-F. (2010). Formation of calcium phosphates on low-modulus Ti-7.5Mo alloy by acid and alkali treatments. *Journal of Materials Science*, 45, 3661–3670.
- Hutmacher, D., Hürzeler, M. B., & Schliephake, H. (2000). A review of material properties of biodegradable and bioresorbable polymers and devices for GTR and GBR applications. *The International Journal of Oral & Maxillofacial Implants*, 11(5), 667–78.
- Ivasyshyn, O. M., & Aleksandrov, A. V. (2008). Status of the titanium production, research, and applications in the CIS. *Materials Science*, 44(3), 311-327.
- Izman, S., Abdul-Kadir, M. R., Anwar, M., Nazim, E. M., Rosliza, R., Shah, A., & Hassan, M. A. (2012). *Surface modification techniques for biomedical grade of titanium alloys: Oxidation, carburization and ion implantation processes, titanium alloys - towards achieving enhanced properties for diversified applications*, Dr. Amin, A. K. M. N. (Ed.)
- Jeong, J., Sekiguchi, K., Lee, W., & Sakamoto, K. (2005). Photodegradation of gaseous volatile organic compounds (VOCs) using TiO₂ photoirradiated by an ozone-producing UV lamp: Decomposition characteristics, identification of

- by-products and water-soluble organic intermediates. *Journal of photochemistry and photobiology A: chemistry*, 169(3), 279-287.
- Jokanović, B., Vilotijevic, M., Jenko, M., Stamenkovic, D., Lazic, V., Rudolf, R., & Anz, I. (2014). Investigations of corrosion on the surface of titanium substrate caused by combined alkaline and heat treatment. *Corrosion Science*, 82, 180–190.
- Jonášová, L., Müller, F. A., Helebrant, A., Strnad, J., & Greil, P. (2004). Biomimetic apatite formation on chemically treated titanium. *Biomaterials*, 25, 1187–1194.
- Jouanny, I., Labdi, S., Aubert, P., Buscema, C., Maciejak, O., Berger, M.-H., Jeandin, M. (2010). Structural and mechanical properties of titanium oxide thin films for biomedical application. *Thin Solid Films*, 518, 3212–3217.
- Karaolia, P., Michael-Kordatou, I., Hapeshi, E., Drosou, C., Bertakis, Y., Christofilos, D., Armatas, G.S., Sygellou, L., Schwartz, T., Xekoukoulotakis, N.P. & Fatta-Kassinou, D. (2018). Removal of antibiotics, antibiotic-resistant bacteria and their associated genes by graphene-based TiO₂ composite photocatalysts under solar radiation in urban wastewaters. *Applied Catalysis B: Environmental*, 224, 810-824.
- Karthega, M., & Rajendran, N. (2010). Hydrogen peroxide treatment on Ti–6Al–4V alloy: A promising surface modification technique for orthopaedic application. *Applied Surface Science*, 256, 2176–2183.
- Kawai, T., Kizuki, T., Takadama, H., Matsushita, T., Unuma, H., Nakamura, T., & Kokubo, T. (2010). Apatite formation on surface titanate layer with different Na content on Ti metal. *Journal of the Ceramic Society of Japan*, 118(1373), 19-24.
- Kawanabe, K., Ise, K., Goto, K., Akiyama, H., Nakamura, T., Kaneuji, A., Sugimori, T., & Matsumoto, T. (2009). A new cementless total hip arthroplasty with bioactive titanium porous-coating by alkaline and heat treatment: Average 4.8-year results. *Journal of Biomedical Materials Research Part B: Applied Biomaterials*, 90(1), 476-481.
- Kazemi, M., & Mohammadzadeh, M. R. (2011). Superhydrophilicity and photocatalytic enhancement of titania nano thin films. *Applied Surface Science*, 257(8), 3780-3785.

- Khan, A. F., Awais, M., Khan, A. S., Tabassum, S., Chaudhry, A. A., & Rehman, I. U. (2013). Raman spectroscopy of natural bone and synthetic apatites. *Applied Spectroscopy Reviews*, 48(4), 329-355.
