Chapter 1

Introductory Chapter: Multi-Aspect Bibliographic Analysis of the Synergy of Technical, Biological and Medical Sciences Concerning Materials and Technologies Used for Medical and Dental Implantable Devices

Leszek A. Dobrzański

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.73094

1. General role of the regenerative medicine and dentistry

In many scientific centres, the World intensive research is under way related to the significant development of science in the field of Materials Engineering in connection with cell biology, thus expanding the new groups of advanced materials and technologies finding their application in regenerative medicine and dentistry. The author has already published on this topic studies [1–4] as well as books [5–9], monographs [10–24], scientific papers [25–76], patents [77–84] awarded in international fairs and exhibitions of research, invention and innovation [85–102]. In this area, several of author's own scientific and research projects have also been realised [103–107]; some are in progress [108], and others are planned for implementation [109]. Generally, one of the main reasons of this activity is the dynamic growth of post-injury defects, post-resection defects, as well as those originating from the operative treatment of cancerous tumours, whereas the number of cases is systematically increasing, or inflammation processes and as a result of other disorders of the human population, including the consequences of tooth decay, in particular due to local and systemic complications. Surgical treatment, often saving human lives, causes the necessity to replace losses in such organs or tissues, including in the dental system, to prevent biological and social degradation of patients and to restore their living functions. A growing number of road accidents and severe injuries of more and more people frequently requires a surgical intervention with replacement or supplementation of losses in organs or tissues and numerous interventions in the stomatognathic system. For example, the data of the Association for Improving Safety of Road Traffic reveal that about 1.7 million people suffer injuries in the EU every year. The growing number of sports accidents

and bodily injuries frequently requires a surgical intervention with supplementation of lost tissues, also in the dental system. For example, according to EU IDB catalogue, annually, an average 6.1 million people in the EU are treated in hospitals for sports injuries. The number of people aged over 65 will have systematically grown, e.g., in EU by 70% to 2050. Systematically proceeding population ageing, which considerably increases the number of patients requiring surgical intervention with supplementation of losses in organs or tissues, often in the stomatognathic system.

One of the fundamental tasks globally, considered also to be one of the European Union's priorities, is to improve the society's condition of health, medical care and health safety. The numerous tasks related to this topic include the prevention of health risks, early recognition of diseases, rapid and effective implementation of medical procedures, comprehensive and continued therapies leading to an improved health condition and the improved health condition and improved quality of the society's life [1]. For example, the European Health Strategy regards health-related aspects to be a central focus of the Community's policy and proposes a programme of actions for citizens, by recognising their right to own health and healthcare and through the promotion of the ageing society's health, through the protection of citizens against risks for their health and life and through supporting dynamic health care systems and new technologies, related to technical support for medicine, including dentistry. The idea is to protect against serious health risks, especially such as civilisational diseases, pandemics and bioterrorism and to support research, especially such applying advanced technologies, to ensure the fullest prophylactics of diseases and safe treatment of patients, taking into account the relationships between health and economic well-being. A significant and costly problem of modern medicine is the necessity to replace or supplement organs or tissues, in particular in orthopaedics and traumatology and maxillofacial surgery and restorative dentistry, to prevent the biological and social degradation of patients and to restore their living functions [1]. It also applies mostly to the elimination of consequences of tooth decay, considered to be an exceptionally burdensome civilisational disease, also one of the costliest ones, in particular, due to local and systemic complications [110–125].

A relatively new branch of medicine is regenerative medicine and dentistry. The achievements of modern implantology depend not only on the knowledge and experience of medicals, but it also requires the application of advanced engineering problems, both in the field of engineering design, material engineering, nanotechnology and material technology. These are very responsible research, and the most avant-garde trends concern the offering of personalised medical devices manufactured according to individual anatomical features of the patient, according to complex and advanced original technologies and ever newer biomaterials used for implantable devices. These issues are the subject of many years of scientific interest of the Author, and they belong to the group of the most avant-garde, so far relatively little known, but extremely promising technical problems for use in regenerative medicine and dentistry. This study presents the results of previous studies and own research, derived from previously published original own work done by the Author with a team of co-workers [1–19]. As in all other cases, in material engineering and material science, in order to satisfy the functional functions of implantable devices as well as all other products, it is necessary to design and apply engineering materials that, subjected to the appropriate technological processes of

http://dx.doi.org/10.5772/intechopen.73094

shaping the geometric form, and especially the structure, will ensure appropriate physico-chemical properties of the material. This book presents exhaustively the achievements of numerous teams from different countries of the world, inscribing itself in the discussed European Health Strategy, in advanced research areas related to biomaterials used in regenerative medicine and dentistry. In the overall analysis of the issue concerning biologically active cellular structures and a substrate with an engineering composite material matrix used for scaffolds and for newly developed implantable devices applied in regenerative medicine and dentistry, further in this description all the aspects are analysed separately, because the lack of holistic approach and general references is in the literature, apart from own works.

2. Importance of regenerative medicine and dentistry and tissue engineering

The development of regenerative medicine, whose technical aspects are covered by the book with the first reports dating back to 1992 [126], is a relatively new field of medicine. Implantable biomedical devices encompass numerous solutions eliminating various dysfunctions of a human organism and are currently aggregately considered to be medical bionic implants. The development of regenerative medicine, whose technical aspects are covered by the book, previously described in author's theoretical study [1], started with the first reports dating back to 1992 [126], as a relatively new field of medicine. Implantable biomedical devices encompass numerous solutions eliminating various dysfunctions of a human organism and are currently aggregately considered to be medical bionic implants. Bionics is understood as production and investigation of biological systems to prepare and implement artificial engineering systems which can restore the lost functions of biological systems [127, 128]. Autographs, allografts or metal devices or such made of other engineering materials are primarily the current methods of organ and tissue replacement employ [129]. The purpose of the regenerative medicine is treatment—by replacing old and sick cells with young cells, also using tissue engineering methods and cell-based therapies or organism regeneration using a gene therapy. It raises numerous new challenges, notably in counteracting the symptoms and consequences of diseases, and even their causes [130–133]. The application of therapies based on living cells in medicine is a relatively new concept. The first successful allogeneic transplantation of human haematopoietic stem cells (HSC) was seen as late as in 1968 [134] (29), then the cells were used for other therapeutic applications [135, 136]. The therapies based on living cells were intensively developed in the 1990s [137], in particular for skin and cartilage implants. Tissue engineering provides technical support for regenerative medicine and is an interdisciplinary field employing the principles of engineering and life sciences for development of biological substitutes, for restoration, maintenance and improvement of functions of tissues or entire organs [138, 139]. Tissue engineering, introduced in 1985 [140], as a field of technical sciences, utilises medical knowledge and materials engineering methods to develop biological materials capable of restoring, maintaining or improving the functions of particular tissues or organs [138] and to produce their functional substitutes [141, 142]. Tissue engineering is based on understanding the principles of tissue growth and on applying this for functional production of a replacement tissue for clinical use [143].

An overview of the present situation points to a diversity of the currently available therapeutic methods based on cells, undergoing the phase of clinical studies [144]. The global market of cell-based therapies boasts a revenue of more than a billion USD per year [145]. Therapeutic strategies include direct transplantation of the desired type of cells collected using biopsy or such originating from cultures of stem cells, both in the autologous and allogeneic system. Multipotent and self-renewing stem cells (MSCs), depending on the tissue development stage, can be grouped into adult and embryonic cells [136, 146, 147]. Embryonic cells exist in umbilical cord blood [148, 149], in the placenta [150], in amniotic fluid [151] or deciduous teeth pulp in infants, termed as multipotent stromal cells (MSCs). The clinical application is most beneficial, especially of autologous cells [136], as they do not cause an immunological response and do not require immunosuppressive treatment [151–154], and, nevertheless, such application is limited [155]. There is a much greater potential for somatic and especially haematopoietic stem cells (HSC) from bone marrow stromal [156–158], supporting bone marrow stromal cells (BMSCs) as a standard [136, 158]. Adult stem cells also occur, in particular, in synovial fluid, tendons, skeletal muscles [158, 159] and adult muscles, fat tissue—ASCs (adipose-derived stem cells ASCs) [158, 159], the stroma of cornea [149], peripheral blood, nervous tissue and dermis and have an ability of transformation into multiple tissues.

The efficiency of cell-based therapies depends on the preservation of their viability after implantation [160, 161], to prevent the ischaemia of tissues and necrosis [162–167]. Stem cells originating from bone marrow and fatty tissue may be used for breeding mesenchymal cells and tissues, in adipocytes, chondrocytes, osteoblasts and skeletal myocytes and can be used for producing tissues, e.g., muscles fat, gristle and bones [168–171]. Stringent safety requirements must be considered in cell-based therapies because raw materials of the animal origin are used, which poses a potential threat of transmitting a pathogen to a recipient or of immunological complications [172] and as post-production cleaning is required [173]. Progress in this domain seen since 2004 requires further detailed considerations concerning the mechanism of *in vivo* therapeutic activity, to facilitate the development and optimisation and for the development of automated processes, with improved efficiency and with quality control and with reference standards established [174–177]. About 100 companies specialised in this area are operating at the American and European market. For better characterisation, the conditions of cell-based therapies must be realised more intensive the basic research. The introduction of the new clinical regenerative procedure having no competition requires the development of breeding techniques of human stem cells. However, the adult stem cells could be used to a limited extent [178]. The fabrication of the majority of therapeutically meaningful cell types (except the mesenchymal stem cells) has not yet been mastered at a technologically satisfactory scale. However, it should be emphasised that the outcomes achieved to date in this area be promising. Therefore, a wide commitment of the scientific environment is generated for the elaboration and explanation of the phenomena accompanying the growth of tissue structures in conditions allowing their industrial production. The purpose is the development of the adequately organised therapeutic processes, introduction appropriate engineering materials and obtaining the technological processes for them, including nanotechnology. A very important cognitive task is the explanation the interaction between the surface structure of engineering materials forming the substrate and the tissue structures deposited onto it and explication the role of a substrate for culturing tissue structures.

Opposite to pure therapies, in which stem cells are injected directly into peripheral circulation or located in particular tissues, in numerous clinical cases it is necessary to use stem cells' carriers to transport them, and especially scaffolds for their three-dimensional grouping in a particular place of an organism, and such research is being constantly developed [179–188]. It should be noted that the notion of scaffolds is quite comprehensive, as it may not only refer to engineered extracellular matrices 'scaffolds', but also to rigid microporous materials into which osteoblasts may grow, and also to microporous mats made of polymer nanofibres, into which living cells are growing and may be used as specific plasters, to treat for example burns or to reconstruct large fragments of skin [7]. The latest publications [5, 6] also note the relevance and need of developing such therapeutic methods for the dental system. A microscopic, porous structure of scaffolds is required, enabling the diffusion of nutrients and metabolism products through them. Scaffolds, including also bone scaffolds, must enable the adhesion and migration of cells and facilitate their development to form a three-dimensional tissue structure in conditions simulating a natural micro-environment [187, 189]. Scaffolds should exhibit adequate mechanical properties for ensuring an appropriate environment of development for cells and ensure the mechanical preservation of living tissues in a three-dimensional structure. The task of scaffolds is to ensure also the necessary conditions of cells growth by the creation of new blood vessels [190–193].

Two separate aspects need to be considered: a porous structure, especially the size of pores and manufacturing technologies of appropriate porous materials, and the selection of engineering materials of which scaffolds are produced. Both aspects are of primary importance for the undertaking's success, and hence each of them has been analysed based on the state-of-the-art.

3. Designing of geometric properties of porous materials

Porous materials have been used for not too long in orthopaedic procedures to replace damaged bones, and porous scaffolds are geometrically similar to natural hard tissues made up of a skeleton penetrated by interlinked pores [194], thus solid metals are unsuitable because they are, by nature, non-permeable and prevent the adhesion and proliferation of living cells. Porous materials, mainly metals, are implanted to repair damaged bones having a critical size and in the majority of cases are used as carrying devices [195]. It is vital that an implant has properties similar to a recipient bone and the surrounding tissue [196]. A human bone has a hierarchical structure with three major anatomic cavities of different sizes which are Haversian canals (50 μm) [197], osteocytic lacunae (few micrometres) [198–201] and canaliculi (<1 μm) [201, 202]. All the three cavities play an important role in the mechanical integrity of the bones and the processes reconstruction [203]. A porous structure ensures appropriate space for the transport of nutrients and the growth of living cells [204, 205]. A bone elasticity modulus, much smaller than for non-noble metals, is regarded to be one of the major problems in the construction of implants because, as a result, the screening of stresses would often lead to implant damages. Porous metals can duplicate bone properties if their structures are digitally designed and are produced using advanced manufacturing technologies [205]. A bone, despite its anisotropy [206], is being replaced by porous engineering materials with similar rigidity,

making them efficient for transmitting loads and for alleviating the effect of stress screening and for regeneration of bone tissue in the damaged place [195]. The following is therefore required: (1) biocompatibility; (2) appropriate surface for adhesion, proliferation and differentiation of cells; (3) a very porous structure with a network of open pores for the growth of cells and for the transfer of nutrients and metabolic wastes; (4) mechanical properties adjusted to the requirements of the surrounding cells to reduce or eliminate excessive stresses and meeting anatomic requirements to avoid a mechanical damage [207–211]. The key features for the design of porous metallic implants include careful selection of porosity, size of pores and mutual connections between pores, aimed at achieving satisfactory clinical results. Such constructional features have a large effect on the mechanical properties and biological activity of scaffolds [195]. Bone regeneration *in vivo* porous implants consists of recruitment and penetration of cells from the surrounding bone tissue and vascularisation [212]. Higher porosity may facilitate such processes and enable bone growth [213, 214]. The influence of the pore size on the growth of cells, e.g., bone cells, is, however, still controversial [195, 215]. Pore sizes of artificially produced scaffolds should be adapted to the specific cell type. They should be small, because then they ensure more space for cells' growth, e.g., bone tissue [195], but small enough to prevent the sealing of pores in a scaffold [187]. They should also be large enough to prevent blood clots [216], enable the migration of cells and ensure conditions to fill up scaffold pores by the reconstructed cells, guaranteeing neovascularisation [217]. For this reason, the upper suggested limit is 400 μm [215], because it is no longer beneficial to increase it. It was found, though, that for pores sized 600–900 μm, the growth of bone cells is higher than for the pores sized 300 μm [195]. The permeability of a porous structure of a scaffold ensures the transport of cells, nutrients and growth factors as a result of blood flow, and a blood pressure gradient depends on the pore size and has also influence on vascularisation and accelerates the osseointegration process [195], although this requires further studies. It is thought that the optimum pore size for cells growth, and especially mineralised bone growth, is 100–400 μm [195]. The aspect is still important, because although increased porosity, pore size and mutual connection of pores are the key factors, which are having a large impact on facilitated bone growth and the transport of cells and nutrients, evidently ameliorating the quality of biological processes, nevertheless they may considerably reduce rigidity and strength of scaffolds [195]. Although the shape and size of pores can be adjusted by changing the conditions of even traditional fabrication processes, e.g., casting or powders metallurgy; however, only a randomly organised porous structure can then be obtained, which is not fully open or is not open at all [218]. To produce porous scaffolds as well as other medical implants, including dental ones, additive technologies are used most often in combination with prior CAD/CAM, as highly competitive against traditional manufacturing methods, such as casting or machining [219–224]. Such technologies can be applied for various engineering materials, not only metals and alloys which are prepared, respectively, as powder or liquid, rolled material or thin fibres. Additive technologies have been widely used for fabricating diverse, customised elements applied in medicine, in particular, scaffolds with required porosity and strength with living cells implanted into an organism [225–227], models of implants and dental bridges [228–230], implants of individualised implants of the upper jaw bone, hip joint and skull fragments [231–238]. Considering the additive technologies applied most widely, the following have found their application for scaffold manufacturing, in implantology and prosthetics, i.e.,

electron beam melting (EBM) [222, 239–243], and also 3D printing for production of indirect models, although selective laser sintering/selective laser melting (SLS/SLM) and its technological variants offers broadest opportunities [220, 222, 244–253], which was noted in discussing each group of materials. SLS/SLM techniques permit to produce a structure with open pores, e.g., with a lattice structure promoting osseointegration, while maintaining different external shapes of the whole implant [254]. The determination of optimum geometric features of scaffolds as a result of computer-aided design in conjunction with the optimisation of technological conditions of the applied additive technology, and broad experimental verification in the engineering and biological aspect, is of key importance.

