Studies About the Initial Fixation of a Mini Tailored Hip Prosthesis with a Scaffold Structure

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Orthopedic research in hip endoprosthesis is advancing rapidly. The new techniques that are being used in the domain of Rapid Prototyping (RP) have given the possibility to build scaffold structures from metallic and plastic materials. This paper presents the designing process and a FEM simulation of a tailored hip endoprosthesis with a scaffold structure which is placed all over the stem and also brings into discussion the fixation place, which is influenced by the in-growth process of the bone tissue. The hip endoprosthesis simulation use as material Ti6Al4V because it is biocompatible and can be used to manufacture the endoprosthesis using RP technology like Electron Beam Melting (EBM).

Keywords: scaffold structures, orthopedic implants, electron beam melting, modeling

Hip joint replacement is one of the most common surgical procedures performed around the world. This is one of the reasons for which it is necessary to design better artificial hip joints [1-7].

Lattice structures are one of the most important subjects of the latest research in the endoprostheses field. The manufacturing of lattice structures is possible owing to the Rapid Prototyping technology. These structures can be manufactured from plastic and metallic materials. The plastic materials that can be used in RP technologies are not biocompatible so these cannot be used to manufacture implants. It is possible to build these structures from biocompatible metallic materials like Ti6Al4V using electron beam melting (EBM) technology.

Lattice structures replace material in implants, thus the resulting structures help facilitate bone in-growth, as well as the lower costs. In general, lattice structures can be engineered to a specific stiffness and can also reduce weight, absorb impact and dampen vibration [8].

A more durable endoprosthesis stem must be able to assure a stable, safe and long-term fixation. The stability of the hip implant depends on the fixation established with the surrounding bone tissues [9,10,14].

An improved fixation of the implant to the bone can be achieved by bone tissue growing into and through a porous matrix of metal.

Mismatch of Young's module of the biomaterials and the surrounding bone has been identified as a major reason for implant loosening. However, the implanted material must be strong and durable enough to withstand the physiological loads placed upon it over the years. A suitable balance between strength and stiffness has to be found to best match the behavior of the bone [13,14].

By combining a personalized hip stem endoprosthesis with scaffold structures, it can be achieved the best possible fit and also sufficient contact between stem surface and vital bone tissue [9].

This paper exhibits the process of design of one tailored hip endoprosthesis with a scaffold structure over the whole surface of the stem.

The model was simulated in order to asses the distribution of the equivalent stress and total deformations and to verify what happens if the bone tissue would grow only in some regions of the stem with a scaffold structure.

Experimental part

*Designing a Hip Stem with Scaffold Structur***e**

In order to design a tailored hip endoprosthesis, Computer Tomography data were collected. These data were necessary to determine the dimensions of the hip endoprostheses.

To design the scaffold structure on the hip endoprostheses (fig. 1.a) it was firstly designed the negative shape of the structure (fig. 1.b) and by using the boolean function, it was implemented in the endoprosthesis (fig. 1.c). The structure (fig. 2.a) has a thickness of 1200 μm (fig. 2.b) and it is composed of two types of layers, one is vertical and the other one is horizontal. The thickness of the layers is 400μm and they are composed of square bars with the dimensions of 400x400 μm. The bars are positioned at a distance of 800μm between them.

These layers are placed at a distance of 800 μm between them, therefore resulting square holes with the dimensions of 800x800 μm.

The recommendations from the Arcam EBM S12 User's Manual were taken into account in what concerns the dimensions of the structure.

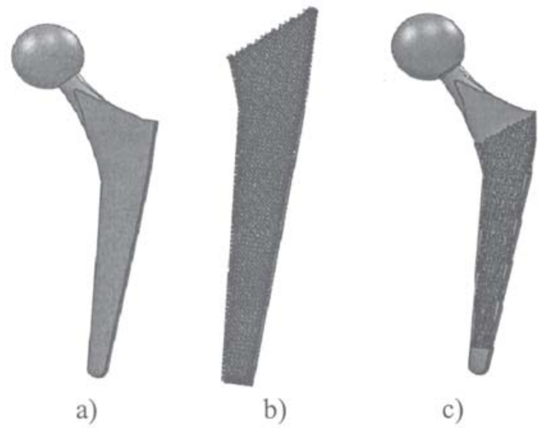

Fig. 1. Different design stage of the hip implant: a) solid hip endoprotheseses, b) the negative shape of the scaffold structure, c) hip endoprotheseses with scaffold structure after bolean operation

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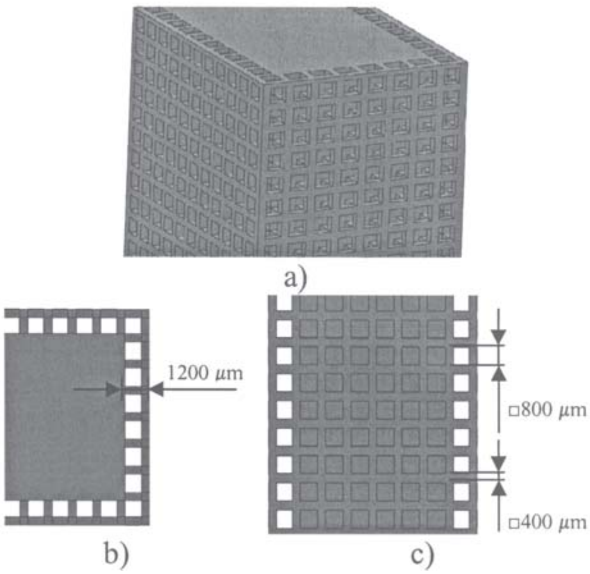

Fig. 2. Scaffolds structure design: a) 3D section view, b) horizontal section view of the structure, c) right view of the structure

The Simulation

The material used for the simulation was Ti6Al4V because it is biocompatible and can be used on the Arcam EBM S12 machine for the stem fabrication.