- Khanna, A. S. (2002). *Introduction to high temperature oxidation and corrosion*. ASM international.
- Kim, H.-M., Miyaji, F., Kokubo, T., & Nakamura, T. (1997). Effect of heat treatment on apatite-forming ability of Ti metal induced by alkali treatment. *Journal of Materials Science. Materials in Medicine*, 8, 341–347.
- Kim, S. H., Shahbaz, H. M., Park, D., Chun, S., Lee, W., Oh, J. W., Lee, D.U. & Park, J. (2017). A combined treatment of UV-assisted TiO₂ photocatalysis and high hydrostatic pressure to inactivate internalized murine norovirus. *Innovative Food Science & Emerging Technologies*, 39, 188-196.
- Kizuki, T., Takadama, H., Matsushita, T., Nakamura, T., & Kokubo, T. (2010). Preparation of bioactive Ti metal surface enriched with calcium ions by chemical treatment. *Acta Biomaterialia*, 6, 2836–2842.
- Klančnik, G., Zdovc, M., Kovšca, U., Praček, B., & Kovač, J. (2010). Osseointegration and rejection of a titanium screw. *Materials and Technology*, 44(5), 261–264.
- Kobayashi, S., Inoue, T., & Nakai, K. (2005). Effect of heat treatment on cohesion of films on alkali-treated titanium. *Materials Transactions*, 46(2), 207–210.
- Kofstad, P. (1988). High temperature corrosion. *Elsevier Applied Science Publishers, Crown House, Linton Road, Barking, Essex IG 11 8 JU, UK, 1988*.
- Kokubo, T., Kim, H. M., & Kawashita, M. (2003). Novel bioactive materials with different mechanical properties. *Biomaterials*, 24(13), 2161-2175.
- Kokubo, T., & Takadama, H. (2006). How useful is SBF in predicting in vivo bone bioactivity?. *Biomaterials*, 27, 2907–2915.
- Kokubo, T., Matsushita, T., & Takadama, H. (2007). Titania-based bioactive materials. *Journal of the European Ceramic Society*, 27(2), 1553-1558.
- Kokubo, T., Matsushita, T., Takadama, H., & Kizuki, T. (2009a). Development of bioactive materials based on surface chemistry. *Journal of the European Ceramic Society*, 29, 1267–1274.
- Kokubo, T., & Yamaguchi, S. (2009b). Novel bioactive titanate layers formed on Ti metal and its alloys by chemical treatments. *Materials*, 3(1), 48-63.
- Kolen'ko, Y. V., Kovnir, K. A., Gavrillov, A. I., Garshev, A. V., Frantti, J., Lebedev, O. I., Churagulov, B.R., Van Tendeloo, G. and Yoshimura, M (2006).

- Hydrothermal synthesis and characterization of nanorods of various titanates and titanium dioxide. *The Journal of Physical Chemistry B*, 110(9), 4030-4038.
- Konstantinou, I. K., & Albanis, T. A. (2004). TiO₂-assisted photocatalytic degradation of azo dyes in aqueous solution: kinetic and mechanistic investigations: a review. *Applied Catalysis B: Environmental*, 49(1), 1-14.
- Kumar, S., Narayanan, T. S. N. S., Raman, S. G. S., & Seshadri, S. K. (2010). Thermal oxidation of CP Ti — an electrochemical and structural characterization. *Materials Characterization*, 61, 589–597.
- Kumar, S. G., & Rao, K. K. (2014). Polymorphic phase transition among the titania crystal structures using a solution-based approach: from precursor chemistry to nucleation process. *Nanoscale*, 6(20), 11574-11632.
- Lan, Y., Lu, Y., & Ren, Z. (2013). Mini review on photocatalysis of titanium dioxide nanoparticles and their solar applications. *Nano Energy*, 2, 1031–1045.
- Langer, R. S., & Vacanti, J. P. (1999). Tissue engineering: The challenges ahead. *Scientific American*, 280(4), 86-89.
- Lee, F. K., Andreatta, G., & Benattar, J. J. (2007). Role of water adsorption in photoinduced superhydrophilicity on TiO₂ thin films. *Applied Physics Letters*, 90(18), 181928.