4. Selection of materials of implantable devices in regenerative medicine and dentistry

The selection of appropriate materials for application in the regenerative medicine and dentistry, in conjunction with the optimisation of technological conditions of fabrication of implantable devices, including porous scaffolds and implant-scaffolds, are the important aspects of the analysed problems, previously just described in author's own theoretical study [2]. It occurs as a synergy of classical prosthetics/implantation of bone and organ post-injury or post-resection losses together with the methods of tissue engineering in the connection (interface) zone of bone or organ stumps with prosthetic elements/implants. It calls for the use of porous and high-strength non-graded metal and/or composite and/or polymer materials (which is strongly, but not exclusively, dependent on the specificity of the clinical application) together with using at the same time biodegradable materials for tissue scaffolds. One of the solutions strives to achieve bioactive connections, as most advantageous regarding bond strength, which is formed between bone tissue and implants/scaffolds made or coated with bioactive materials, considerably improving the stability and durability of connection, especially for porous scaffolds/implants. Another acceptable approach is a very durable biological connection characteristic for porous implants/scaffolds whereby the bone tissue is growing through the material pores and is mechanically "anchored" in the bone. Porous resorbable bioglass may be used for scaffold fabrication [255], e.g., from the $CaO\text{-}SiO_2\text{-}P_2O_5$ system, Hench bioglass [256], produced both, with classical melting methods and with sol-gel methods, and also bioglass from the $SiO_2\text{-}Al_2O_3$ system endowed with silver, due to their biocompatibility [257, 258] and bacteriocidity, and with pore walls coated with hydroxy carbonate apatite (HCA) [259], ensuring enhanced activity of osteoblasts [260] and expression of genes connected with bones [261]. The formation methods of porous structures from ceramic materials, in particular such as aluminium oxide, zirconium oxide, calcium carbonate, hydroxyapatite (HA), titanium oxide, include casting of sections from mass containing a fine-grained ceramic material with additives facilitating foaming and then material sintering, and also the use of other methods, e.g., an organic matrix and lyophilisation of ceramic slip [255]. The basic bioactive ceramic materials used for scaffolds is calcium phosphate (CaPs), as the main component of bone, and in hydroxyapatite (HA), β-tricalcium phosphate (β-TCP) or a mixture of HA and b-TCP, known as biphasic calcium phosphate [262–264]. A classical solution in the domain

of ceramics, are porous scaffolds/corundum implants completely biocompatible, growing through the fully valuable bone tissue. They possess mechanical strength sufficient for many types of clinical procedures and ensuring freedom of manipulation during a surgical procedure. After growing through, have an appropriate modulus of elasticity, which ensures their good interworking with the bone and also allow for sterilisation with any method. Both, bioactive and biodegradable polymers can be employed [193, 265, 266], including in particular natural polymers such as: alginate, chitosan, collagen, fibrin, hyaluronic acid and silk, and used, e.g., for bone reconstruction [267], as well as synthetic ones, such as poly(lactic acid) (PLA), poly(glycolic acid) (PGA), and polycaprolactone (PCL) and poly(propylene fumarate) (PPF) with high compressive strength, comparable to this of a cortical layer of bone [266]. Some of them, such as poly(lactic acid) (PLA), poly(glycolic acid) (PGA) may cause negative tissue reactions [268]. Composite materials satisfy mechanical and physiological requirements, e.g., CaP-polymer scaffolds, interconnected tricalcium phosphate (TCP) scaffolds coated inside pores with polycaprolactone (PCL) [269], hydroxyapatite HA/poly(ester-urethane)(PU) [270] or a nanocomposite of collagen and Bioglass [271].

Metallic materials represent one of the largest groups of engineering materials used for this purpose and comprise, among others, titanium, tantalum, niobium and their alloys, and in dentistry also cobalt-matrix alloys and alloys of noble metals, for which, SLS/SLM technologies were especially applied [272, 273], irrespective of stainless steels often used until now. The SLS/SLM technique has been used successfully for production of complex porous and cellular structures made of austenite stainless steels [218]. One of the main grades of stainless austenitic steel which can be used for medical purposes is nickel, now thought to be one of the main allergens [274], with 17% of adults [275] and 8% of children [276] being sensitised to it, approx. 50–60 million people altogether in the EU. Apart from many disorders [277, 278], this chemical element causes rejection of orthopaedic gradients [279], and dental implants [280] and, for this reason, Directive 94/27/EC [281] was put into force prohibiting the use of nickel and materials containing it for prosthetic and implantological purposes. Co-matrix alloys such as Co-Cr-Mo, Co-Cr-W and cast Co-Cr-W-Mo alloys, for machining or manufactured by powder metallurgy methods, for which the SLS/SLM technology was successfully employed [272, 273, 282–289], can be seen as the basic classical materials for dental prosthetic restorations [290–296], despite their high density, which is more and more often considered as counter-indicative for their application for such purposes.

Porous metal materials, though not biodegradable, are used for scaffolds, mainly Ti and Ta [297], also after treatment of pores' surface [298]. Therefore, interest in light metals and their alloys have been on the rise. Ti and its alloys represent engineering materials which are particularly suitable for use in additive technologies, e.g., for selective laser sintering [5, 6, 10, 77–81, 85–91, 299–305]. Porous Ti [297] can be utilised for non-biodegradable scaffolds, including such after treatment of the pore surface, applied primarily due to relatively high compressive strength and fatigue strength [193, 306]. It was proven that structures of porous Ti6Al4V are also effective in aiding the growth of cells and bone tissue [307–311]. Ti and its alloys with Al, Nb and Ta and Ti alloys with Al, V and Nb, well tolerated by a human organism, are the metallic materials more and more often used these days for joint prostheses and for various implants, also intramedullary wires and for prosthetic restorations and dental

implants [33, 312–322]. When used for dental crowns, though, they have a significant disadvantage, consisting of porcelain reactions with titanium oxide, causing bruising and colour darkening, which - for aesthetic reasons - practically eliminates such prosthetic restorations, but does not exclude their use for a root part of the implant [323]. Titanium-matrix materials do not cause allergic reactions and are stainless and feature high strength and hardness, and also thermal conductivity several times lower than traditional prosthetic materials [324]. Titanium is a very thrombogenic material [240]. The biocompatibility, especially thrombocompatibility, of Ti can be enhanced by introducing alloy elements [325]. Some publications [326–334] provide limited information on the toxic activity of V as an alloy element in the Ti6Al4V alloy, because it was found that V could be regarded as a potentially toxic factor [335, 336], which is, however, true only for a considerable concentration of V in a body, due to development of its undesired immunological response, when the freed V ions migrate from the material surface to a soft tissue, binding with proteins [337, 338]. Some research on cells implies that Ti6Al4V exhibits high cytotoxicity [307–311, 339]; there are reports that V may cause sterile abscesses, and Al may cause scarring, while Ti, Zr, Nb and Ta show good biocompatibility [340]. Some publications argue that a risk associated with an unfavourable effect of Ti alloys can be limited by replacing V, as in, e.g., Ti6Al4V alloy, by Nb, e.g., in Ti6Al7Nb alloy, which would show better properties, e.g., corrosion resistance and bioavailability [334, 341–346]. It was revealed, however, by direct comparison in the same conditions that differences between Nb and V in Ti alloys are not too high [334], and even that Ti6Al4V alloys exhibit better properties than Ti6Al7Nb alloy [334, 347–349], such as thrombocompatibility, more intensive antibacterial activity and resistance to colonisation of Gram-positive bacteria, although worse for colonisation of Gram-negative bacteria [334]. Other alloys, with a higher concentration of Nb, are however employed successfully, e.g., Ti24Nb4Zr8Sn, including those manufactured by selective laser sintering, with an elasticity modulus better adapted to a bone than Ti6Al4V alloy, which prevents bone resorption and does not cause implant loosening in use [350]. Although porous Ti6Al4V was comprehensively studied, the potential release of toxic ions has led to a search for alternative Ti alloys, including, among others, Ti24Nb4Zr8Sn, Ti7.5Mo and Ti40Nb, with comparable mechanical properties as their counterparts manufactured traditionally [350–353].

The concept of the synergic use, for this purpose, of the existing achievements in tissue engineering in the scope of selection of materials and scaffold fabrication technologies, in materials engineering and production engineering in the scope of design and manufacture of prostheses/implants with different engineering materials, and in surgery and regenerative medicine in the scope of prosthetics/implantation in the treatment of the above-mentioned civilisational diseases and their effects have been outlined in the earlier works and projects by the author [1–109].

Regeneration in a natural condition is forcing the removal of an artificial scaffold [354–356]. The topic of scaffolds and biodegradable implants, including porous ones, both made of polymers [193], despite doubts of Mg-Ca alloys [357], and of composite materials [269–271], as well as a concept of separating the redundant pieces of cell-based products after finishing a therapy performed with their use [7], were thoroughly analysed in the own works [5, 6, 10]. Relatively high compressive strength and fatigue strength [193, 306] are primarily the reason for the application of Mg and its alloys [358–360]. Introducing pure Mg with interconnected porosity

onto bearing plates, bolts and networks made by rapid pressure assisted densification methods, such as rapid hot pressing/Spark Plasma Sintering (SPS) is an innovative approach [361]. Due to Mg biocompatibility, and the manufacturing technology ensuring good mechanical strength and recovery of the bone pure Mg gives an optimum solution. Mg with Ca, Zn and Mn alloys can be used, to reduce the rate of *in vivo* corrosion and prevent necrosis and the blocking of blood flow. A human organism well tolerates these alloys [362, 363] mainly with coatings adapted to bioresorbable implants [364–367]. Reinforcements of magnesium MMCs usually include, notably, HA [368–373], FA [374], calcium polyphosphate [375], and calcium [374] and well affect biocompatibility. Mg and its alloys can be used for non-biodegradable scaffolds [372]. Except for several studies, the application of Mg as a biomaterial has not won popularity as late as until the end of the 1990s, because this pure metal cannot ensure appropriate mechanical properties or corrosion resistance in orthopaedic uses [376, 377]. Such popularity, though, has risen exponentially since then [378], owing to major improvements in Mg production [378] and various techniques elaborated, including the use of Mg alloys, substrate surface treatment or coating technologies [379–381]. Generally speaking, such alloys contain Al or rare-earth elements (REE) [382–384], although there are reports about studies over additives of non-toxic elements, such as Ca, Mn, Zn and Zr, and even Li, Cd, Sn, Sr., Si, Ag and Bi [378]. Al is a common additive for Mg alloys, as it is conceded that it improves strength and resistance to Mg alloys' corrosion Mg (258), although Al is shown in numerous pathological conditions in humans [385–388]. The additives of rare-earth elements are used for increasing strength, plasticity and wear resistance of Mg alloys and their corrosion resistance [383] in environments with a high content of chlorides in connection with a passivation layer rich in oxygen [389, 390]. The influence of such elements on the physiological system is unknown, [378], although it was found that they possess both, anti-carcinogenic and anti-coagulation properties [391], and when used as vascular stents without side effects [392], and also without La and Ce, do not have an effect on cytotoxicity and have a positive effect on cellular life [393], although quite the opposite was also found, that at least some REEs are highly toxic [393, 394]. The value of the research carried out in this scope may be limited if it turns out that such elements are too toxic in use for biomaterials [377] and this requires further systematic studies. Magnesium synthesised by SLM is closely adapted to a human bone [395]. This technology was employed for producing complex porous/cellular structures of magnesium alloys [350, 396–398], although the results of such studies are normally not available in the available literature [254]. A selective laser sintered Mg2Mn alloy is predisposed to use for bone implants [254]. The use of Mn, as a component of Mg alloys, consists of the improvement of corrosion resistance and may increase the plasticity of Mg alloys [383, 399]. Zn improves the strength of Mg alloys [399, 400] and their corrosive resistance [401]. However, its influence on increased cytotoxicity was identified [402, 403]. Magnesium and its alloys feature a high potential for orthopaedic uses because it has proven to be fully bioresorbable, their mechanical properties are adapted to bones and do not cause an inflammatory response; moreover, they are osteoconductive, supportive to bone growth and play a positive role in the binding of cells [404]. The application of biomaterials made of Mg highly increases a risk of hypomagnesia and, probably, of the excessively stored and circulating Mg [378]. Corrosion analysis and Mg concentration monitoring in serum must be an important aspect of Mg-based biomaterials' assessment [378]. Due to an effect of diverse factors such as pH, concentration and type of ions,

adsorption of proteins on orthopaedic implants and the biochemical activity of the surrounding cells in the presence of body fluids [405, 406], further research into biomedical uses of Mg is indispensable. Powders are serially manufactured for, in particular, SLS/SLM [407].

Third-generation scaffolds made of CaP, Si-TCP/HA [408] and collagen hydrogel [409] are osteoinductive and allow to create a new bone and also its biomineralisation. Substitute scaffolds of bones are often administered with medicines, including gentamycin, vancomycin, alendronate, methotrexate and ibuprofen [410, 411] and with growth factors and transcription factors [265, 412, 413].

