NANOTECHNOLOGIES FOR LOAD-BEARING IMPLANTS

Andrzej ZIELIŃSKI, Sylwia SOBIESZCZYK
Faculty of Mechanical Engineering
Bio-Nano-Med Research Group
Gdansk University of Technology, Poland

Background

Fundamental applications of nanotechnologies in medicine include: oncology, orthopaedics, ophtalmology, treatment of metabolic diseases, infections and inflammations, and autoagressive diseases.
Nanotechnologies are used as either specific systems or nanoengineering devices - multifunctional nanoparticles for delivery of drugs, based on nanotechnologies sensors for diagnostics.
Nanotechnologies are important for diagnostics and therapy of cancers, tissue and genetic engineering, load-bearing implants in orthopaedics and dentistry.

Nanotechnologies for load-bearing implants

In load-bearing implants the nanotechnologies are applied so far to increase the mechanical strength and structure-enhanced bioactivity.
Specific solutions involve:

- development of both microroughness and nanoroughness for titanium dental implants, which makes adhesion of enamel ceramic and/or polymer coatings to the metallic implant better,
- nanometric reinforcement of dental resins to increase their mechanical properties,
- substitution of conventional PMMA-based cements by materials containing hydroxyapatite nanoparticles,
- application of nano-hydroxyapatite in composite scaffolds.

Concept of bioactive titanium scaffolds long-term implants

New concept elaborated at Gdańsk University of Technology to improve the biocompatibility and bioactivity of load-bearing implants: titanium scaffold filled in with a degradable and mechanically resistant biopolymer – bioceramic core material.

- In order to improve the bioactivity:
- the micro- and nanoporous intrinsic structure is created
- the nanoxide layers are formed on titanium surface,
- hydroxyapatite coating with micro- and nanoroughness is deposited,
- nanosilver is incorporated within different parts of an implant.

Materials and methods

Material for hip joint cone: non-toxic Ti13Zr13Nb alloy with open porous structure
Fabrication techniques:

- powder metallurgy with space holders
- rapid prototyping by selective laser melting

Oxidation:

- anticorrosion electrochemical, chemical or gaseous oxidation
- bioactive nanooxidation

Deposition of hydroxyapatite (HA) coating:
•Alternate immersion method

- Biomimetic deposition in simulated body fluid
- Sol-gel deposition
- Electrochemical deposition

Infiltration of a core material into pores
Incorporation of nanosilver (in course):

- into nanotubes
- into HA coating
- into a core material

Micro- and nanoporous structure

As a substrate, the powdered Ti13Zr13Nb alloy has been used, with spheroidal particles ranged between 0 and 245 micrometers.
For powder metallurgy the proper space holder, preliminary load, temperature and time of sintering have been found.
Applied techniques can possible to create:

- Open porous structures
- Rigid and strong materials due to high and solid joints between adjacent grains.

Nanotechnologies in creation of bioactive oxide layer

In order to improve the bioactivity, the nanoxide layers are created from the base rutile oxide structure by preferential dissolution in presence of fluorides. Such oxide layers demonstrate the increased bioactivity and because of their specific structure may attract and release such important constituents of an implant as antibiotics, nanosilver and growth factors.

Nanotechnologies in deposition of hydroxyapatite coating

Another possible solution is a deposition of nanometric hydroxyapatite coating by sol-gel or electrochemical technique, which adhesion and elasticity are substantially better than that of conventional plasma sprayed coatings. Even for thicker ceramic coatings, their nanoroughness is important for better adhesion of core material.