- Lee, J., Mubeen, S., Ji, X., Stucky, G. D., & Moskovits, M. (2012). Plasmonic photoanodes for solar water splitting with visible light. *Nano letters*, 12(9), 5014-5019.
- Lemons, J. E. (1990). Bioceramics: Is there a difference?. *Clinical Orthopaedics and Related Research*, 261, 153-158.
- Lemons, J. E. (1996). Ceramics: Past, present, and future. *Bone*, 19(1), S121-S128.
- Lenarduzzi, E., Bounie, P., Schuman, C., Philippe, M.-J., & Petelot, D. (2003). Titanium oxidation during thermal treatment: Inhibiting role of nitrogen and epitaxial orientation relations evidenced by EBSD. *Advanced Engineering Materials*, 5, 587–593.
- Leyens, C., & Peters, M. (Eds.) (2003). *Titanium and titanium alloys: Fundamentals and applications*. Wiley-VCH Verlag GmbH & Co. KGaA.
- Liang, F., Zhou, L., & Wang, K. (2003). Apatite formation on porous titanium by alkali and heat-treatment. *Surface and Coatings Technology*, 165, 133–139.

- Lim, Y. J., Oshida, Y., Andres, C. J., & Barco, M.T. (2001). Surface characterizations of variously treated titanium materials. *The International Journal of Oral & Maxillofacial Implants*, 16, 333–342.
- Lin, F.-H., Hsu, Y.-S., Lin, S.-H., & Chen, T.-M. (2004). The growth of hydroxyapatite on alkaline treated Ti–6Al–4V soaking in higher temperature with concentrated $\text{Ca}^{2+}/\text{HPO}_4^{2-}$ simulated body fluid. *Materials Chemistry and Physics*, 87, 24–30.
- Lin, J.-H., Chang, C.-H., Chen, Y.-S., & Lin, G.-T. (2006). Formation of bone-like apatite on titanium filament by a simulated body fluid inducing process. *Surface and Coatings Technology*, 200, 3665–3669.
- Lin, L., Wang, H., Ni, M., Rui, Y., Cheng, T.-Y., Cheng, C.-K., Pan, X., Li, G., Lin, C. (2013). Enhanced osteointegration of medical titanium implant with surface modifications in micro/nanoscale structures. *Journal of Orthopaedic Translation*, 1–8.
- Linsebigler, A. L., Lu, G., & Yates Jr, J. T. (1995). Photocatalysis on TiO_2 surfaces: principles, mechanisms, and selected results. *Chemical Reviews*, 95(3), 735–758.
- Lindahl, C., Engqvist, H., & Xia, W. (2013). Influence of surface treatments on the bioactivity of Ti. *ISRN Biomaterials*, 2013, 1-13.
- Liu, F., Song, Y., Wang, F., Shimizu, T., Igarashi, K., & Zhao, L. (2005). Formation characterization of hydroxyapatite on titanium by microarc oxidation and hydrothermal treatment. *Journal of Bioscience and Bioengineering*, 100(1), 100-104.
- Liu, H., Waclawik, E. R., Zheng, Z., Yang, D., Ke, X., Zhu, H., & Frost, R. L. (2010a). TEM investigation and FBB model explanation to the phase relationships between titanates and titanium dioxides. *The Journal of Physical Chemistry C*, 114, 11430–11434.
- Liu, H., Yang, D., Zheng, Z., Ke, X., Waclawik, E., Zhu, H., & Frost, R. L. (2010b). A raman spectroscopic and TEM study on the structural evolution of $\text{Na}_2\text{Ti}_3\text{O}_7$ during the transition to $\text{Na}_2\text{Ti}_6\text{O}_{13}$. *Journal of Raman Spectroscopy*, 41, 1331–1337.
- Liu, X., Chu, P., & Ding, C. (2004). Surface modification of titanium, titanium alloys, and related materials for biomedical applications. *Materials Science and Engineering: R: Reports*, 47(3), 49–121.