5. Selection of technologies of implantable devices in regenerative medicine and dentistry

The issue was previously considered in the Author's own review work [2], and some of the information compiled there was used here. The traditional, and also the oldest fabrication technologies of scaffolds with a porous structure differentiate the method of emulsifying/lyophilisation [414], to thermally induced phase separation (TIPS) [415], solvent casting & particulate leaching (SCPL), where solvent residues may have an adverse effect on cellular structures [416]. The aforementioned classical methods being unable to control accurately a general shape of the scaffold as well as the size, shape, distribution and interconnections of pores. Nevertheless, these methods have not been completely abandoned. They are used as a modern method in tissue engineering replication technologies with micro-/nanopatterned-surfaces [417–419]. The master moulds are produced using a hard or soft material, for the reason of mould rigidity. The structures with small feature resolution and micro/nanofabricated moulds, including for hot embossing (also known as nanoimprint lithography) and soft lithography (micro-casting) for achieving patterns with dimensions about of 5 nm [420–423] can be cast using synthetic and natural biodegradable polymers [424, 425]. Currently used methods do not require moulds for fabrication of scaffolds (solid freeform fabrication SFF) made not only polymer materials and hydrogels but also ceramic and metallic materials [193, 426–429]. The particular fabrication methods find wide application for the processing both the mentioned biocompatible engineering materials and biological materials [430]. The particular layers of powder are sprayed with an adequate biocompatible binding agent, e.g., for merging powder to fabricate scaffold from collagen [431], and a 25% acrylic acid solution in a mixture of water with glycerine [432] using the three-dimensional printing method (3DP) [433]. This method is also used for the integration of hydroxyapatite used for bone regeneration, and an aqueous citric acid solution is used for integration of ceramics based on calcium phosphate [434]. A method of three-dimensional printing hot wax droplets [435] could be used for manufacture a replica of the scaffold surface, e.g., bone and gristle substitutes fabricated with the SFF method. The limitations of the method originate from wax impurities with biologically incompatible solvents [436], which are not exhibited by new generation materials such as BioBuild and BioSupport dissolving in ethanol or water [436]. The stereolithography method permits to shape three-dimensional form of liquid polymer [437], in particular using poly(propylene fumarate) (PPF) [438, 439], poly(ethylene glycol) (PEG) [440, 441]. Polymer

materials without solvents, including poly(ε-caprolactone) PCL [429, 442], poly(ethylene glycol)–poly(ε-caprolactone)–poly(lactide), PEG-PCL-PLA [442, 443] acrylonitrile-butadiene-styrene (ABS) and hydroxyapatite-poly(ε-caprolactone) HA-PCL [442, 444] are used in fused deposition modelling (FDM) [445]. The particular layers are placed from a computer controller and using computer-aided design (CAD) methods. Selective laser sintering (SLS) is similar to 3D printing. The process is starting with uniform spreading of a thin layer of powder onto the surface and then followed by the merging of powder grains as a result of sintering with the neighbouring grains with partial pre-melting. The next layers are manufactured subsequently according to the same method until the full dimensions of the manufactured element are achieved. The manufactured element, including the scaffolds, shows the assumed constructional features. This technique, used commonly for additive manufacturing of products, includes scaffolds and implants for the dental purpose, from metallic and ceramic materials [5, 6, 10, 446]. This technology was also utilised for scaffolds preparation [426] from biodegradable polymers, e.g., polyether polymer, poly (vinyl alcohol), polycaprolactone [447] and poly(L-lactic acid) [448], and also hydroxyapatite [449] and from composites composed of some of such polymers and hydroxyapatite [448, 450, 451].

Nanofibrous scaffolds are manufactured by electrospinning, and the so obtained nanofibres with the diameter of 5 nm to over 1 mm are continuous and randomly interconnected [452, 453]. Due to the character of electrospinning, fibres are arranged in an orderly manner or are oriented randomly [454]. They have a large specific surface area, exhibit high porosity, the small size of pores and small density [453] and their structure is similar to the extracellular matrix (ECM). Natural and engineering materials can be used as a material, including, in particular, collagen, gelatin and chitosan [453]. Scaffolds are fabricated using of non-covalent interactions for spontaneous fabrication of a three-dimensional structure in response to the activity of environmental factors [455]. The ability of peptides and nucleic acids, to self-organisation, is utilised for scaffolds fabrication. Such types of scaffolds were used, e.g., for regeneration of nervous tissue to stop bleeding and repair infatuated myocardia, as well as in medical products for slow release of a medicine [456, 457] and for DNA, where the branched DNA particles are hybridising with each other in the presence of ligases in hydrogel [458]. The scaffold fabrication method employing self-organisable nanofibres is one of few allowing to produce biocomponents with their properties similar to the natural extracellular matrix (ECM), and scaffolds containing hydrogel, made using such technology, employ more advantageous toxicological properties and higher biocompatibility than traditional materials. Conventional hydrogels are particularly useful for three-dimensional placement of cells [459]. Hydrogels used in tissue engineering should have low viscosity before injection and should be gelling fast in the physiological environment of the tissue, and the most important is gelling (sol-gel transition) by cross-linking, which may take place when producing them *in vitro* and *in vivo* during injection. Physical cross-linking is used in particular in the case of poly(N-isopropylacrylamide) (poly(NIPAAM)), which may be used in tissue engineering after introducing acrylic acid (AAc) or PEG [460, 461] or biodegradable polymers, including such as chitosan, gelation, hyaluronic acid and dextran [462–466] to block copolymers, such as poly(ethylene oxide) PEO-PPO-PEO (Pluronic), poly(lactide-co-glycolide) PLGA-PEG-PLGA, PEG-PLLA-PEG, polycaprolactone PCL-PEG-PCL and PEG-PCL-PEG [467–471], and also agarose (a polysaccharide polymer material, extracted from seaweed as one of the two principal components of agar) [459], as thermo-sensitive systems [472], to avoid the use of

potentially cytotoxic ultraviolet radiation. Poly(NIPAAM) and block copolymer hydrogels may undergo cross-linking as a consequence of temperature and pH acting at the same time, as in the case of acrylates [473, 474], such as 2-(dimethylamino)ethyl-methacrylate (DMAEMA) or 2-(diethylaminoethyl) methyl methacrylate. Self-assembling peptides hydrogels, including such containing peptide amphiphiles (PAs), can form nanofibres [475, 476] used for three-dimensional formation of tissue cultures [476–480].

Chemical cross-linking hydrogels having convalescent bonds include photo-cross-linkable poly(ethylene glycol)-diacrylate (PEGDA), poly(ethylene glycol)-dimethacrylate (PEGDMA), poly(propylene fumarate) (PPF) and oligo(poly(ethylene glyco) fumarate) (OPF) [481–485], and also natural hydrogels such as dextran, alginate, chitosan and hyaluronic acid synthesised from PEGDA/PEGDMA [486–489] and Michael-type addition reaction [490–492] and Schiff base-cross-linked hydrogels [465, 493–495]. In the case of enzyme-mediated cross-linking [458], transglutaminases (including Factor Xllla) and horseradish peroxidases (HRP) [459] are used for the catalysis of star-shaped PEG hydrogels [496] and tissue transglutaminase catalysed PEG hydrogels [497]. This also applies tyrosinase, phosphopantetheinyl transferase, lysyl oxidase, plasma amine oxidase, and phosphatases [498]. It made it possible in particular to develop new gels by engrafting tyramine groups into natural and synthetic polymers such as dextran, hyaluronic acid, alginate, cellulose, gelatin, heparin and PEG-PPO [499–505, 509].

Ionic cross-linking hydrogels include calcium-cross-linked alginate [459] and chitosan-polylysine, chitosan-glycerol phosphate salt and chitosan-alginate hydrogels [506–508]. Different synthetic and natural polymers were used for this purpose, including polyethylene glycol (PEG), and copolymers containing PEG [486, 510], hyaluronic acid (HA) [511] after an oxidation reaction through HA-tyramine conjugates [505] and as a result of the formation between HA–SH [492, 512] and Michael addition [491, 513], collagen and gelatin hydrogels mostly cross-linked using glutaraldehyde, genipin or water- soluble carbodiimides [513–515], chitosan [516–519], dextran 192 [520, 521] and alginate [522]. Hydrogels were used for reconstruction of the retina [523], ligament [524], fatty tissue [465], kidneys [525], muscles [526], blood vessels [527, 528], and also heart, neural cells, invertebral discs, bones and gristle [459]. Hydrogels were used to prevent adhesions [529, 530, 531], to promote cellular adhesion [490, 532, 533]. So-called strong hydrogels were developed to improve mechanical properties [534]. The three-dimensional representation is possible of placement of cells with energy in the hydrogel to vascular structures using a laser [535, 536], notably for recording directly the endothelial cell [535].

The general criteria of materials selection for tissue scaffolds relate to the material type and its structure, osteoconductivity ability, mechanical strength, ease of production and manipulation in clinical applications. **Table 1** presents numerous examples of the application of various bioactive and engineering materials, and their respective materials processing and tissue engineering technologies for manufacturing of the hybrid personalised implants and scaffolds [2].

Many layers of different types of cells at present can be three-dimensionally printed to directly create an organ, ensuring the highest currently possible degree of control over the structure of the regenerated tissues [537–542]. The first production system for three-dimensional printing of tissues was delivered only in 2009 based on the NovoGen bioprinting technology [543]. China has invested nearly 0.5 billion USD to establish 10 national institutes for development of organ

Fabrication stage	Investigated materials	Technologies applied	Areas of application
Fabrication of implant bearing structure	Ti, Ti alloys with V or Nb, Mg (possibly with additives of Ca, Zn and Mn), ceramic materials Al_2O_3 and ZrO_2, TiO_2, resorbable bioglass, e.g., Hench bioglass, from the CaO-SiO_2-P_2O_5 and SiO_2-Al_2O_3 system, hydroxyapatites, polymers, composites	Selective laser sintering, sintering, the use of organic matrix, lyophilisation of ceramic slip, rapid pressure assisted densification methods, such as rapid hot pressing/spark plasma sintering (SPS), skeletal casting, plastic working, cutting micro-treatment, computer-aided manufacturing, sol-gel methods, 3D printing, electrospinning, atomic layer deposition, and physical vapour deposition	Filling the losses of long bones, hip and knee joints, facial-skull bone, losses of joint cartilage cells, oesophagus losses and/or blood vessel losses, dental restorations, and skin restorations
Fabrication of porous implant part	Ti, Ti alloys with V or Nb, Mg (possibly with additives of Ca, Zn and Mn), ceramic materials Al_2O_3 and ZrO_2, TiO_2, resorbable bioglass, e.g., Hench bioglass, from the CaO-SiO_2-P_2O_5 I SiO_2-Al_2O_3 system, hydroxyapatites, polymers, composites		
Fabrication of coatings inside pores of porous implant part	A natural protein, synthetic and polysaccharide polymers, including thermosetting, including collagen, fibrin, alginate, silk, hyaluronic acid, chitosan, poly (lactic acid) (PLA), poly(glycolic acid) (PGA), polycaprolactone (PCL) and poly(propylene fumarate) (PPF), polyethylene glycol, Al_2O_3, resorbable bioglass, hydroxy carbonate apatite (HCA), calcium phosphate (CaPs), hydroxyapatite (HA), B-tricalcium phosphate (B-TCP), biphasic calcium phosphate, composites: collagen + hydroxy - apatite CaP-polymer tricalcium phosphate (TCP)-polycaprolactone (PCL), hydroxyapatite HA/poly(ester-urethane)(PU), collagen-bioglass	Infiltration, 3D printing, selective laser sintering, electrospinning, atomic layer deposition, physical vapour deposition, pressing, and sol-gel methods	
Fabrication and application of tissue cultures	Adipocytes, chondrocytes, osteoblasts, fibroblasts and skeletal myocytes	Cell transplantation, matrix implantation, cell implantation with matrix, breeding of xenogeneic and autologous cells and the stage of clinical activities	

Table 1. Examples of the application of various bioactive and engineering materials, and their respective material processing and tissue engineering technologies for manufacturing of the hybrid personalised implants and scaffolds [2].

printing [544], in which the printing of ears, liver and kidneys from living tissues was started in 2013. It is expected that fully functional printed organs can be achieved over the next dozens of years or so [545, 546]. In the meanwhile, there were reports that an Australian team obtained a kidney tissue print with this method for the first time [547]. An American team confirmed in 2014 it is ready to print a heart [548]. A three-dimensional structure is obtained by subsequent formation of layers of living tissues on the gel or sugar matrix substrate [549]. To use the three-dimensional printing technique, a polymer-cell mixture can be dosed, leading to the formation of

cell hydrogel [550]. Microfluidics allows for the creation of three-dimensional systems of cells [551]. It is possible to obtain such cell systems from hydrogels by photopolymerisation of polymer solutions [552]. Using SFF techniques, including stereolithography techniques can create scaffolds made of PEG hydrogels also [440]. Vascularisation for organ printing remains a significant challenge in tissue engineering. The development of a vascular network in metabolically functional tissues enables the transport of nutrients and removal of wastes, ensuring maintenance of cells' viability for a long time [553]. Micro-formation techniques, by the three-dimensional printing of templates made of agarose fibres, are used for the creation of a microchannel network inside hydrogel products, including, in particular, inside star poly(ethylene glycol-co-lactide)acrylate (SPELA), methacrylated gelatin (GelMA), poly(ethylene glycol) dimethacrylate (PEGDMA) and poly(ethylene glycol) diacrylate (PEGDA) with different concentrations. In the last several years, the efficient formation of endothelial monolayers within the fabricated channels has also been confirmed [554]. Unfortunately, the progress in vascularisation control is limited, despite immense progress in the production of complicated tissue structures.

6. Contents of the book on regenerative medicine and dentistry

The book on Biomaterials in Regenerative Medicine contains a total of 18 chapters. Selected issues discussed in the previous five sub-chapters were presented in it. The literature review, in this first chapter, deals with technical, biological and medical aspects concerning materials and technologies for medical and dental implantable devices. In the second chapter, the metallic biomaterials and their application in regenerative medicine are presented in detail by the literature review. In addition to these two chapters, all the rest contain the results of their scientific research done by the authors of these chapters. Indeed, the originality of the presented research results constitutes the real value of the book at this moment passed to the readers' hands. The next chapters contain issues about additive technologies and laser manufacturing of materials used in regenerative medicine and mainly in regenerative dentistry. The third chapter is on microporous titanium-based materials located inside the pores by biocompatible thin films to facilitate the implantation and proliferation of living cells in the scaffolds thus produced. In turn, the fourth chapter includes mechanical properties comparison of engineering materials produced by additive and subtractive technologies for dental prosthetic restoration application. It discusses both solid and milled sintered titanium and its alloy, Co-Cr alloy, and sintered ZrO_2. In the fifth and sixth chapters, properties of Co-Cr dental alloys fabricated using an additive, technologies were presented. The progress of the application of 3D printing for tissue regeneration in oral and maxillofacial surgery is presented in chapter seven. In the eighth chapter, the issues of the tissue engineering and use of growth factors in bone regeneration are discussed. Laser processing was analysed in chapter nine concerning silicon for its synthesis as better biomaterials. Prospective of characterisation of the skin models and associated with it measurements and simulation of permeation and diffusion in 3D tissues are presented in the tenth chapter. The eleventh chapter also contains the skin regeneration problems explanation and also a description of the biomaterials for tendon and ligament regeneration. The next few chapters deal with natural and artificial gels of polymeric materials. In the twelfth chapter, authors described the hydrogels for regenerative

medicine. Natural rubber latex biomaterials in bone regenerative medicine are presented in the thirteenth chapter. A systematic study of ethylene-vinyl acetate (EVA) in the manufacturing of protector devices for the orofacial system was described in the fourteenth chapter. The next few chapters outline other issues regarding regenerative medicine and tissue engineering. The fifteenth chapter includes tailoring bioengineered scaffolds for regenerative medicine. Biomaterials and stem cells as promising tools in tissue engineering and biomedical applications are the content of the sixteenth chapter. Identification of Fe_3O_4 nanoparticles biomedical purpose by magnetometric methods is the title of the seventeenth chapter. The eighteenth chapter applies to biomaterials for tissue engineering applications in diabetes mellitus.