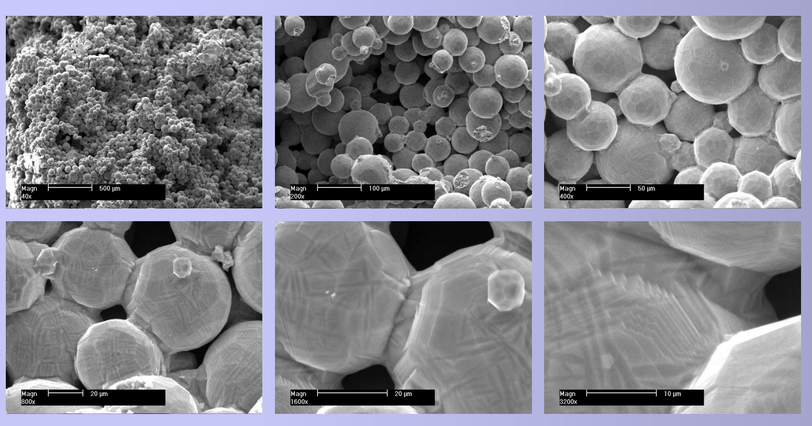

Fig.1. Fabrication of Ti biomaterial by powder metallurgy

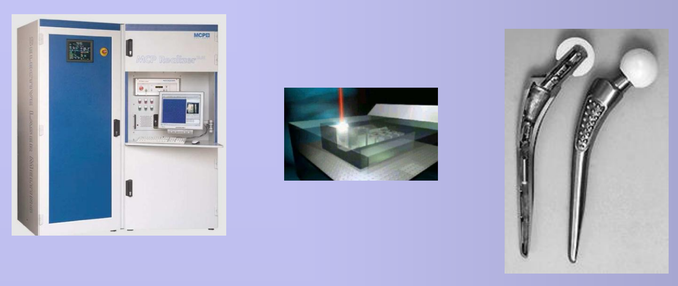

Fig.2. Rapid prototyping of implants by selective laser melting

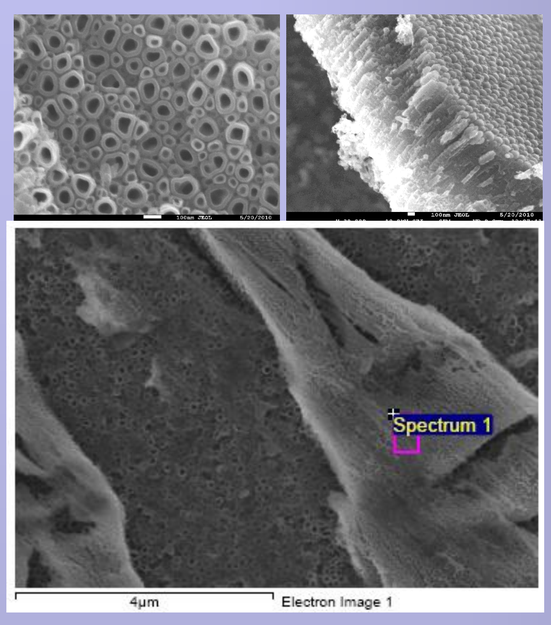

Fig.3. Nanotubular titanium oxide layers

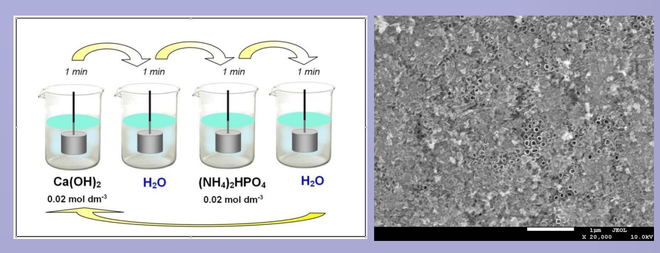

Fig.4. Alternative immerstion deposition HA coating

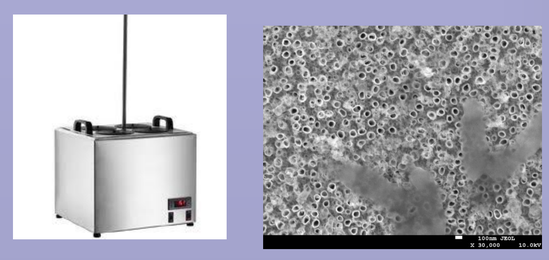

Fig.5. Electrochemical deposition of HA coating

Nanotechnologies in incorporation of biologically active compounds

An application of silver in form of single atoms or isolated clusters of nanometric size into bulk of nanotubes of the oxide layer, into hydroxyapatite coating or core material, or as an element of hybride material, can be crucial for achievement of better bioactivity, i.e. preventing the adhesion of bacteria on the surface of metallic implant and then inflammation processes.

CONCLUSIONS

1. Nanotechnologies can be important for development of bioactive and biocompatible load-bearing orthopaedic and dental implants.
2. For such purposes nanotechnologies are especially important as they can affect the processes and mechanisms at the interface implant – bone tissue, which decide on long term stability.
3. Development of load-bearing new titanium implants resulting in their increased behaviour must follow the needs of present society, in which 60% of population over 60. year should be subject to total hip replacement.