- Liu, X., Zhao, X., Li, B., Cao, C., Dong, Y., Ding, C., & Chu, P. K. (2008). UV-irradiation-induced bioactivity on TiO₂ coatings with nanostructural surface. *Acta Biomaterialia*, 4, 544–552.
- Lu, H., Zhou, L., Wan, L., Li, S., Rong, M., & Guo, Z. (2012). Effects of storage methods on time-related changes of titanium surface properties and cellular response. *Biomedical Materials*, 7, 1-9.
- Lu, X., Wang, Y., Yang, X., Zhang, Q., Zhao, Z., Weng, L. T., & Leng, Y. (2008). Spectroscopic analysis of titanium surface functional groups under various surface modification and their behaviors in vitro and in vivo. *Journal of Biomedical Materials Research Part A*, 84(2), 523-534.
- Malhotra, R. (Ed.) (2012). *Total hip arthroplasty*. New Delhi: Jaypee Brothers Medical Publishers (P) Ltd.
- Mavrogenis, A. F., Dimitriou, R., Parvizi, J., & Babis, G. C. (2009). Biology of implant osseointegration. *Journal of Musculoskeletal & Neuronal Interactions*, 9(2), 61–71.
- Milan, T., Biljana, G., Dimitri, B., Desai, D. (2006). Surface modifications of a titanium implant by a picoseconds Nd: YAG laser operating at 1064 and 532nm. *Applied Surface Science*, 253, 2551-2556.
- Murphy, C. M., O'Brien, F. J., Little, D. G., & Schindeler, A. (2013). Cell-scaffold interactions in the bone tissue engineering triad. *European Cells & Materials*, 26, 120–132.
- Nada, A. A., Barakat, M. H., Hamed, H. A., Mohamed, N. R., & Veziroglu, T. N. (2005). Studies on the photocatalytic hydrogen production using suspended modified TiO₂ photocatalysts. *International Journal of Hydrogen Energy*, 30(7), 687-691.
- Nayak, A. K. (2010). Hydroxyapatite synthesis methodologies: An overview. *International Journal of ChemTech Research*, 2(2), 903–907. Mucalo, M. (Ed.). (2015). *Hydroxyapatite (HAp) for biomedical applications*. Elsevier
- Nishiguchi, S., Nakamura, T., Kobayashi, M., Kim, H.-M., Miyaji, F., & Kokubo, T. (1999). The effect of heat treatment on bone-bonding ability of alkali-treated titanium. *Biomaterials*, 20, 491–500.
- Nishio, K., Neo, M., Akiyama, H., Nishiguchi, S., Kim, H.-M., Kokubo, T., & Nakamura, T. (2000). The effect of alkali-and heat-treated titanium and apatite-

- formed titanium on osteoblastic differentiation of bone marrow cells. *Journal of Biomedical Materials Research*, 52(4), 652-661.
- Nolan, N. T., Seery, M. K., & Pillai, S. C. (2009). Spectroscopic investigation of the anatase-to-rutile transformation of sol-gel-synthesized TiO₂ photocatalysts. *The Journal of Physical Chemistry C*, 113(36), 16151-16157.
- Ochiai, T., Hoshi, T., Slimen, H., Nakata, K., Murakami, T., Tatejima, H., Koide, Y., Houas, A., Horie, T., Morito, Y. & Fujishima, A. (2011). Fabrication of a TiO₂ nanoparticles impregnated titanium mesh filter and its application for environmental purification. *Catalysis Science & Technology*, 1(8), 1324-1327.
- Ohtsu, N., Masahashi, N., Mizukoshi, Y., & Wagatsuma, K. (2009). Hydrocarbon decomposition on a hydrophilic TiO₂ surface by UV irradiation: spectral and quantitative analysis using in-situ XPS technique. *Langmuir*, 25(19), 11586-11591.
- Okazumi, T., Ueda, K., Tajima, K., Umetsu, N., & Narushima, T. (2010). Anatase formation on titanium by two-step thermal oxidation. *Journal of Materials Science*, 46, 2998-3005.
- Ozaki, Y., & Kawata, S. (Eds.). (2015). *Far-and deep-ultraviolet spectroscopy*. Tokyo, Japan: Springer.