The editor, publisher and the whole team of authors, by making this book available to the readers, deeply believe that the detailed information collected in the book, largely deriving from own and original research and R&D works pursued by the authors, will be beneficial for the readers to develop their knowledge and harmonise specific information concerning these topics, and will convince the engineers and medicals about the advantages of using the manufacturing and tissue engineering and advanced biomaterials in regenerative medicine and dentistry. On one hand, it makes possible gaining positive effects in the economic manufacturing of biomaterials and implantable devices; on the other hand, it will ameliorate the fate of many people affected by severe diseases. This awareness justifies the involvement in the execution of research and the effort put in describing their results in this book.

Notice

The study presented in the chapter was realised in the Medical and Dental Engineering Centre for Research, Design and Production ASKLEPIOS in Gliwice, Poland in the framework of the Project POIR.01.01.01-00-0485/16-00 on 'IMSKA-MAT Innovative dental and maxillofacial implants manufactured using the innovative additive technology supported by computer-aided materials design ADDMAT' co-financed by the National Centre for Research and Development in Warsaw, Poland.

Author details

Leszek A. Dobrzański

Address all correspondence to: leszek.adam@gmail.com

Science Centre of the Medical and Dental Engineering Centre for Research, Design and Production Asklepios, Gliwice, Poland

References

[1] Dobrzański LA. The concept of biologically active microporous engineering materials and composite biological-engineering materials for regenerative medicine and dentistry. Archives of Materials Science and Engineering. 2016;**80**(2):64-85. DOI: 10.5604/18972764.1229638

[2] Dobrzański LA. Overview and general ideas of the development of constructions, materials, technologies and clinical applications of scaffolds engineering for regenerative medicine. Archives of Materials Science and Engineering. 2014;**69**(2):53-80

[3] Dobrzański LA. Applications of newly developed nanostructural and microporous materials in biomedical, tissue and mechanical engineering. Archives of Materials Science and Engineering. 2015;**76**(2):53-114

[4] Dobrzański LA. Korszerű mérnöki anyagok kutatásának nanotechnológiai aspektusai. Miskolci Egyetem, Multidiszciplináris tudományok. 2016;**6**(1):21-44

[5] Dobrzański LA, Dobrzańska-Danikiewicz AD. Metalowe materiały mikroporowate i lite do zastosowań medycznych i stomatologicznych. Open Access Library. 2017;Annal **VII** (1):1-580 (ISBN 978-83-63553- 44-9; International OCSCO World Press, Gliwice)

[6] Dobrzański LA, editor. Powder Metallurgy – Fundamentals and Case Studies. Rijeka, Croatia: InTech; 2017. pp. 1-392 (ISBN 978-953-51- 3053-6)

[7] Dobrzański LA, editor. Polymer nanofibers produced by electrospinning applied in regenerative medicine. Open Access Library. 2015;**V**(3):1-168 (ISBN 978-83-63553-88-3)

[8] Dobrzański LA. Metale i ich stopy. Open Access Library. 2017;**VII**(2):1-982 (ISBN 978-83-63553-47-0; International OCSCO World Press, Gliwice)

[9] Nowacki J, Dobrzański LA, Gustavo F. Intramedullary implants for osteosynthesis of long bones. Open Access Library. 2012;**11**(17):1-150 (in Polish) (ISBN 978-83-63553-07-4)

[10] Dobrzański LA, Dobrzańska-Danikiewicz AD, Achtelik-Franczak A, Szindler M. Structure and properties of the skeleton microporous materials with coatings inside the pores for medical and dental applications. In: Muruganant M et al., editors. Frontiers in Materials Processing, Applications, Research and Technology. Springer Nature Singapore Pte Ltd; 2018. pp. 297-320. DOI: 10.1007/978-981-10-4819-7_26

[11] Dobrzański LA, Dobrzańska-Danikiewicz AD, Achtelik-Franczak A, Dobrzański LB, Szindler M, Gaweł TG. Porous selective laser melted Ti and Ti6Al4V materials for medical applications. In: Dobrzański LA, editor. Powder Metallurgy – Fundamentals and Case Studies. Rijeka, Croatia: InTech; 2017. pp. 161-181 (ISBN 978-953-51-3053-6, DOI: 10.5772/65375)

[12] Dobrzański LA, Matula G, Dobrzańska-Danikiewicz AD, Malara P, Kremzer M, Tomiczek B, Kujawa M, Hajduczek E, Achtelik-Franczak A, Dobrzański LB, Krzysteczko J. Composite materials infiltrated by aluminium alloys based on porous skeletons from alumina, Mullite and titanium produced by powder metallurgy techniques. In: Dobrzański LA,

editor. Powder Metallurgy – Fundamentals and Case Studies. Rijeka, Croatia: InTech; 2017. pp. 95-137 (ISBN 978-953-51-3053-6, DOI: 10.5772/65377)

[13] Dobrzański LA, Dobrzańska-Danikiewicz AD, Achtelik-Franczak A, Dobrzański LB, Hajduczek E, Matula G. Fabrication Technologies of the Sintered Materials Including Materials for medical and dental application. In: Dobrzański LA, editor. Powder Metallurgy – Fundamentals and Case Studies. Rijeka, Croatia: InTech; 2017. pp. 17-52 (ISBN 978-953-51-3053-6, DOI: 10.5772/65376)

[14] Dobrzański LA. Stan wiedzy o materialach stosowanych w implantologii oraz medycynie regeneracyjnej. In: Dobrzański LA, Dobrzańska-Danikiewicz AD, editors. Metalowe materiały mikroporowate i lite do zastosowań medycznych i stomatologicznych. Gliwice: International OCSCO World Press. Open Access Library, 2017;**VII**(1):117-120 (ISBN 978-83-63553-44-9)

[15] Dobrzański LA, Achtelik-Franczak A. Struktura i wlasnosci tytanowych szkieletowych materialów mikroporowatych wytworzonych metoda selektywnego spiekania laserowego do zastosowan w implantologii oraz medycynie regeneracyjnej. In: Dobrzański LA, Dobrzańska-Danikiewicz AD, editors. Metalowe materiały mikroporowate i lite do zastosowań medycznych i stomatologicznych. Gliwice: International OCSCO World Press, Open Access Library, 2017;**VII**(1):186-244 (ISBN 978-83-63553-44-9)

[16] Dobrzanska-Danikiewicz AD, Gawel TG, Kroll L, Dobrzanski LA. Nowe porowate materialy kompozytowe metalowo-polimerowe wytwarzane z udzialem selektywnego stapiania laserowego. In: Dobrzański LA, Dobrzańska-Danikiewicz AD, editors. Metalowe materiały mikroporowate i lite do zastosowań medycznych i stomatologicznych. Gliwice: International OCSCO World Press, Open Access Library. 2017;**VII**(1):245-288 (ISBN 978-83-63553-44-9)

[17] Dobrzanska-Danikiewicz AD, Dobrzanski LA, Szindler M, Achtelik-Franczak A, Dobrzanski LB. Obróbka powierzchni materialów mikroporowatych wytworzonych metoda selektywnego spiekania laserowego w celu uefektywnienia proliferacji zywych komórek. In: Dobrzański LA, Dobrzańska-Danikiewicz AD, editors. Metalowe materiały mikroporowate i lite do zastosowań medycznych i stomatologicznych. Gliwice: International OCSCO World Press, Open Access Library. 2017;**VII**(1):289-375 (ISBN 978-83-63553-44-9)

[18] Dobrzański LA, Achtelik-Franczak A. Struktura i wlasnosci materialów kompozytowych do zastosowan medycznych o osnowie odlewniczych stopów aluminium wzmacnianych tytanowymi szkieletami wytworzonymi metoda selektywnego spiekania laserowego. In: Dobrzański LA, Dobrzańska-Danikiewicz AD, editors. Metalowe materiały mikroporowate i lite do zastosowań medycznych i stomatologicznych. Gliwice: International OCSCO World Press, Open Access Library, 2017;**VII**(1):376-433 (ISBN 978-83-63553-44-9)

[19] Dobrzański LA. Autorska koncepcja rozwoju implanto-skafoldów oraz materialów biologiczno-inzynierskich do aplikacji w medycynie i stomatologii. In: Dobrzański LA,

Dobrzańska-Danikiewicz AD, editors. Metalowe materiały mikroporowate i lite do zastosowań medycznych i stomatologicznych. Gliwice: International OCSCO World Press, Open Access Library, 2017;**VII**(1):535-580 (ISBN 978-83-63553-44-9)

[20] Dobrzański LA, Pakuła D, Staszuk M. Chemical vapor deposition in manufacturing. In: Nee AYC, editor. Handbook of Manufacturing Engineering and Technology. London: Springer-Verlag; 2015. pp. 2755-2803 (ISBN 978-1-4471-4669-8)

[21] Dobrzański LA, Gołombek K, Lukaszkowicz K. Physical vapor deposition in manufacturing. In: Nee AYC, editor. Handbook of Manufacturing Engineering and Technology. London: Springer-Verlag; 2015. pp. 2719-2754 (ISBN 978-1-4471-4669-8)

[22] Dobrzański LA, Dobrzańska-Danikiewicz AD, Tański T, Jonda E, Drygała A, Bonek M. Laser surface treatment in manufacturing. In: Nee AYC, editor. Handbook of Manufacturing Engineering and Technology. London: Springer-Verlag; 2015. pp. 2677-2717 (ISBN 978-1- 4471-4669-8)

[23] Dobrzański LA, Dobrzańska-Danikiewicz AD. Foresight of the surface Technology in Manufacturing. In: Nee AYC, editor. Handbook of Manufacturing Engineering and Technology. London: Springer-Verlag; 2015. pp. 2587-2637 (ISBN 978-1-4471-4671-1)

[24] Dobrzański LA, Trzaska J, Dobrzańska-Danikiewicz AD. Use of neural networks and artificial intelligence tools for Modeling, characterization, and forecasting in material engineering. In: Hashmi S, editor. Comprehensive Materials Processing, G.F. Batalha (Ed.): Vol. 2: Materials Modeling and Characterization. Elsevier Ltd; 2014. pp. 161-198 (ISBN 978-0-08-096532-1)

[25] Dobrzański LA, Dobrzańska-Danikiewicz AD, Gaweł TG, Achtelik-Franczak A. Selective laser sintering and melting of pristine titanium and titanium Ti6Al4V alloy powders and selection of chemical environment for etching of such materials. Archives of Metallurgy and Materials. 2015;**60**(3):2039-2045

[26] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Gaweł T, Dobrzański LB, Achtelik-Franczak A. Fabrication of scaffolds from Ti6Al4V powders using the computer aided laser method. Archives of Metallurgy and Materials. 2015;**60**(2):1065-1070

[27] Reimann Ł, Żmudzki J, Dobrzański LA. Strength analysis of a three-unit dental bridge framework with the finite element method. Acta of Bioengineering and Biomechanics. 2015;**17**(1):51-59

[28] Żmudzki J, Chladek G, Kasperski J, Dobrzański LA. One versus two implant-retained dentures: Comparing biomechanics under oblique mastication forces. Journal of Biomechanical Engineering. 2013;**135**(5):054503-1-054503-4

[29] Nowak AJ, Dobrzański LA. Geometrical structure investigation of the surface of internal oesophagus prosthesis. Archives of Materials Science and Engineering. 2017;**83**(2):79-85

[30] Dobrzański LA, Dobrzańska-Danikiewicz AD, Achtelik-Franczak A. The structure and properties of aluminium alloys matrix composite materials with reinforcement made of

titanium skeletons. Archives of Materials Science and Engineering. 2016;**80**(1):16-30. DOI: 10.5604/18972764.1229614

[31] Dobrzański LA, Hudecki A, Chladek G, Król W, Mertas A. Biodegradable and antimicrobial polycaprolactone nanofibers with and without silver precipitates. Archives of Materials Science and Engineering. 2015;**76**(1):5-26

[32] Kremzer M, Dobrzański LA, Dziekońska M, Macek M. Atomic layer deposition of TiO2 onto porous biomaterials. Archives of Materials Science and Engineering. 2015;**75**(2):63-69

[33] Dobrzański LA, Dobrzańska-Danikiewicz AD, Szindler M, Achtelik-Franczak A, Pakieła W. Atomic layer deposition of TiO_2 onto porous biomaterials. Archives of Materials Science and Engineering. 2015;**75**(1):5-11

[34] Dobrzański LA, Dobrzańska-Danikiewicz AD, Achtelik-Franczak A, Dobrzański LB. Comparative analysis of mechanical properties of scaffolds sintered from Ti and Ti6Al4V powders. Archives of Materials Science and Engineering. 2015;**73**(2):69-81

[35] Dobrzański LA, Hudecki A, Chladek G, Król W, Mertas W. Surface properties and antimicrobial activity of composite nanofibers of polycaprolactone with silver precipitations. Archives of Materials Science and Engineering. 2014;**70**(2):53-60

[36] Dobrzański LA, Hudecki A. Structure, geometrical characteristics and properties of biodegradable micro- and polycaprolactone nanofibers. Archives of Materials Science and Engineering. 2014;**70**(1):5-13

[37] Nowak AJ, Dobrzański LA, Rybczyński R, Mech R. Finite element method application for modelling of internal oesophageal prosthesis. Archives of Materials Science and Engineering. 2013;**64**(2):198-204

[38] Stefański T, Malara P, Kloc-Ptaszna A, Janoszka B, Postek-Stefańska L, Tyrpień-Golder K, Dobrzański LA. Erosive potential of calcium-supplemented citric acid on bovine enamel. Archives of Materials Science and Engineering. 2013;**64**(2):175-181

[39] Żmudzki J, Chladek G, Malara P, Dobrzański LA, Zorychta M, Basa K. The simulation of mastication efficiency of the mucous- borne complete dentures. Archives of Materials Science and Engineering. 2013;**63**(2):75-86

[40] Malara P, Kloc-Ptaszna A, Dobrzański LA, Górniak M, Stefański T. Water dilution and alcohol mixing on erosive potential of orange juice on bovine enamel. Archives of Materials Science and Engineering. 2013;**62**(1):15-21

[41] Chladek G, Żmudzki J, Malara P, Dobrzański LA, Krawczyk C. Effect of influence of introducing silver nanoparticles on tribological characteristics of soft liner. Archives of Materials Science and Engineering. 2013;**62**(1):5-14

[42] Reimann Ł, Dobrzański LA. Influence of the casting temperature on dental co-base alloys properties. Archives of Materials Science and Engineering. 2013;**60**(1):5-12

[43] Dobrzański LA, Reimann Ł, Krawczyk C. Effect of age hardening on corrosion resistance and hardness of CoCrMo alloys used in dental engineering. Archives of Materials Science and Engineering. 2012;**57**(1):5-12

[44] Szindler M, Dobrzański LA, Szindler MM, Pawlyta M, Jung T. Comparison of surface morphology and structure of Al2O3 thin films deposited by sol-gel and ALD methods. Journal of Achievements in Materials and Manufacturing Engineering. 2017;**2**(82):49-57. DOI: 10.5604/01.3001.0010.2354

[45] Dobrzański LA, Dobrzańska-Danikiewicz AD, Gaweł TG. Individual implants of a loss of palate fragments fabricated using SLM equipment. Journal of Achievements in Materials and Manufacturing Engineering. 2016;**77**(1):24-30. DOI: 10.5604/17348412.1229665

[46] Dobrzański LA, Dobrzańska-Danikiewicz AD, Gaweł TG. Ti6Al4V porous elements coated by polymeric surface layer for biomedical applications. Journal of Achievements in Materials and Manufacturing Engineering. 2015;**71**(2):53-59

