TECHNOLOGICAL ISSUES OF ADDITIVE MANUFACTURING OF PREPROTOTYPES OF THE MULTISPIKED CONNECTING SCAFFOLD FOR NON-CEMENTED RESURFACING ARTHROPLASTY ENDOPROSTHESES

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The biomimetic MultiSpiked Connecting Scaffold (MSC-Scaffold) is the essential innovation in fixation technique of the components of the resurfacing arthroplasty (RA) endoprostheses providing theirs entirely non-cemented and bone tissue preserving fixation in the periarticular trabecular bone – invented by Rogala [1-3] and designed, manufactured and tested in our research team [4-7]. The spikes of the MSC-Scaffold were designed to mimic the interdigitations of the periarticular subchondral bone and for this reason it is a biomimetic structure and it can be manufactured only in one of Direct Metal Manufacturing (DMM) technology. This fixation technique of RHA endoprosthesis components in surrounding bone preserves the femoral head blood vessels and the near-physiological regional blood supply and circulation. Consequently, the proper remodeling potential of the trabecular bone of femoral head can be preserved. In this way, the near-physiologic biodynamics and remodeling of bone tissue around the implant will be ensured and the desired promotion of bone tissue ingrowth into the MSC-Scaffold can be reasonably expected. In FIG.1a there is presented the 3D diagram of articular hyaline cartilage and subchondral bone with interdigitations interlocking with trabeculae of cancellous bone. In FIG.1b there is showed the prototype of the stemless and entirely cementless total resurfacing hip arthroplasty (TRHA) endoprosthesis with the MSC-Scaffold manufactured in Selective Laser Melting (SLM) technology. In FIG.1c there is demonstrated the femoral head component of our prototype of innovating THRA endoprosthesis – designed to preserve the subcapsular arteriae retinaculares: superior (3), and inferior (4); (1) – a.circumflexa femoris lateralis, (2) – ramus ascenens of (1).

The presented here pre-prototypes of the MSC-Scaffold were comprehensively designed as fragments of the central part of the TRHA endoprosthesis femoral component (see FIG.1b), for various tasks of the research project (no. NN518412638, Polish Ministry of Science), i.e.: the electrothermochemical modification of theirs spikes' surfaces contacting with bone [8], the optimization of the MSC-Scaffold general design on the basis of: the preliminary preclinical in vivo evaluation on animal models and the biological evaluation with human osteoblasts cultures [9] and also the biomechanical push-in tests performed to evaluate the implant push-in force [10].

Our attempts to manufacture the MSC-Scaffold pre-prototypes using various technologies from group of the DMM technologies, like Selective Laser Sintering (SLS) or Electron Beam Melting (EBM), despite referred in literature good potential to manufacture titanium porous structures or bone scaffolds [11-12], were not satisfying, because of disqualifying defects found in the interspike space of the MSC-Scaffold, as well as, in its microsections (high corrugation of the lateral surface of the MSC-Scaffold, the large quantity of the unmelted and unremovable powder granulates accumulated between the spikes' bases in case of EBM, the high number of discontinuity and microcracks revealed at their surface and in microsections in case of SLS). The DMM technology experimentally chosen for manufacturing our MSC-Scaffold preprototypes – the Selective Laser Melting (SLM) – also revealed some limitations, but was judged to have best potential to manufacture the MSC-Scaffold preprototypes in comparison to EDM or SLS. The variety of the CAD models of the biomimetic MSC-Scaffold pre-prototypes arranged as they were set up in one CAD file and then transferred into one STL file is presented in FIG.2a; in FIG.2b there is shown the screen presenting the pre-processing step – the formation of supports for all pre-prototypes of the MSC-Scaffold to be generated in SLM technology, while in FIG.2c the exemplary pre-prototype of the MSC-Scaffold is shown as seen directly after manufacturing with support to be cut out. The SLM machine (Realizer II 250, MTT Technologies, Germany) and the stages of the manufacturing process of the MSC-Scaffold pre-prototypes are presented in FIG.3: (1) selective laser melting of the first layer of TiAl6V4 powder, (2) selective laser melting of one of last layers of TiAl6V4 powder, (3) cleaning of the working chamber of not melted TiAl6V4 powder and (4) the set of the MSC-Scaffold pre-prototypes fixed to the platform pedestal via supports to be later cut out.