- Padma, R., Ramkumar, K., & Satyam, M. (1988). Growth of titanium oxide overlayers by thermal oxidation of titanium. *Journal of Materials Science*, 23, 1591-1597.
- Pan, H., Zhao, X., Darvell, B. W., & Lu, W. W. (2010). Apatite-formation ability-predictor of "bioactivity"? *Acta Biomaterialia*, 6, 4181-4188.
- Park, J. B., & Bronzino, J. D. (Eds.). (2002). *Biomaterials: Principles and applications*. CRC Press.
- Park, J., & Lakes, R. S. (2007). *Biomaterials: An introduction*. Springer Science Business Media, LLC.
- Park, K., Meunier, V., Pan, M., & Plummer, W. (2013). Defect-driven restructuring of TiO₂ surface and modified reactivity toward deposited gold atoms. *Catalysts*, 3(1), 276-287
- Patel, N. R., & Gohil, P. P. (2012). A review on biomaterials: Scope, applications & human anatomy significance. *International Journal of Emerging Technology and Advanced Engineering*, 2(4), 91-101.
- Patka, P. (1984). *Bone replacement by calcium phosphate ceramics. An experimental study*. Amsterdam: Free University Press: Thesis.

- Pattanayak, D. K., Kawai, T., Matsushita, T., Takadama, H., Nakamura, T., & Kokubo, T. (2009). Effect of HCl concentrations on apatite-forming ability of NaOH-HCl- and heat-treated titanium metal. *Journal of Materials Science: Materials in Medicine*, 20, 2401–2411.
- Pattanayak, D. K., Yamaguchi, S., Matsushita, T., Nakamura, T., & Kokubo, T. (2012). Apatite-forming ability of titanium in terms of pH of the exposed solution. *Journal of the Royal Society Interface*, rsif20120107.
- Paz, Y., & Heller, A. (1997). Photo-oxidatively self-cleaning transparent titanium dioxide films on soda lime glass: The deleterious effect of sodium contamination and its prevention. *Journal of Materials Research*, 12(10), 2759-2766.
- Peng, X., & Chen, A. (2004). Aligned TiO₂ nanorod arrays synthesized by oxidizing titanium with acetone. *Journal of Materials Chemistry*, 14, 2542–2548.
- Pezzotti, G., & Yamamoto, K. (2014). Artificial hip joints: The biomaterials challenge. *Journal of the Mechanical Behavior of Biomedical Materials*, 31, 3-20.
- Prakasam, M., Locs, J., Salma-Ancane, K., Loca, D., Largeteau, A., & Berzina-Cimdina, L. (2015). Fabrication, properties and applications of dense hydroxyapatite: A review. *Journal of Functional Biomaterials*, 6(4), 1099-1140.
- Puma, G. L., Puddu, V., Tsang, H. K., Gora, A., & Toepfer, B. (2010). Photocatalytic oxidation of multicomponent mixtures of estrogens (estrone (E1), 17 β -estradiol (E2), 17 α -ethynylestradiol (EE2) and estriol (E3)) under UVA and UVC radiation: Photon absorption, quantum yields and rate constants independent of photon absorption. *Applied Catalysis B: Environmental*, 99(3), 388-397.
- Ravelingien, M., Mullens, S., Luyten, J., Meynen, V., Vinck, E., Vervaet, C., & Paul, J. (2009). Thermal decomposition of bioactive sodium titanate surfaces. *Applied Surface Science*, 255, 9539–9542.
- Reis, D. A. P., Machado, J. P. B., Martins, G. V., Moura, C. N., Barboza, M. J. R., & Couto, A. A. (2010). Study of oxide layers in creep of Ti alloy. *Materials Science Forum*, 660-661, 1087–1092.

- Ribeiro, A. A., Balestra, R. M., Rocha, M. N., Peripolli, S. B., Andrade, M. C., Pereira, L. C., & Oliveira, M. V. (2013). Dense and porous titanium substrates with a biomimetic calcium phosphate coating. *Applied Surface Science*, 265, 250–256.