[47] Nowak AJ, Dobrzański LA. Wear abrasive resistance of intracorporeal prosthesis of oesophagus. Journal of Achievements in Materials and Manufacturing Engineering. 2015; **69**(1):26-32

[48] Dobrzański LA, Adamiak M, Karoń M, Nieradka B. Influence of inorganic additives on morphology of electrospun fibres. Journal of Achievements in Materials and Manufacturing Engineering. 2015;**68**(2):64-71

[49] Hudecki A, Pawlyta M, Dobrzański LA, Chladek G. Micro and ceramic nanoparticles surface properties examination with gas adsorption method and microscopic transmission. Journal of Achievements in Materials and Manufacturing Engineering. 2013;**61**(2):257-262

[50] Dobrzański LA, Achtelik-Franczak A, Król M. Computer aided design in selective laser sintering (SLS) – Application in medicine. Journal of Achievements in Materials and Manufacturing Engineering. 2013;**60**(2):66-75

[51] Reimann Ł, Dobrzański LA, Nieradka B, Kusy M, Riedlmajer R. Influence the heat treatment of two base metal alloys used on dental prosthesis on corrosion resistance. Journal of Achievements in Materials and Manufacturing Engineering. 2013;**57**(2):83-90

[52] Dobrzański LA, Reimann Ł. Digitization procedure of creating 3D model of dental bridgework reconstruction. Journal of Achievements in Materials and Manufacturing Engineering. 2012;**55**(2):469-476

[53] Dobrzański LA, Dobrzańska-Danikiewicz AD, Gaweł TG. Computer-aided design and selective laser melting of porous biomimetic materials. Advances in Materials and Processing Technologies. 2017;**3**(1):70-82. DOI: 10.1080/2374068X.2016. 1247339

[54] Nowak AJ, Dobrzański LA. Badania struktury geometrycznej powierzchni wewnątrzustrojowej protezy przełyku. Przetwórstwo Tworzyw. 2015;**21**(4(166)):337-342

[55] Dobrzański LA, Wolany W. Biomaterials manufacturing using SLS method, 20th Jubilee international seminar of Ph.D. students, SEMDOK 2015, Terchova, Slovakia; 2015. pp. 109–112

[56] Dobrzański LA, Dobrzańska-Danikiewicz AD, Łukowiec D. Research methodology laser sintered biomaterials, 20th Jubilee international seminar of Ph.D. students, SEMDOK 2015, Terchova, Slovakia; 2015. pp. 57-66

[57] Czaja I, Hudecki A, Dobrzański LA. Examination of selected surface properties of solids by gas adsorption, 19th International seminar of Ph.D. students, SEMDOK 2014, Terchova, Slovakia; 2014. pp. 22-25

[58] Reimann Ł, Dobrzański LA. Forming the CoCrMo alloys properties by casting conditions, 18th International of PhD. students' seminar, SEMDOK 2013, Terchova, Slovakia; 2013. pp. 56-61

[59] Dobrzański LA, Reimann Ł, Krawczyk C. Heat Treatment Remanium 2000+ Cobalt Alloy Used as Substrate on Dentures, 14th International Materials Symposium, IMSP'2012, Proceedings, Denizli, Turkey; 2012. pp. 598-605

[60] Dobrzański LA, Reimann Ł. Influence of cobalt and chromium on properties of cobalt base alloys, Proceedings of the International Forum of Young Researchers, (Problemy Nedropol'zovaniâ, Meždunarodnyj Forum-Konkurs Molodyh Učenyh, Sbornik Naučnyh Trudov, Sankt-Peterburg), St Petersburg, Russia; 2012, Part II. pp. 7-10

[61] Dobrzański LA, Pusz A, Nowak AJ. Implanty wewnątrzustrojowe. Wady powierzchniowe w materiałach kompozytowych do implantów wewnątrzustrojowych, Materiały kompozytowe. Ludzie, Innowacje, Technologie. 2012;**1**:48-52

[62] Reimann Ł, Dobrzański LA. Zmiany odporności korozyjnej stopów na osnowie kobaltu po obróbce cieplnej. In: Pacyna J, XLI Szkoła Inżynierii Materiałowej, Kraków; 2013. pp. 294-299

[63] Dobrzańska-Danikiewicz A., Dobrzański LA, Gaweł TG. Scaffolds applicable as implants of a loss palate fragments, International Conference on Processing & Manufacturing of Advanced Materials. Processing, fabrication, properties, applications. THERMEC'2016, Graz, Austria; 2016. p. 193

[64] Hudecki A, Dobrzański LA. Biodegradable PVA and PEO polimeric nanofibers received in electrostatic field, Programme and Proceedings of the Twenty First International Scientific Conference "Achievements in Mechanical and Materials Engineering", AMME'2013, Gliwice – Kraków; 2013. p. 129

[65] Król M, Dobrzański LA, Kujawa M. Influence of technological parameters of the SLS method on AM steel parts, Programme and Proceedings of the Twenty First International Scientific Conference „Achievements in Mechanical and Materials Engineering", AMME'2013, Gliwice – Kraków; 2013. p. 87

[66] Reimann Ł, Żmudzki J, Dobrzański LA. Dobór materiałów na protezy stałe z wykorzystaniem system komputerowego, XVI Konferencja, Biomateriały i mechanika w stomatologii, Ustroń; 2016. p. 62

[67] Postek-Stefańska L, Stefański T, Malara P, Kloc-Ptaszna A, Dobrzański LA. Ocena biopolimerów polisacharydowych jako inhibitorów procesu roztwarzania szkliwa w kwasie cytrynowym, Biomateriały i mechanika w stomatologii, XV Konferencja, Program i streszczenia referatów, Ustroń; 2015. p. 66

[68] Reimann Ł, Dobrzański LA, Żmudzki J. Struktura i własności utwardzanego wydzieleniowo stopu CoCrMoW, Biomateriały i mechanika w stomatologii, XIII Konferencja, Program i streszczenia referatów, Ustroń; 2013. p. 66

[69] Reimann Ł, Dobrzański LA, Żmudzki J. Wpływ własności materiału metalowego na ugięcie trzypunktowego mostu protetycznego, Biomateriały i mechanika w stomatologii, XIII Konfrencja, Program i streszczenia referatów, Ustroń; 2013. p. 65

[70] Malara P, Kloc-Ptaszna A, Dobrzański LA, Stefański T, Górniak M, Chladek G. Wpływ wybranych dodatków na potencjał erozyjny soku pomarańczowego w stosunku do szkliwa zębów, Biomateriały i mechanika w stomatologii, XIII Konfrencja, Program i streszczenia referatów, Ustroń; 2013. p. 45

[71] Hudecki A, Dobrzański LA, Chladek. Własności nanowłókien polimerowych PLA i PCL z dodatkiem wypełniacza o własnościach przeciwdrobnoustrojowych otrzymywanych w polu elektrostatycznym, Biomateriały i mechanika w stomatologii, XIII Konfrencja, Program i streszczenia referatów, Ustroń; 2013. p. 34

[72] Hudecki A, Dobrzański LA, Chladek G. Własności mikro i nanowypełniaczy ceramicznych przewidywanych do poprawy własności materiałów polimerowych przeznaczonych dla stomatologii, Biomateriały i mechanika w stomatologii, XIII Konfrencja, Program i streszczenia referatów, Ustroń; 2013. p. 33

[73] Dobrzański LA, Achtelik-Franczak A. Zastosowanie narzędzi komputerowego projektowania w technologii selektywnego spiekania laserowego, Biomateriały i mechanika w stomatologii, XIII Konfrencja, Program i streszczenia referatów, Ustroń; 2013. p. 27

[74] Dobrzański LA, Achtelik-Franczak A. Zastosowanie technologii selektywnego laserowego spiekania proszków metali w medycynie, Biomateriały i mechanika w stomatologii, XIII Konfrencja, Program i streszczenia referatów, Ustroń; 2013. p. 26

[75] Reimann Ł, Dobrzański LA, Krawczyk C. Wpływ temperatury odlewania na własności stopów kobaltu, Biomateriały i mechanika w stomatologii. Program i materiały XII Konfrencji, Ustroń; 2012. p. 69

[76] Reimann Ł, Dobrzański LA. Odporność korozyjna stopów kobaltu stosowanych w inżynierii stomatologicznej, Proceedings of the Eighteenth International Scientific Conference on Contemporary Achievements in Mechanics, Manufacturing and Materials Science, CAM3S'2012, Gliwice – Ustroń; 2012, p. 82

[77] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Achtelik-Franczak A, Dobrzański LB, Kremzer M. Sposób wytwarzania materiałów kompozytowych o mikroporowatej szkieletowej strukturze wzmocnienia, Zgłoszenie Patentowe P 417552 z dn. 13.06.2016

[78] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Dobrzański LB, Achtelik-Franczak A. Kompozyty biologiczno-inżynierskie dla medycyny regeneracyjnej, Zgłoszenie Patentowe P 414723 z dn. 9.11.2015

[79] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Gaweł TG, Dobrzański LB, Achtelik-Franczak A. Implanto-skafold kostny, Zgłoszenie Patentowe P 414424 z dn. 19.10.2015

[80] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Gaweł TG, Dobrzański LB, Achtelik-Franczak A. Implanto-skafold lub proteza elementów anatomicznych układu stomatognatycznego oraz twarzoczaszki, Zgłoszenie Patentowe P 414423 z dn. 19.10.2015 1848

[81] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Gaweł TG, Dobrzański LB, Achtelik A. Kompozyt wykonany z użyciem komputerowo wspomaganych metod laserowych na implanty twarzoczaszki oraz sposób jego wytwarzania (Composite produced using the computer-aided laser methods, intended for the facial skeleton implants and method for producing it), Zgłoszenie Patentowe P 411689 z dn. 23.03.2015, Biuletyn Urzędu Patentowego, Rok. 2016;**44**(20):6

[82] Dobrzański LA, Hudecki A. Sposób wytwarzania materiału kompozytowego o własnościach bioaktywnych i bakteriobójczych (Method for producing composite material with bioactive and bactericidal properties), Zgłoszenie Patentowe P 410452 z dn. 08.12.2014, Biuletyn Urzędu Patentowego, Rok. 2016;**44**(13):25

[83] Dobrzański LA, Hudecki A. Sposób wytwarzania materiału kompozytowego o własnościach bioaktywnych i bakteriobójczych (Method for producing composite material with bioactive and bactericidal properties), Zgłoszenie Patentowe P 410427 z dn. 08.12.2014, Biuletyn Urzędu Patentowego, Rok. 2016;**44**(13):25

[84] Dobrzański LA, Nowak A, Lampe P, Pusz A. Wewnątrzustrojowa proteza przełyku i sposób jej wykonania (Internal esophageal prosthesis and method of implementation thereof), Biuletyn Urzędu Patentowego, Rok. 2012;**40**(21):4-5, Opis patentowy PL 218012; 2014

[85] Dobrzańska-Danikiewicz AD, Achtelik-Franczak A, Wolany W, Dobrzański LA. Dental implants and bridges with scaffold structure – Gold Medal; 10th International Warsaw Invention Show IWIS 2016, Warsaw, Poland, 10–12.10.2016

[86] Dobrzańska-Danikiewicz AD, Achtelik-Franczak A, Wolany W, Dobrzański LA. Dental implants and bridges with scaffold structure –Gold Award, 9th Korea International Women's Invention Exposition, KIWIE 2016, Seoul, Korea, 16–19.06.2016

[87] Dobrzańska-Danikiewicz AD, Achtelik-Franczak A, Wolany W, Dobrzański LA. Dental implants and bridges with scaffold structure – The First Institute Inventors and Researches in I. R. Iran (FIRI) Award for the Best Invention, 9th Korea International Women's Invention Exposition, KIWIE 2016, Seoul, Korea, 16–19.06.2016

[88] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Dobrzański LB, Achtelik-Franczak A, Gaweł TG. Implant-scaffold or Prosthesis Anatomical Structures of the Stomatognathic System and the Craniofacial – Gold Medal, International Exhibition of Technical Innovations, Patents and Inventions, INVENT ARENA 2016, Třinec, Czech Republic, 16–18.06.2016

[89] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Dobrzański LB, Achtelik-Franczak A, Gaweł TG. Implant-scaffold or Prosthesis Anatomical Structures of the Stomatognathic System and the Craniofacial – Gold Medal, International Intellectual Property, Invention, Innovation and Technology Exposition, IPITEX 2016, Bangkok, Thailand, 2–6.02.2016

[90] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Dobrzański LB, Achtelik-Franczak A, Gaweł TG. Implant-scaffold or Prosthesis Anatomical Structures of the Stomatognathic System and the Craniofacial – International Intellectual Property Network Forum (IIPNF) Leading Innovation Award, International Intellectual Property, Invention, Innovation and Technology Exposition, IPITEX 2016, Bangkok, Thailand, 2–6.02.2016

[91] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Gaweł TG, Dobrzański LB, Achtelik-Franczak A. Global Inventions and Innovations Exhibitions Innova Cities Latino-America, ICLA 2015, Foz do Iguaçu, Brazil, 10–12.12.2015: The novel composite consisting of a metallic scaffold, manufactured using a computer aided laser method, coated with thin polymeric surface layer for medical applications – Semi Grand Prize;

[92] Dobrzański LA, Hudecki A. Composite material with bioactive and bacteriocidal properties and the way of its manufacturing – Silver Medal, Global Inventions and Innovations Exhibitions Innova Cities Latino-America, ICLA 2015, Foz do Iguaçu, Brazil, 10–12.12.2015

[93] Dobrzański LA, Dobrzańska-Danikiewicz AD, Malara P, Gaweł TG, Dobrzański LB, Achtelik-Franczak A. The novel composite consisting of a metallic scaffold, manufactured using a computer aided laser method, coated with thin polymeric surface layer for medical applications – Gold Medal, 9th International Warsaw Invention Show IWIS 2015, Warsaw, Poland, 12–14.10.2015

[94] Dobrzański LA, Hudecki A. Composite material with bioactive and bacteriocidal properties and the way of its manufacturing – Silver Medal, 9th International Warsaw Invention Show IWIS 2015, Warsaw, Poland, 12–14.10.2015

[95] Dobrzański LA, Hudecki A. Composite material with bioactive and bacteriocidal and the way of its manufacturing – Bronze Medal, 26th International Invention, Innovation & Technology Exhibition "ITEX 2015", Kuala Lumpur, Malaysia, 21–23.05.2015

[96] Nowak AJ, Dobrzański LA, Lampe P, Pusz A. Biocompatible composite material based on polymer matrix for the internal oesophageal prosthesis – Silver Medal, 64th International Trade Fair Ideas - Inventions - New Products, iENA 2012, Nuremberg, Germany, 1–4.11.2012

[97] Nowak AJ, Dobrzański LA, Lampe P, Pusz A. Biocompatible composite material based on polymer matrix for the internal oesophageal prosthesis with a specific functional properties – Gold Medal, 6th International Warsaw Invention Show IWIS 2012, Warsaw, Poland, 16–19.10.2012

[98] Nowak AJ, Dobrzański LA, Lampe P, Pusz A. Biocompatible composite material based on polymer matrix for the internal oesophageal prosthesis with a specific functional properties – Special Prize awarded by Chinese Innovation & Invention Society, Taiwan, 6th International Warsaw Invention Show IWIS 2012, Warsaw, Poland, 16–19.10.2012