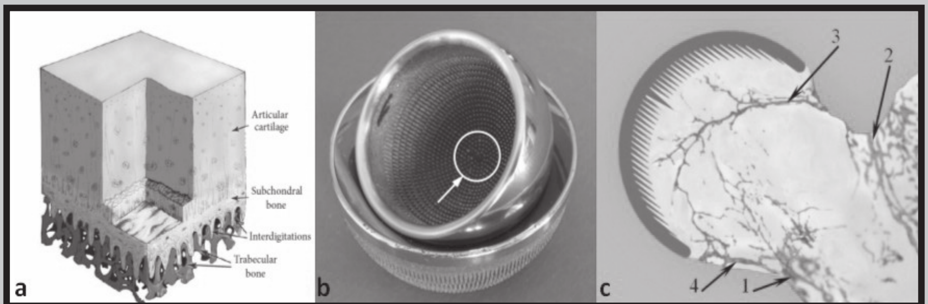

FIG. 1. a) The 3D diagram of articular hyaline cartilage and subchondral bone with interdigitations interlocking with trabeculae of cancellous bone; b) the prototype of the stemless and entirely cementless total resurfacing hip arthroplasty (TRHA) endoprosthesis with the multispiked connecting scaffold (MSC -Scaffold) manufactured in Selective Laser Melting (SLM) technology; c) the femoral head component of our prototype of innovating THRA endoprosthesis – designed to preserve the subcapsular arteriae retinaculares: superior (3), and inferior (4); (1) – a.circumflexa femoris lateralis, (2) – ramus ascenens of (1).

The major purpose of the presented here work is the examination of the MSC-Scaffold design to improve the inter-spike structural osteoconductive potential of the MSC-Scaffold and, having regard to technological limitations of the SLM, to provide the key information about the necessary modification in CAD model design of the MSC-Scaffold taking into account the adjustments of the appeared technological limitations in this case. Before the essential research there had to be also worked out and performed the additional non-standard technological tasks, like removing of the supports from the SLM-manufactured MSC-Scaffold pre-prototypes, threading of the special grips in case of some specific MSC-Scaffold specimens, and the glass pearl blasting treatment which is useful in removing the powder aggregates from the lateral surface of MSC-Scaffold's spikes.

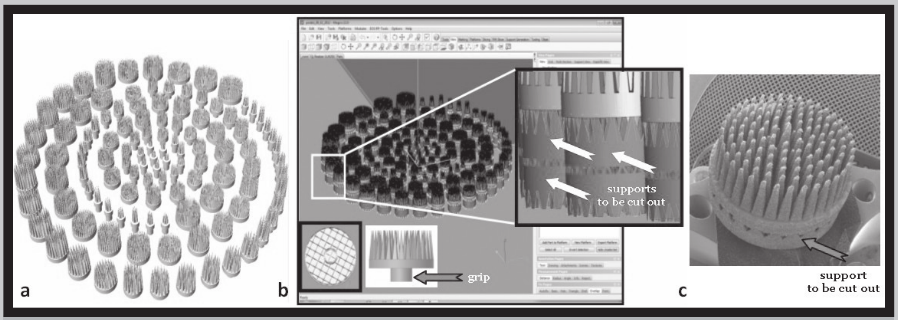

FIG. 2. a) The screen presenting variety of the CAD models of the biomimetic MSC-Scaffold pre-prototypes (designed with special grip for biomechanical push-in tests provided to evaluate the implant push-in force) arranged as they were set up in one CAD file and then transferred into one STL file; b) the screen presenting the pre-processing step – the formation in Magic 13.0 software of supports for all pre-prototypes of the MSC-Scaffold to be generated in SLM technology; c) the exemplary pre-prototype of the MSC -Scaffold directly after manufacturing with support to be cut out.

The applied SLM post-processing treatment is indispensable before the surface modification of the MSC-Scaffold's spikes, but still requires the improvement or alternative post-treatment process to be worked out. The change in the MSC-Scaffold prototype design (i.e.: optimal enlarging of the distances between the spikes base edges) is expected to increase the effectiveness of the glass pearl blasting of spikes surface of the MSC-Scaffold prototypes and cleaning this region from the metallic remains from SLM manufacturing process. The review of the most important technological issues of the additive manufacturing of the MSC-Scaffold will be presented in series of photos in our poster at the PSB Conference 2014.

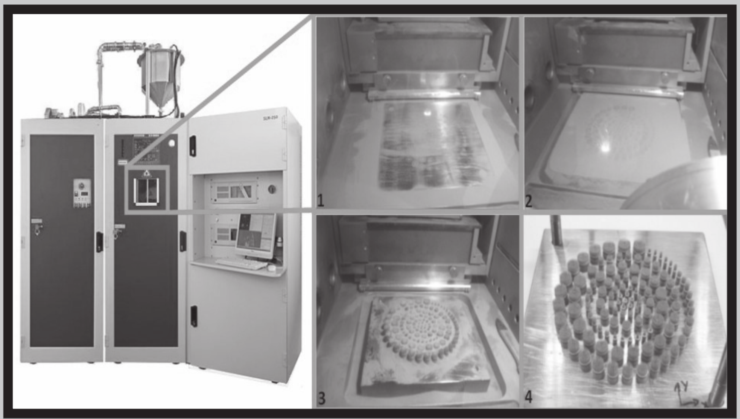

FIG. 3. The SLM machine (Realizer II 250, MTT Technologies, Germany) and the main stages of the manufacturing process of the MSC-Scaffold pre-prototypes.

Aknowledgements

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