- Rtimi, S., Nestic, J., Pulgarin, C., Sanjines, R., Bensimon, M., & Kiwi, J. (2015). Effect of surface pretreatment of TiO₂ films on interfacial processes leading to bacterial inactivation in the dark and under light irradiation. *Interface focus*, 5(1), 20140046.
- Rupp, F., Scheideler, L., Rehbein, D., Axmann, D., & Geis-Gerstorfer, J. (2004). Roughness induced dynamic changes of wettability of acid etched titanium implant modifications. *Biomaterials*, 25(7), 1429-1438.
- Rupp, F., Scheideler, L., Olshanska, N., De Wild, M., Wieland, M., & Geis-Gerstorfer, J. (2006). Enhancing surface free energy and hydrophilicity through chemical modification of microstructured titanium implant surfaces. *Journal of Biomedical Materials Research Part A*, 76(2), 323-334.
- Saita, M., Ikeda, T., Yamada, M., Kimoto, K., Lee, M. C. I., & Ogawa, T. (2016). UV photofunctionalization promotes nano-biomimetic apatite deposition on titanium. *International Journal of Nanomedicine*, 11, 223-234.
- Samavedi, S., Whittington, A. R., & Goldstein, A. S. (2013). Calcium phosphate ceramics in bone tissue engineering: A review of properties and their influence on cell behavior. *Acta Biomaterialia*, 9, 8037–8045.
- Santos Jr, A. R. (2010). Bioresorbable polymers for tissue engineering. Tissue engineering, Daniel Eberli (Ed.)
- Saunders, S. R. J., Monteiro, M., & Rizzo, F. (2008). The oxidation behaviour of metals and alloys at high temperatures in atmospheres containing water vapour: A review. *Progress in Materials Science*, 53(5), 775-837.
- Seal, B. L., Otero, T. C., & Panitch, A. (2001). Polymeric biomaterials for tissue and organ regeneration, *Material Science and Engineering R*, 34, 147–230.
- Shannon, R. D., & Pask, J. A. (1965). Kinetics of the anatase-rutile transformation. *Journal of the American Ceramic Society*, 48(8), 391-398.
- Shozui, T., Tsuru, K., Hayakawa, S., & Osaka, A. (2008). Enhancement of in vitro apatite-forming ability of thermally oxidized titanium surfaces by ultraviolet irradiation. *Journal of the Ceramic Society of Japan*, 116(4), 530–535.
- Shtil'man, M. I. (2003). *Polymeric biomaterials* (Vol. 15). Vsp.

- Simonsen, M. E., Li, Z., & Sjøgaard, E. G. (2009). Influence of the OH groups on the photocatalytic activity and photoinduced hydrophilicity of microwave assisted sol-gel TiO₂ film. *Applied Surface Science*, 255(18), 8054-8062.
- Singhatanadgit, W. (2009). Bone and tissue regeneration insights biological responses to new advanced surface modifications of endosseous medical implants. *Bone and Tissue Regeneration Insights*, 2, 1-11.
- Smith, L. (1963). *Cerosium*, *Archives of Surgery*. 87:653- 655.
- Spurr, R. A., & Myers, H. (1957). Quantitative analysis of anatase-rutile mixtures with an X-ray diffractometer. *Analytical Chemistry*, 29(5), 760-762.
- Shultz, A. N., Jang, W., Hetherington, W. M., Baer, D. R., Wang, L. Q., & Engelhard, M. H. (1995). Comparative second harmonic generation and X-ray photoelectron spectroscopy studies of the UV creation and O₂ healing of Ti³⁺ defects on (110) rutile TiO₂ surfaces. *Surface Science*, 339(1-2), 114-124.
- Sul, Y. T., Johansson, C., Wennerberg, A., Cho, L. R., Chang, B. S., & Albrektsson, T. (2005). Optimum surface properties of oxidized implants for reinforcement of osseointegration: Surface chemistry, oxide thickness, porosity, roughness, and crystal structure. *International Journal of Oral & Maxillofacial Implants*, 20(3).
- Surmenev, R. A., Surmeneva, M. A., & Ivanova, A. A. (2014). Significance of calcium phosphate coatings for the enhancement of new bone osteogenesis—A review. *Acta Biomaterialia*, 10(2), 557-579.