[99] Nowak AJ, Dobrzański LA, Lampe P, Pusz A. Biocompatible composite material based on polymer matrix for the internal oesophageal prosthesis with a specific functional properties – Special Prize awarded by King Saud University, Saudi Arabia, 6th International Warsaw Invention Show IWIS 2012, Warsaw, Poland, 16–19.10.2012

[100] Nowak AJ, Dobrzański LA, Lampe P, Pusz A. Biocompatible composite material based on polymer matrix for the internal oesophageal prosthesis – Gold Medal, 8th Taipei International Invention Show & Technomart for Intellectual Property, Patents, Trademarks, Inventions, INST 2012, Taipei, Taiwan, 20–23.09.2012

[101] Dobrzański LA, Lampe P, Nowak AJ. Internal prosthesis of oesophagus from polymer based composite material reinforced with continuous aramid fibre – Medal "INVENTICA", 16th International Salon of Research, Innovation and Technological Transfer "INVENTICA 2012", Iasi, Romania, 13–15.06.2012

[102] Dobrzański LA, Nowak AJ, Lampe P, Pusz A. Biocompatible composite material based on polymer matrix for the internal oesophageal prosthesis – Bronze Medal, 23rd International Invention, Innovation & Technology Exhibition "ITEX 2012", Kuala Lumpur, Malaysia, 17–19.05.2012

[103] Dobrzański LA, et al. Badanie struktury i własności nowoopracowanych porowatych materiałów biomimetycznych wytwarzanych metodą selektywnego spiekania laserowego, BIOLASIN, Projekt UMO-2013/08/M/ST8/00818 Gliwice, 2013–2016

[104] Dobrzański LA, et al. Ustalenie istoty wpływu jednowymiarowych materiałów nanostrukturalnych na strukturę i własności nowo opracowanych funkcjonalnych materiałów nanokompozytowych i nanoporowatych, NANOCOPOR, Projekt UMO-2012/07/B/ST8/04070, Gliwice, 2013–2016

[105] Dobrzański LA, et al. Opracowanie nowego gradientowego materiału kompozytowego o osnowie polimerowej wzmacnianego włóknami aramidowymi oraz cząstkami proszku tytanu, przeznaczonego do produkcji protezy wewnątrzustrojowej przełyku, Projekt N507 422136, Gliwice, 2009–2011

[106] Dobrzański LA, et al. Opracowanie metodologii komputerowego wspomagania projektowania materiałowego, technologicznego oraz konstrukcyjnego stałych stomatologicznych protez wieloczłonowych w celu predykcji ich własności użytkowych, Projekt N507 438539, Gliwice, 2010–2013

[107] Dobrzański LA, et al. Foresight wiodących technologii kształtowania własności powierzchni materiałów inżynierskich i biomedycznych, FORSURF, Projekt UDA-POIG.01.01.01–00.23/08–00, Gliwice 2009–2012

[108] Centrum Projektowo-Badawczo-Produkcyjne Inżynierii Medycznej i Stomatologicznej ASKLEPIOS w Gliwicach, Projekt POIR.01.01.01–00-0485/16–00 pt. "IMSKA-MAT Innowacyjne implanto-skafoldy stomatologiczne i szczękowo-twarzowe wytwarzane z wykorzystaniem innowacyjnej technologii addytywnej wspomaganej komputerowym projektowaniem materiałowym ADD-MAT", Gliwice; 2017–2021, w toku

[109] Dobrzański LA. ONCO-ATIS Interaction of osteoblast natural cells ordered in the selectively laser sintered metallic materials as a basis for the creation of orthopedic and dental advanced types of implant-scaffalds, Project Proposal NCN 2017/26/A/ST8/00232, Gliwice-Cracow; 2017

[110] Yu C, Abbott PV. Australian Dental Journal. 2007;**52**(1):4-16

[111] Miyagi SPH et al. The Journal of Endocrinology. 2010;**36**(5):826-831

[112] Seltzer S, Farber PA. Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology. 1994;**78**:634-645

[113] Wójcicka A et al. Przegląd Epidemiologiczny. 2012;**66**(4):705-711

[114] Szymańska J, Szalewski L. Zdrowie Publiczne. 2011;**121**(1):86-89

[115] Bromblik A et al. Czasopismo Stomatologiczne. 2010;**63**(5):301-309

[116] Pawka B et al. Prob Hig Epid (in Polish). 2010;**91**(1):5-7

[117] Aas JA et al. Journal of Clinical Microbiology. 2008;**46**(4):1407-1417

[118] Petersen PE. Changing Oral Health Profiles of Children in Central and Estern Europe – Challenges for the 21st Century. Geneva, Switzerland: WHO Global Oral Health; 2003

[119] Jańczuk Z. Próchnica zębów, zapobieganie, klinika i leczenie. Warszawa: PZWL; 1994

[120] Scannapieco FA. Role of oral bacteria in respiratory infection. Journal of Periodontology. 1999;**70**:793-802

[121] Scannapieco FA et al. An Period. 2003;**8**:54-69

[122] Kustra P, Zarzecka J. Por Stom (in Polish). 2009;**9**(12):453-456

[123] Aleksander M et al. Oral and Maxillofacial Surgery. 2008;**12**(3):129-130

[124] Li X et al. Endodontics & Dental Traumatology. 1999;**15**:95-101

[125] Calayatud-Perez V et al. Journal of Cranio-Maxillofacial Surgery. 1993;**21**(3):127-129

[126] Kaiser LR. Topics in Health Care Financing. 1992;**18**:32-45

[127] Arsiwala A et al. Journal of Controlled Release. 2014;**189**:25-45

[128] Yang F et al. Biomaterials. 2005;**26**:5991-5998

[129] Atala A. Principles of Regenerative Medicine. Elsevier Academic Press; 2007

[130] USNIH. Regenerative Medicine, Report. US National Institutes of Health; 2006

[131] Cogle CR et al. Mayo Clinic Proceedings. 2003;**78**:993-1003

[132] Metallo CM et al. Journal of Cellular and Molecular Medicine. 2008;**12**:709-729

[133] Placzek MR et al. Journal of the Royal Society Interface. 2009;**6**:209-232

[134] Tavassoli M, Crosby WH. Science. 1968;**161**:54-56

[135] Caplan AI. Journal of Orthopaedic Research. 1991;**9**:641-650

[136] Pittenger MF et al. Science. 1999;**284**:143-147

[137] Culme-Seymour EJ et al. Regenerative Medicine. 2012;**7**:455-462

[138] Langer R, Vacanti JP. Science. 1993;**260**:920-926

[139] Viola J et al. The Emergence of Tissue Engineering as a Research Field. USA: The National Science Foundation; 2003

[140] Fung YC. UCSD #865023; 2001

[141] Lanza RP, Langer R, Vacanti J, editors. Principles of Tissue Engineering. San Diego: Academic Press; 2000

[142] Atala A, Lanza RP, editors. Methods of Tissue Engineering. San Diego: Academic Press; 2002

[143] Macarthur BD, Oreffo RO. Nature. 2005;**433**:19

[144] Trounson A et al. BMC Medicine. 2011;**9**(52):3

[145] Mason C et al. Cell Stem Cell. 2012;**11**:735-739

[146] Thomson JA et al. Science. 1998;**282**:1145-1147

[147] Shamblott MJ et al. Proceedings of the National Academy of Sciences of the United States of America. 1998;**95**:13726-13731

[148] Cetrulo CL Jr. Stem Cell Reviews. 2006;**2**:163-168

[149] Branch MJ et al. Investigative Ophthalmology & Visual Science. 2012;**53**:5109-5116

[150] Wang S et al. Journal of Hematology & Oncology. 2012;**5**:19

[151] AMERICORD. What is Cord Tissue? 2015. http://americordblood.com/cord-tissue-banking

[152] Le Blanc K et al. Scandinavian Journal of Immunology. 2003;**57**:11-20

[153] Maitra B et al. Bone Marrow Transplantation. 2004;**33**:597-604

[154] Aggarwal S, Pittenger MF. Blood. 2005;**105**:1815-1822

[155] Lee EH, Hui JH. Journal of Bone and Joint Surgery. British Volume (London). 2006;**88**:841-851

[156] Raff M. Annual Review of Cell and Developmental Biology. 2003;**19**:1-22

[157] Morrison SJ, Weissman IL. Immunity. 1994;**1**:661-673

[158] Bajada S et al. Journal of Tissue Engineering and Regenerative Medicine. 2008;**2**:169-183

[159] Johal KS et al. Regenerative Medicine. 2015;**10**:79-96

[160] Wilson CE et al. Journal of Materials Science. Materials in Medicine. 2002;**13**:1265-1269

[161] Kruyt MC et al. Tissue Engineering. 2003;**9**:327-336

[162] Helmlinger G et al. Nature Medicine. 1997;**3**:177-182

[163] Folkman J. The New England Journal of Medicine. 1971;**285**:1182-1186

[164] Mooney DJ et al. Cell Transplantation. 1994;**3**:203-210

[165] Li G et al. Cell Biology International. 2000;**24**:25-33

[166] Sanders JE et al. Microvascular Research. 2002;**64**:174-178

[167] Muschler GF et al. Journal of Bone and Joint Surgery. 2004;**86-A**:1541-1558

[168] Baksh D et al. Experimental Hematology. 2003;**31**:723-732. Stem Cells. 2007;**25**:1384-1392

[169] Caplan AI, Bruder SP. Trends in Molecular Medicine. 2001;**7**:259-264

[170] Zuk PA et al. Tissue Engineering. 2001;**7**:211-228

[171] Izadpanah R et al. Journal of Cellular Biochemistry. 2006;**99**:1285-1297

[172] Moll G et al. PLoS One. 2014;**9**:e85040

[173] Rayment EA, Williams DJ. Stem Cells. 2010;**28**:996-1004

[174] Thomas RJ et al. Cytotechnology. 2007;**55**:31-39

[175] Thomas RJ et al. Biotechnology and Bioengineering. 2009;**102**:1636-1644

[176] Thomas RJ et al. Biotechnology Letters. 2009;**31**:1167-1172

[177] Liu Y et al. Journal of Tissue Engineering and Regenerative Medicine. 2010;**4**:45-54

[178] Yang F, et al. 2008. In: Laurencin & Nair; 2008

[179] Peppas NA, Langer R. Science. 1994;**263**:1715-1720

[180] Hubbell JA. Biotechnology (N. Y). 1995;**13**:565-576

[181] Hubbell JA. Current Opinion in Biotechnology. 1999;**10**:123-129

[182] Healy KE et al. Annals of the New York Academy of Sciences. 1999;**875**:24-35

[183] Langer R, Tirrell DA. Nature. 2004;**428**:487-492

[184] Lütolf MP, Hubbell JA. Nature Biotechnology. 2005;**23**:47-55

[185] Elisseeff J et al. Stem Cells and Development. 2006;**15**:295-303

[186] Hwang NS et al. Stem Cells. 2006;**24**:284-291

[187] Yang F, et al. 2008. In: Laurencin & Nair; 2008

[188] Bettinger CJ, et al. 2008. In: Laurencin & Nair; 2008

[189] Noga M, et al. E-MRS Fall Meeting, Warsaw; 2013

[190] Rouwkema J et al. Trends in Biotechnology. 2008;**26**:434-441

[191] Bramfeldt H et al. Current Medicinal Chemistry. 2010;**17**:3944-3967

[192] Jain RK et al. Nature Biotechnology. 2005;**23**:821-823

[193] Bose S et al. Trends in Biotechnology. 2012;**30**:546-554

[194] Griss P, Heimke G. In: Williams D, editor. Biocompatibility of Implant Materials. London: Sector Publishing; 1976. pp. 52-68

[195] Taniguchi N et al. Materials Science and Engineering: C. 2016;**59**:690-701

[196] Robertson DM et al. Journal of Biomedical Materials Research. 1976;**10**:335-344

[197] Martin R. Critical Reviews in Biomedical Engineering. 1983;**10**:179-222

[198] Ramirez JM, Hurt WC. Journal of Periodontology. 1977;**48**:74-77

[199] Bentolila V et al. Bone. 1998;**23**:275-281

[200] Prendergast P, Huiskes R. Journal of Biomechanical Engineering. 1996;**118**:240-246

[201] Wang X, Ni Q. Journal of Orthopaedic Research. 2003;**21**:312-319

[202] Kufahl RH, Saha SA. Journal of Biomechanics. 1990;**23**:171-180

[203] Sietsema W. Bone. 1995;**17**:297-305

[204] Zardiackas LD et al. Journal of Biomedical Materials Research. 2001;**58**:180-187

[205] Wang X et al. Biomaterials. 2016;**83**:127-141

[206] Bernard S et al. Journal of the Mechanical Behavior of Biomedical Materials. 2013;**18**:12-19

[207] Hollister SJ. Advanced Materials. 2009;**21**:3330-3342

[208] Langer RS, Vacanti JP. Scientific American. 1999;**280**:86-89

[209] Langer R, Vacanti JP. Science. 1993;**260**:920-926

[210] Cima LG et al. Journal of Biomechanical Engineering. 1991;**113**:143-151

[211] Langer R et al. Biomaterials. 1990;**11**:738-745

[212] Karageorgiou V, Kaplan D. Biomaterials. 2005;**26**:5474-5491

[213] Story BJ et al. The International Journal of Oral & Maxillofacial Implants. 1998;**13**:749-757

[214] Lewandrowski KU et al. Journal of Biomaterials Science, Polymer Edition. 2000;**11**:879-889

[215] Bai F. Tissue Engineering. Part A. 2010;**16**:3791-3803

[216] Karp JM et al. Journal of Biomedical Materials Research. Part A. 2004;**71**:162-171

[217] Street J et al. Clinical Orthopaedics and Related Research. 2000;**378**:224-237

[218] Yan C et al. Materials and Design. 2014;**55**:533-541

[219] Lu L et al. Materials Research Bulletin. 2000;**35**(9):1555-1561

[220] Kumar S. Mod Char. 2003;**55**(10):43-47

[221] Mellor S et al. International Journal of Production Economics. 2014;**149**:194-201

[222] Guo N, Leu MC. Frontiers of Mechanical Engineering. 2013;**8**(3):215-243

[223] Melechow R et al. Tytan i jego stopy. Częstochowa: Wyd Pol Częst; 2004

[224] Kevorkijan VM. Journal of Computer Science and Technology. 1999;**59**:683-686

[225] Balla VK et al. Acta Biomaterialia. 2010;**6**(8):3349-3359

[226] Das K et al. Scra Mat. 2008;**59**(8):822-825

[227] Witte F et al. Journal of Biomedical Materials Research Part A. 2007;**81**(3):757-765

[228] Bandyopadhyay A et al. Acta Biomaterialia. 2010;**6**:1640-1648

[229] Nouri A et al. In: Mukherjee A, editor. Biomimetics Learning from Nature. Rijeka: InTech; 2010. pp. 415-450

[230] Yoshida K et al. Hut – Wiad Hut. 2011;**78**(1):153-156

[231] Lia JP et al. Biomacromolecules. 2007;**28**:2810-2820

[232] Choi JW et al. Biomedical Microdevices. 2010;**12**(5):875-886

[233] Wu G et al. The Journal of Prosthetic Dentistry. 2008;**100**(1):56-60

[234] Ciocca L et al. Medical & Biological Engineering & Computing. 2011;**49**(11):1347-1352

[235] Nałęcz M. Bioch i inż biom, t 6. In: Duch W, et al., EXIT, Warszawa; 2000

[236] Leiggener C et al. International Journal of Maxillofacial and Oral Surgery. 2009;**38**(2): 187-194

[237] Jacobs PF. Rapid Prototyping & Manufacturing: Fundamentals of Stereolithography. Dearborn: SME publication; 1992

[238] Lee M et al. Biomaterials. 2005;**26**(20):4281-4289

[239] Cormier B et al. Rapid Prototyping Journal. 2004;**10**(1):35-41

[240] Rännar LE et al. Rapid Prototyping Journal. 2007;**13**(3):128-135

[241] Murr LE et al. Materials Science and Engineering: A. 2010;**527**(7–8):1861-1868

[242] Han GW et al. Materials Science and Engineering: A. 1997;**225**(1–2):204-207

[243] Murr LE et al. Acta Materialia. 2010;**58**(5):1887-1894

[244] Xue W et al. Acta Biomaterialia. 2007;**3**:1007-1018

[245] Osakada K, Shiomi M. International Journal of Machine Tools and Manufacture. 2006;**46**:1188-1193

[246] Kruth Mercelis JP et al. Rapid Prototyping Journal. 2005;**11**(1):26-36

[247] Bertol LS et al. Materials and Design. 2010;**31**:3982-3988

[248] Pattanayak DK et al. Acta Biomaterialia. 2011;**7**:1398-1406

[249] Abe F et al. Journal of Materials Processing Technology. 2001;**111**(1–3):210-213

[250] Darłak P, Dudek P. Odl: Nauka i praktyka. 2004;**1**:3-17

[251] Kruth JP et al. Journal of Materials Processing Technology. 2004;**149**(1–3):616-622

[252] Lethaus B et al. Journal of Maxillofacial and Oral Surgery. 2012;**40**(1):43-46

[253] Liao YS et al. International Journal of Advanced Manufacturing Technology. 2006;**27**(7–8):703-707

[254] Manakari V et al. Meta. 2017;**7**:2-35

[255] Jaegermann Z, Ślósarczyk A. Gęsta i porowata bioceramika korundowa w zastosowaniach medycznych. Kraków: Ucz. Wyd. Nauk.-Techn; 2007

[256] Hench LL, Andersson Ö. In: Hench LL, Wilson J, editors. An Introduction to Bioceramics. 1993. pp. 41-62

[257] Ciołek L et al. Engineering Biomaterials. 2009;**12**:91-93

[258] Ciołek L. Engineering Biomaterials. 2010;**13**:21-23

[259] Łączka M et al. Szkło Ceram. 1996;**47**:14-19

[260] Miguel BS et al. Journal of Biomedical Materials Research. Part A. 2010;**94**:1023-1033

[261] Wu C et al. Biomaterials. 2012;**33**(7):2076-2085

[262] Rezwan K et al. Biomaterials. 2006;**27**:3413-3431

[263] Karageorgiou V, Kaplan D. Biomaterials. 2005;**26**:5474-5491

[264] Wilson CE et al. Journal of Materials Science. Materials in Medicine. 2011;**22**:97-105

[265] Lichte P et al. Injury. 2011;**42**:569-573

[266] Deepthia S et al. International Journal of Biological Macromolecules. 2016;**93B**:1338-1353

[267] Lee S-H, Shin H. Advanced Drug Delivery Reviews. 2007;**59**:339-359

[268] Cheung H-Y et al. Composites: Part B. 2007;**38**:291-300

[269] Xue W et al. Journal of Biomedical Materials Research Part B. 2009;**91**:831-838

[270] Laschke MW et al. Acta Biomaterialia. 2010;**6**:2020-2027

[271] Banerjee SS et al. Acta Biomaterialia. 2010;**6**:4167-4174

[272] Tara MA et al. The International Journal of Prosthodontics. 2011;**24**:46-48

[273] Quante K et al. Dental Materials. 2008;**24**:1311-1315

[274] Śpiewak R, Piętowska J. ALERG-IM. 2006;**3**(34):5862

[275] Uter W et al. The European standard series in 9 European countries, 2002/2003 first results of the European surveillance system on contact allergies. Contact Dermatitis. 2005;**53**:136145

[276] Śpiewak R. Allergy. 2002;**25**:374381

[277] Obtułowicz K et al. Przegląd Lekarski. 2001;**58**(5):2427

[278] Antoszczyk G, Obtułowicz K. Post Derm Allergy. 2005;**22**:2936

[279] Śpiewak R, Brewczyński PZ. Polski Tygodnik Lekarski. 1993;**48**(28–30):651-652

[280] Rahilly G, Price N. Journal of Orthodontics. 2003;**30**:171174

[281] EU Parliament & Council (1994) Directive 94/27/EC of 30 June 1994 amending for the 12th time Directive 76/769/EEC… Of J L 188, 22.07.1994, 12

[282] Koutsoukis T et al. Journal of Prosthodontics. 2015;**24**:303-312

[283] Oyague RC et al. Journal of Dentistry. 2012;**40**:123-130

[284] Ucar Y et al. The Journal of Prosthetic Dentistry. 2009;**102**:253-259

[285] Castillo-De-Oyague R et al. Medicina Oral, Patología Oral y Cirugía Bucal. 2012;**17**: 610-617

[286] Castillo-Oyague R et al. Journal of Dentistry. 2013;**41**:90-96

[287] Oyague RC et al. Odontología. 2012;**100**:249-253

[288] Ortorp A et al. Dental Materials. 2011;**27**:356-363

[289] Kim KB et al. Journal of Advanced Prosthodontics. 2013;**5**:179-186

[290] Marciniak J. Biomateriały. Gliwice: Wyd Pol Śl; 2002

[291] Górny Z. Odlewnicze stopy kobaltu. Kraków: Inst Odl; 2008

[292] Klimek L, Zimmer D. The Dental Technician. 2015;**6**:26-30

[293] Surowska B et al. Post Nauki i Tech (in Polish). 2011;**11**:81-88

[294] Lucchetti MC et al. The Journal of Prosthetic Dentistry. 2015;**114**(4):602-608

[295] Kacprzyk B et al. Archives of Foundry Engineering. 2013;**13**(3):47-50

[296] Sokołowski J et al. J Stom. 2014;**67**(1):28

[297] Balla VK et al. Acta Biomaterialia. 2010;**6**:3349-3359

[298] Das K et al. Scripta Materialia. 2008;**59**:822-825

[299] Liu Y et al. Acta Materialia. 2016;**113**:56-67

[300] Challis VJ et al. Materials and Design. 2014;**63**:783-788

[301] Liu Y et al. Materials Science and Engineering: A. 2015;**642**:268-278

[302] Attar H et al. Materials Science and Engineering: A. 2015;**625**:350-356

[303] Gehrmann R et al. Materials Science and Engineering: A. 2005;**395**:338-349

[304] Kulekci MK. International Journal of Advanced Manufacturing Technology. 2008;**39**: 851-865

[305] Bettles CJ. Journal of Materials Engineering and Performance. 2008;**17**:297-301

[306] Yun Y et al. Materials Today. 2009;**12**:22-32

[307] Chai YC et al. Biomaterials. 2012;**33**:4044-4058

[308] Markwardt J et al. Journal of Biomedical Materials Research. Part A. 2014;**102**:1422-1430

[309] Pattanayak DK et al. Acta Biomaterialia. 2011;**7**:1398-1406

[310] Van Bael S et al. Acta Biomaterialia. 2012;**8**:2824-2834

[311] Bandyopadhyay A et al. Acta Biomaterialia. 2010;**6**:1640-1648

[312] Klimas J et al. Archives of Materials Science and Engineering. 2016;**78**(1):10-16

[313] Kirmanidou Y, et al. BioMed Res In, art.no.2908570. 2016

[314] Elias C et al. Journal of Metals. 2008;**60**(3):46-49

[315] Parchalskakowalik M, Klimek L. Inżynieria Materiałowa. 2013;**34**(5):526-529

[316] Dobrzański LA. Archives of Materials Science and Engineering. 2015;**76**(2):53-114

[317] Dobrzańska-Danikiewicz AD et al. Archives of Materials Science and Engineering. 2015;**76**(2):150-156

[318] Burnat B et al. Archives of Foundry Engineering. 2014;**14**(3):11-16

[319] Majkowska B et al. Archives of Metallurgy and Materials. 2015;**60**(2):755-758

[320] Klimas J et al. Archives of Materials Science and Engineering. 2016;**77**(2):65-71

[321] Jedynak B, Mierzwińska-Nastalska E. Dental Forum 2013;**41**(1):75-78

[322] Dobrzański LA et al. J Ach Mat Man Eng. 2015;**71**(2):53-59

[323] Dobrzański LB. PhD in progress, AGH; Kraków; 2017

[324] Emsley J. Nature's Building Blocks: An A-Z Guide to the Elements. Oxford: Oxford University Press; 2001

[325] Hong J et al. Thrombosis and Haemostasis. 1999;**82**(1):58-64

[326] Zięty A, Lachowicz M. Akt/PKB signaling pathway. 2014;**8**:187-192

[327] Okazaki Y et al. Materials Science and Engineering: A. 1966;**213**:138-147

[328] Semlitsch MF et al. Biomaterials. 1992;**13**(11):781-788

[329] Michalik R et al. Inżynieria Materiałowa. 1998;**19**(2):53-56

[330] Oliveira V et al. Brazilian Journal of Chemical Engineering. 1998;**15**(4)

[331] Al-Mobarak NA et al. Int J El-chem Sci 2011;**6**:2031-2042

[332] Dąbrowski R et al. Acta Bio-Optica et Informatica Medica, Biomedical Engineering. 2016;**22**(3):130-137

[333] Boehlert CJ et al. Materials Science and Engineering: C. 2008;**28**(3):323-330

[334] Walkowiak-Przybyło W et al. Journal of Biomedical Materials Research Part A. 2012; **100**(3):768-775

[335] Venkatarman BV, Sudha S. Asian Journal of Experimental Sciences. 2005;**19**(2):127-134

[336] Ngwa HA et al. Toxicology and Applied Pharmacology. 2009;**240**(2):273-285

[337] Williams DF. Biomaterials. 2008;**29**(20):2941-2953

[338] Steinemann SG. Injury. 1996;**27**(Suppl 3):SC16-SC22

[339] Braem A et al. Acta Biomaterialia. 2014;**10**:986-995

[340] Abdel-Hady Gepreel M, Niinomi M. Journal of the Mechanical Behavior of Biomedical Materials. 2013;**20**:407-415

[341] Khan MA et al. Biomaterials. 1999;**20**(7):631-637

[342] Paszenda Z et al. Journal of Achievements in Materials and Manufacturing Engineering. 2010;**38**(1):24-32

[343] Hong J et al. Thrombosis and Haemostasis. 1999;**82**(1):58-64

[344] Chlebus E et al. Materials Characterization. 2011;**62**:488-495

[345] Marcu T et al. Powder Metallurgy. 2012;**55**:309-314

[346] Szymczyk P et al. Acta of Bioengineering and Biomechanics. 2013;**15**:69-76

[347] Okrój W et al. Inż Biomaterials. 2005;**8**(43–44):13-16

[348] Tanaka Y et al. Journal of Artificial Organs. 2009;**12**(3):182-186

[349] Harris LG et al. Journal of Materials Science: Materials in Medicine. 2007;**18**(6):1151-1156

[350] Zhang LC et al. Scripta Materialia. 2011;**65**:21-24

[351] Hsu HC et al. Materials and Design. 2013;**47**:21-26

[352] Yao Y et al. Journal of Alloys and Compounds. 2014;**583**:43-47

[353] Zhuravleva K et al. Maturitas. 2013;**6**:5700-5712

[354] Leong KF et al. Biomaterials. 2003;**24**:2363-2378

[355] Nair LS, Laurencin CT. Advances in Biochemical Engineering/Biotechnology. 2006;**102**: 47-90

[356] Velema J, Kaplan D. Advances in Biochemical Engineering/Biotechnology. 2006;**102**:187-238

[357] Nowosielski R et al. Journal of Achievements in Materials and Manufacturing Engineering. 2013;**61**:367-374

[358] Witte F et al. Journal of Biomedical Materials Research. Part A. 2007;**81**(3):757-765

[359] Zhang X et al. Materials Science and Engineering: C. 2014;**42**:362-367

[360] Farraro KF et al. Journal of Biomechanics. 2014;**47**:1979-1986

[361] Jaworska L, De Benedetti B. priv. inf; 2014

[362] Li N, Zheng Y. Journal of Materials Science and Technology. 2013;**29**:489-502

[363] Kirkland NT et al. Acta Biomaterialia. 2012;**8**:925-936

[364] Wu G et al. Surface and Coating Technology. 2013;**233**:2-12

[365] Hornberger H et al. Acta Biomaterialia. 2012;**8**:2442-2455

[366] Yazdimamaghani M et al. Materials Letters. 2014;**132**:106-110

[367] Chen Z et al. Biomaterials. 2014;**35**:8553-8565

[368] Gu XN et al. Materials Science and Engineering: C. 2010;**30**:827-832

[369] Khanra AK et al. Materials Science and Engineering: A. 2010;**527**:6283-6288

[370] Khanra AK et al. Bulletin of Materials Science. 2010a;**33**:43-47

[371] Liu DB et al. Rare Metal Materials and Engineering. 2008;**37**:2201-2205

[372] Witte F et al. Biomaterials. 2007;**28**:2163-2174

[373] Ye XY et al. Journal of Materials Science. Materials in Medicine. 2010;**21**:1321-1328

[374] Razavi M et al. Materials Science and Engineering A. 2010;**527**:6938-6944

[375] Feng A, Han Y. Journal of Alloys and Compounds. 2010;**504**:585-593

[376] Brar HS et al. Journal of Metals. 2009;**61**:31-34

[377] Kirkland N. Corrosion Engineering Science and Technology. 2012;**47**:322-328

[378] Walker J et al. Journal of Biomedical Materials Research. Part B, Applied Biomaterials. 2014;**102B**(6):1316-1331

[379] Alvarez-Lopez M et al. Acta Biomaterialia. 2010;**6**:1763-1771

[380] Wong HM et al. Biomaterials. 2010;**31**:2084-2096

[381] Liu C et al. Materials Science and Engineering: A. 2007;**456**:350-357

[382] Vojtech D et al. Acta Biomaterialia. 2011;**7**:3515-3522

[383] Witte F et al. Current Opinion in Solid State & Materials Science. 2008;**12**:63-72

[384] Wan YZ et al. Materials and Design. 2008;**29**:2034-2037

[385] Gu X et al. Biomaterials. 2009;**30**:484-498

[386] Flaten T. Environmental Geochemistry and Health. 1990;**12**:152-167

[387] Wills M, Savory J. Lancet. 2001;**2**:29-34

[388] Flaten T. Brain Research Bulletin. 2001;**55**:187-196

[389] Pinto R et al. Electrochimica Acta. 2011;**56**:1535-1545

[390] Johnson I et al. Journal of Biomedical Materials Research. Part A. 2011:477-485