- Takemoto, M., Fujibayashi, S., Neo, M., Suzuki, J., Matsushita, T., Kokubo, T., & Nakamura, T. (2006). Osteoinductive porous titanium implants: Effect of sodium removal by dilute HCl treatment. *Biomaterials*, 27(13), 2682-2691.
- Takeuchi, M., Sakamoto, K., Martra, G., Coluccia, S., & Anpo, M. (2005). Mechanism of photoinduced superhydrophilicity on the TiO₂ photocatalyst surface. *The Journal of Physical Chemistry B*, 109(32), 15422-15428.
- Teixeira, R. L. P., Godoy, G. C. D. D., & Pereira, M. D. M. (2004). Calcium phosphate formation on alkali-treated titanium alloy and stainless steel. *Materials Research*, 7(2), 299-303.
- Tomaszewski, H., Eufinger, K., Poelman, H., Poelman, D., De Gryse, R., Smet, P. F., & Marin, G. B. (2006). Effect of substrate sodium content on crystallization and photocatalytic activity of TiO₂ films prepared by DC magnetron sputtering. *International Journal of Photoenergy*, 1-5.

- Tunay, O., Kabdasli, I., Arslan-Alaton, I., & Olmez-Hanci, T. (2010). *Chemical oxidation applications for industrial wastewaters*. IWA Publishing.
- Uchida, M., Kim, H. M., Kokubo, T., & Nakamura, T. (2001). Apatite-forming ability of sodium-containing titania gels in a simulated body fluid. *Journal of the American Ceramic Society*, 84(12), 2969-2974.
- Uchida, M., Kim, H.-M., Kokubo, T., Fujibayashi, S., & Nakamura, T. (2002). Effect of water treatment on the apatite-forming ability of NaOH-treated titanium metal. *Journal of Biomedical Materials Research*, 63(5), 522-530.
- Uchida, M., Kim, H. M., Kokubo, T., Fujibayashi, S., & Nakamura, T. (2003). Structural dependence of apatite formation on titania gels in a simulated body fluid. *Journal of Biomedical Materials Research Part A*, 64(1), 164-170.
- Uetsuki, K., Kaneda, H., Shirosaki, Y., Hayakawa, S., & Osaka, A. (2010). Effects of UV-irradiation on in vitro apatite-forming ability of TiO₂ layers. *Materials Science and Engineering: B*, 173(1), 213-215.
- Uetsuki, K., Nakai, S., Shirosaki, Y., Hayakawa, S., & Osaka, A. (2013). Nucleation and growth of apatite on an anatase layer irradiated with UV light under different environmental conditions. *Journal of Biomedical Materials Research Part A*, 101(3), 712-719.
- Ulian, G., Valdrè, G., Corno, M., & Ugliengo, P. (2013). The vibrational features of hydroxylapatite and type A carbonated apatite: A first principle contribution. *American Mineralogist*, 98(4), 752-759.
- Umar, A. & Hahn, Y.-B. (Ed.) (2010). *Metal oxide nanostructures and their applications*. Vol. 4. California: American Scientific Publishers.
- Unosson, E., Welch, K., Persson, C., & Engqvist, H. (2013). Stability and prospect of UV/H₂O₂ activated titania films for biomedical use. *Applied Surface Science*, 285, 317-323.
- Wang, Y. M., & Liu, H. (2011). Preparation and characterizations of Na₂Ti₃O₇, H₂Ti₃O₇ and TiO₂ nanobelts. In *Advanced Materials Research* (Vol. 306, pp. 1233-1237). Trans Tech Publications.
- Wei, M., Kim, H.-M., Kokubo, T., & Evans, J. H. (2002). Optimising the bioactivity of alkaline-treated titanium alloy. *Materials Science and Engineering*, 20, 125-134.
- Williams, D. F., Cahn, R. W., & Bever, M. B. (1990). *Concise encyclopedia of medical & dental materials*. Pergamon Press.

- Williams, D. F. (2008). On the mechanisms of biocompatibility. *Biomaterials*, 29(20), 1–13.
- Wouters, Y., Galerie, A., & Petit, J. P. (1997). Thermal oxidation of titanium by water vapour. *Solid State Ionics*, 104(1), 89-96.
- Xiong, L. B., Li, J. L., Yang, B., & Yu, Y. (2012). Ti³⁺ in the surface of titanium dioxide: generation, properties and photocatalytic application. *Journal of Nanomaterials*, 2012, 1-13.
- Xu, Z., Rosso, K. M., & Bruemmer, S. (2012). Metal oxidation kinetics and the transition from thin to thick films. *Physical Chemistry Chemical Physics*, 14(42), 14534-14539.
- Yamaguchi, S., Takadama, H., Matsushita, T., Nakamura, T., & Kokubo, T. (2011). Preparation of bioactive Ti-15Zr-4Nb-4Ta alloy from HCl and heat treatments after an NaOH treatment. *Journal of Biomedical Materials Research Part A*, 97(2), 135-144.
- Yamamoto, O., Alvarez, K., Kikuchi, T., & Fukuda, M. (2009). Fabrication and characterization of oxygen-diffused titanium for biomedical applications. *Acta Biomaterialia*, 5, 3605–3615.
- Yan, W.-Q., & Davies, J. E. (1998). Bone formation around surface modified titanium implants. In *Bioceramics-Conference-* (Vol. 11, pp. 659-662).
- Yan, W.-Q., Nakamura, T., Kobayashi, M., Kim, H.-M., Miyaji, F., & Kokubo, T. (1997a). Bonding of chemically treated titanium implants to bone. *Journal of Biomedical Materials Research*, 37(2), 267–275.
- Yan, W.-Q., Nakamura, T., Kawanabe, K., Nishigochi, S., Oka, M., & Kokubo, T. (1997b). Apatite layer-coated titanium for use as bone bonding implants. *Biomaterials*, 18(17), 1185–1190.
- Yin, H., Wada, Y., Kitamura, T., Kambe, S., Murasawa, S., Mori, H., Sakata, T. and Yanagida, S. (2001). Hydrothermal synthesis of nanosized anatase and rutile TiO₂ using amorphous phase TiO₂. *Journal of Materials Chemistry*, 11(6), 1694-1703.
- Zadpoor, A. A. (2014). Relationship between in vitro apatite-forming ability measured using simulated body fluid and in vivo bioactivity of biomaterials. *Materials Science and Engineering*, 35, 134–143.

- Zárate, R. A., Fuentes, S., Cabrera, A. L., & Fuenzalida, V. M. (2008). Structural characterization of single crystals of sodium titanate nanowires prepared by hydrothermal process. *Journal of Crystal Growth*, 310, 3630–3637.
- Zhang, S., Peng, L.-M., Chen, Q., Du, G. H., Dawson, G., & Zhou, W. Z. (2003). Formation mechanism of $\text{H}_2\text{Ti}_3\text{O}_7$ nanotubes. *Physical Review Letters*, 91, 256103.
- Zhao, G. (2007). *Interaction of surface energy and microarchitecture in determining cell and tissue response to biomaterials*. Georgia Institute of Technology: Ph.D. Thesis.
- Zhao, G., Schwartz, Z., Wieland, M., Rupp, F., Geis-Gerstorfer, J., Cochran, D. L., & Boyan, B. D. (2005). High surface energy enhances cell response to titanium substrate microstructure. *Journal of Biomedical Materials Research Part A*, 74(1), 49-58.
- Zhao, J., Guo, Y., Luo, W., Wang, X., Fu, L., Cai, Q., & Zhou, Y. (2017). The effect of amino plasma-enhanced chemical vapor deposition-treated titanium surface on Schwann cells. *Journal of Biomedical Materials Research Part A*, 106(1), 265-271.
- Zhu, H., Gao, X., Lan, Y., Song, D., Xi, Y., & Zhao, J. (2004). Hydrogen titanate nanofibers covered with anatase nanocrystals: A delicate structure achieved by the wet chemistry reaction of the titanate nanofibers. *Journal of the American Chemical Society*, 126, 8380–8381.