[391] Haley T. Journal of Pharmaceutical Sciences. 1965;**54**:663-670

[392] Zartner P et al. Catheterization and Cardiovascular Interventions. 2005;**66**:590-594

[393] Drynda A et al. Journal of Biomedical Materials Research. Part A. 2008;**91**:360-369

[394] Bruce D et al. Toxicology and Applied Pharmacology. 1963;**5**:750-759

[395] Gupta M et al. Magnesium, Magnesium Alloys, and Magnesium Composites. John Wiley & Sons; 2011. pp. 1-257, ISBN 9781118102701

[396] Savalani M et al. Journal of Engineering Manufacture. 2006;**220**:171-182

[397] Ng C et al. Applied Surface Science. 2011;**257**:7447-7454

[398] Ponader S et al. Journal of Biomedical Materials Research. Part A. 2010;**92**:56-62

[399] Zhang E et al. Materials Science and Engineering: C. 2009;**29**:987-993

[400] Xu L et al. Journal of Materials Science: Materials in Medicine. 2008;**19**:1017-1025

[401] Song GL, Atrens A. Advanced Engineering Materials. 1999;**1**:11-33

[402] Koh J, Choi D. Neuroscience. 1994;**60**:1049-1057

[403] Walker J et al. Chemico-Biological Interactions. 1989;**69**:279-291

[404] Alvarez K, Nakajima H. Maturitas. 2009;**2**:790-832

[405] Xin Y et al. Acta Biomaterialia. 2011;**7**:1452-1459

[406] Rettig R, Virtanen S. Journal of Biomedical Materials Research. Part A. 2008;**85**:167-175

[407] http://www.magnesium-elektron-powders.com/index.php/contacts

[408] Papadimitropoulos A et al. Biotechnology and Bioengineering. 2007;**98**:271-281

[409] Naito H et al. Tissue Engineering Part A. 2011;**17**:2321-2329

[410] Bose S, Tarafder S. Acta Biomaterialia. 2012;**8**:1401-1421

[411] Verron E et al. Drug Discovery Today. 2010;**15**:547-552

[412] Kimelman-Bleich N et al. Molecular Therapy. 2010;**19**:53-59

[413] Keeney M et al. Biomaterials. 2010;**31**:2893-2902

[414] Dagalakis N et al. Journal of Biomedical Materials Research. 1980;**14**:511-528

[415] Mooney DJ et al. Cell Transplantation. 1994;**3**:203-210

[416] Wald HL et al. Biomaterials. 1993;**14**:270-278

[417] Tay CY et al. Small. 2011;**7**:1361-1378

[418] Wang GJ et al. Microsystem Technologies. 2005;**12**:120-127

[419] Lima MJ et al. Materials Science and Engineering: C. 2014;**42**:615-621

[420] Zhang S et al. Biomaterials. 1999;**20**:1213-1220

[421] Schvartzman M, Wind SJ. Nano Letters. 2009;**9**:3629-3634

[422] Cao H et al. Applied Physics Letters. 2002;**81**:174-176

[423] Chou SY, et al. 41st Int Conf Electron, Ion, and Photon Beam; 1997

[424] Kim J et al. Tissue Engineering Part A. 2014;**20**:2127-2130

[425] Delamarche E et al. Science. 1997;**276**:779-781

[426] Mazzoli A. Medical & Biological Engineering & Computing. 2013;**51**:245-256

[427] Darsell J et al. Journal of the American Ceramic Society. 2003;**86**:1076-1080

[428] Bose S et al. Scripta Materialia. 1999;**41**:1009-1014

[429] Hutmacher DW et al. Journal of Biomedical Materials Research. 2001;**55**:203-216

[430] Bettinger CJ, et al. 2008. In: Laurencin & Nair; 2008

[431] Yeong W-Y et al. Rapid Prototyping Journal. 2006;**12**:229-237

[432] Dutta Roy T et al. Journal of Biomedical Materials Research. Part A. 2003;**67**:1228-1237

[433] Sachs EM, et al. 1993. U.S. Patent 5,204,055

[434] Khalyfa A et al. Journal of Materials Science. Materials in Medicine. 2007;**18**:909-916

[435] Manjubala I et al. Journal of Materials Science. Materials in Medicine. 2005;**16**:1111-1119

[436] Sachlos E et al. Biomaterials. 2003;**24**:1487-1497

[437] Sawkins MJ et al. Recent Patents on Biomedical Engineering. 2013;**6**:3-21

[438] Lee KW et al. Biomacromolecules. 2007;**8**:1077-1084

[439] Cooke MN et al. Journal of Biomedical Materials Research Part B. 2003;**64**:65-69

[440] Arcaute K et al. Annals of Biomedical Engineering. 2006;**34**:1429-1441

[441] Dhariwala B et al. Tissue Engineering. 2004;**10**:1316-1322

[442] Liao H-T, et al. BioMed Res Inter. 2014; Article ID 321549

[443] Hoque ME et al. Journal of Biomaterials Science. Polymer Edition. 2005;**16**:1595-1610

[444] Sun JJ et al. Journal of Materials Science. Materials in Medicine. 2007;**18**:1017-1023

[445] Crump SS. U.S. Patent 5,121,329A; 1992

[446] Karoluk M, Pawlak A, Chlebus E. XI Konf. Nauk. im. Prof. D. Tejszerskiej, Ustroń; 2014. pp. 53-54

[447] Williams JM et al. Biomaterials. 2005;**26**:4817-4827

[448] Tan KH et al. Bio-medical Materials and Engineering. 2005;**15**:113-124

[449] Shuai C et al. Nanotechnology. 2011;**22**:285703

[450] Wiria FE et al. Acta Biomaterialia. 2007;**3**:1-12

[451] Chua CK et al. Journal of Materials Science. Materials in Medicine. 2004;**15**:1113-1121

[452] Sill TJ, von Recum HA. Biomaterials. 2008;**29**:1989-2006

[453] Murugan R, Ramakrishna S. Tissue Engineering. 2007;**13**:1845-1866

[454] Matthews JA et al. Biomacromolecules. 2002;**3**:232-238

[455] Hartgerink JD et al. Proceedings of the National Academy of Sciences of the United States of America. 2002;**99**:5133-5138

[456] Zhang S et al. Seminars in Cancer Biology. 2005;**15**:413-420

[457] Gelain F et al. Macromolecular Bioscience. 2007;**7**:544-551

[458] Um SH et al. Nature Materials. 2006;**5**:797-801

[459] Hunt JA et al. Journal of Materials Chemistry B. 2014;**2**:5319-5338

[460] Qin S et al. Advanced Materials. 2006;**18**:2905-2909

[461] Guan J et al. Biomacromolecules. 2008;**9**:1283-1292

[462] Lee SB et al. Journal of Applied Polymer Science. 2004;**92**:2612-2620

[463] Liu R et al. Colloid & Polymer Science. 2009;**287**:627-643

[464] Wang LQ et al. Reactive and Functional Polymers. 2002;**53**:19-27

[465] Tan H et al. Biomaterials. 2009;**30**:2499-2506

[466] Ohya S et al. Journal of Artificial Organs. 2004;**7**:181-186

[467] Gong CY et al. International Journal of Pharmaceutics. 2009;**365**:89-99

[468] Shim WS et al. Biomaterials. 2006;**27**:5178-5185

[469] Hiemstra C et al. Biomacromolecules. 2006;**7**:2790-2795

[470] Jeong B et al. Macromolecules. 1999;**32**:7064-7069

[471] Lau BK et al. Journal of Polymer Science. Part B. 2004;**42**:2014-2025

[472] Park K et al. Key Engineering Materials. 2007;**342-343**:301-304

[473] Nagase K et al. Biomacromolecules. 2008;**9**:1340-1347

[474] Kurata K, Dobashi A. Journal of Macromolecular Science, Part A. 2004;**41**:143-164

[475] Xu C, Kopecek J. Polymer Bulletin. 2007;**58**:53-63

[476] Loo Y et al. Biotechnology Advances. 2012;**30**:593-603

[477] Zhang S. Nature Biotechnology. 2003;**21**:1171-1178

[478] Gabriel SA et al. Science. 2004;**303**:1352-1355

[479] Chen R, Hunt JA. Journal of Materials Chemistry. 2007;**17**:3974-3979

[480] Bokhari MA et al. Biomaterials. 2005;**26**:5198-5208

[481] Hui JH et al. Clinical Orthopaedics. 2013;**471**:1174-1185

[482] Killion JA et al. Journal of Materials Science. 2012;**47**:6577-6585

[483] Ye C et al. Acta Polymerica Sinica. 2012;**10**:1143-1150

[484] Lihong H et al. Macromolecules. 2007;**40**:4429-4438

[485] Yu Q et al. Macromolecules. 2001;**34**:1612-1618

[486] Rouillard AD et al. Tissue Engineering Part C. 2011;**17**:173-179

[487] Ibrahim S et al. Acta Biomaterialia. 2011;**7**:653-665

[488] Kamoun EA, Menzel H. Journal of Applied Polymer Science. 2010;**117**:3128-3138

[489] Choi JS, Yoo HS. Journal of Biomedical Materials Research. Part A. 2010;**95**:564-573

[490] Shu XZ et al. Journal of Biomedical Materials Research. Part A. 2004;**68**:365-375

[491] Lütolf MP et al. Advanced Materials. 2003;**15**:888-892

[492] Overstreet DJ et al. Journal of Polymer Science. Part B. 2012;**50**:881-903

[493] Wang DA et al. Nature Materials. 2007;**6**:385-392

[494] Nishi KK, Jayakrishnan A. Biomacromolecules. 2004;**5**:1489-1495

[495] Maia J et al. Polymer. 2005;**46**:9604-9614

[496] Sperinde JJ, Griffith LG. Macromolecules. 2000;**33**:5476-5480

[497] Ryan BJ et al. Trends in Biotechnology. 2006;**24**:355-363

[498] Moreira Teixeira LS et al. Biomaterials. 2012;**33**:1281-1290

[499] Park KM et al. Biomacromolecules. 2010;**11**:706-712

[500] Fernandez C et al. Carbohydrate Research. 2006;**341**:1253-1265

[501] Amini AA, Nair LS. Journal of Bioactive and Compatible Polymers. 2012;**27**:342-355

[502] Sakai S et al. Acta Biomaterialia. 2009;**5**(2):554-559

[503] Sakai S, Kawakami K. Journal of Biomedical Materials Research. Part A. 2008;**85**:345-351

[504] Wennink JWH et al. Macromolecular Symposia. 2011;**309-310**:213-221

[505] Jin R et al. Tissue Engineering Part A. 2010;**16**:2429-2440

[506] Rowley JA et al. Biomaterials. 1999;**20**:45-53

[507] Berger J et al. European Journal of Pharmaceutics and Biopharmaceutics. 2004a;**57**:19-34

[508] Crompton KE et al. Biomaterials. 2007;**28**:441-449

[509] Patil JS et al. Digest Journal of Nanomaterials and Biostructures. 2010;**5**:241-248

[510] Tessmar JK, Gopferich AM. Macromolecular Bioscience. 2007;**7**:23-39

[511] Baier Leach J et al. Biotechnology and Bioengineering. 2003;**82**:578-589

[512] Young JL et al. Acta Biomaterialia. 2013;**9**:7151-7157

[513] Shu XZ et al. Biomaterials. 2004;**25**:1339-1348

[514] Hwang YJ, Lyubovitsky JG. Biopolymers. 2013;**99**:349-356

[515] Macaya D et al. Advanced Functional Materials. 2011;**21**:4788-4797

[516] Fathima NN et al. International Journal of Biological Macromolecules. 2004;**34**:241-247

[517] Lahiji A et al. Journal of Biomedical Materials Research. 2000;**51**:586-595

[518] Hong Y et al. Acta Biomaterialia. 2007;**3**:23-31

[519] Berger J et al. European Journal of Pharmaceutics and Biopharmaceutics. 2004;**57**:35-52

[520] Leach JB et al. Journal of Biomedical Materials Research. Part A. 2004;**70**:74-82

[521] Jukes JM et al. Tissue Engineering Part A. 2010;**16**:565-573

[522] Jin R et al. Biomaterials. 2007;**28**:2791-2800

[523] Mosahebi A et al. Tissue Engineering. 2001;**7**:525-534

[524] Ballios BG et al. Biomaterials. 2010;**31**:2555-2564

[525] Noth U et al. Cytotherapy. 2005;**7**:447-455

[526] Gao J et al. Biomaterials. 2012;**33**:3673-3681

[527] Hume SL et al. Acta Biomaterialia. 2012;**8**:2193-2202

[528] Liu Y, Chan-Park MB. Biomaterials. 2009;**30**:196-207

[529] Shinohara S et al. Journal of Bioscience and Bioengineering. 2013;**116**:231-234

[530] Yeo Y et al. Biomaterials. 2006;**27**:4698-4705

[531] Sawada T et al. Human Reproduction. 2001;**16**(2):353-356

[532] Rowley JA et al. Biomaterials. 1999;**20**:45-53

[533] Hern DL, Hubbell JA. Journal of Biomedical Materials Research. 1998;**39**:266-276

[534] Kaneko T et al. Macromolecules. 2005;**38**:4861-4867

[535] Nahmias Y et al. Biotechnology and Bioengineering. 2005;**92**:129-136

[536] Odde DJ, Renn MJ. Biotechnology and Bioengineering. 2000;**67**:312-318

[537] Boland T et al. The Anatomical Record. Part A, Discoveries in Molecular, Cellular, and Evolutionary Biology. 2003;**272**:497-502

[538] Mironov V et al. Trends in Biotechnology. 2003;**21**:157-161

[539] Mironov V et al. Biofabrication. 2009;**1**:1-16

[540] Mironov V et al. Current Opinion in Biotechnology. 2011;**22**(5):667-673

[541] Ringeisen BR et al. MRS Bulletin. 2013;**38**(10):834-843

[542] Ozbolat IT, Yin Y. IEEE Transactions on Biomedical Engineering. 2013;**60**(3):691-699

[543] Writers S. http://lifescientist.-com.au/content/biotechnology/news/invetech-helps-bring-bio-printers-to-life-413047968. 2009

[544] CFR. http://www.cfr.org/technology-and-science/3d-printing-challenges-opportunities-international-relations/-p31709. 2013

[545] Quigley JT http://thediplomat.com/2013/08/-chinese-scientists-are-3d-printing-ears-and-livers-with-living-tissue/. 2013

[546] 3ders.org. http://www.3ders.org/articles/20130815-how-do-they-3d-print-kidney-in-china.html. 2013

[547] Littre M. http://www.dailymail.co.uk/sciencetech/article-2637158/Humans-fitted-kidneys-3D-printers.html. 2014

[548] Hoying J, et al. http://www.techrepublic.com/article/new-3d-bioprinter-to-reproduce-human-organs/. 2014

[549] BBC. http://www.bbc.com/news/technology-18677627; 2012

[550] Landers R, Mülhaupt R. Macromolecular Materials and Engineering. 2000;**282**:17-21

[551] Tan W, Desai TA. Biomaterials. 2004;**25**:1355-1364

[552] Albrecht DR et al. Nature Methods. 2006;**3**:369-375

[553] Rzeszutko L et al. Kardiologia Polska. 2014. DOI: 10.5603/KP.a2014.0147

[554] Bertassoni LE et al. Lab on a Chip. 2014;**14**:2202-2211

IntechOpen