The bone tissue grows through the structure hole fixing the stem in that region. To simulate the fixation only in some regions (fig. 3), fixed points are located, firstly on the proximal region of the structure, secondly in the distal region of the structure, thirdly on the entire structure and fourthly in the middle and distal part of the stem. In all cases, a growth of 400 µm of the tissue into the structure was simulated.

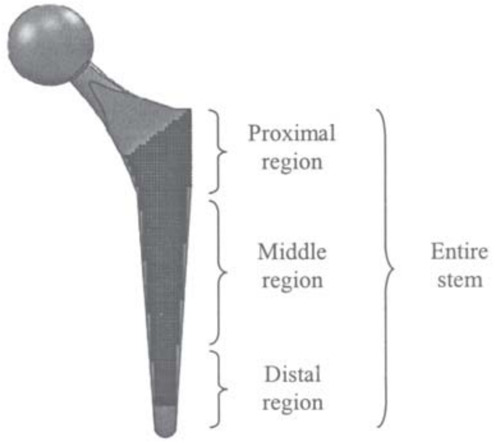

Fig. 3. Regions of fix points

These points were chosen because it was desired to see the distribution of the equivalent stress and total deformation at the structure level in case the bone tissue is not increasing uniformly on the whole structure.

A force of 1630 N was applied against the endoprosthesis head. The force was applied to the midline of the endoprostheses head from an inferior-posterior-lateral direction, with an angle of 10° in the frontal plane and 10° in the sagittal plane, as specified in ISO7206-4 [1].

The high quality mesh was generated by using a maximum edge length of 2 mm.

Results and discutions

The conclusions are based on the simulation plots and on the graphs from figure 4. The graphs exemplify the maximum values of the equivalent stress and the total deformation at the structure level.

From figure 4 it can be observed that the values of the equivalent stress and the total deformations are very high at the structure level if the fixation of the endoprosthesis appears in the distal region. If the fixation appears over the whole stem or only in the proximal region, then the equivalent stress and the total deformations are minimal.

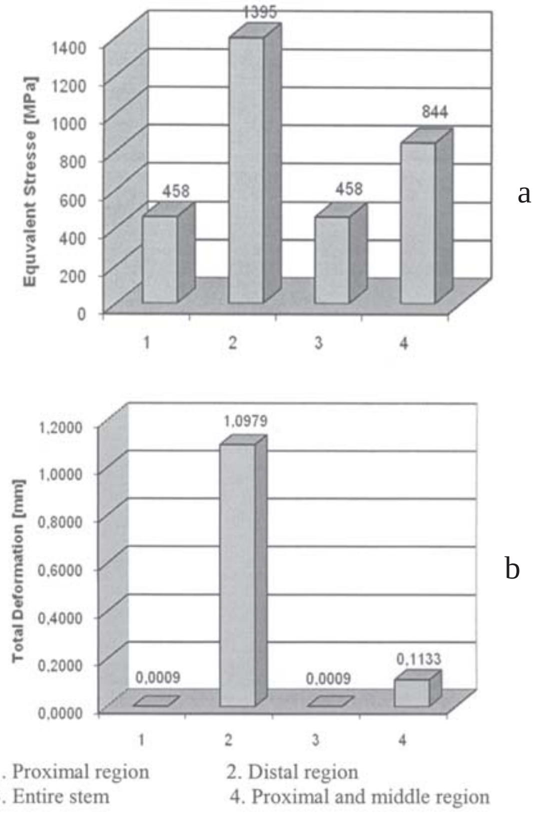

Fig. 4.Graphs: equivalent stress (a) and total deformation (b) at the structure level

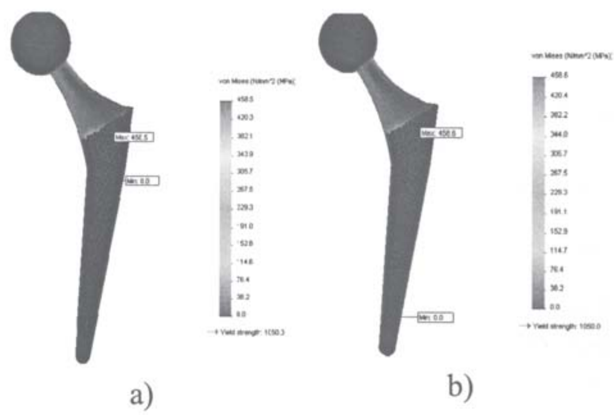

Fig. 5. Equivalent stresses distribution: a) proximal fixation, b) entire steme fixation

The fixation of the stem will occur faster if the surrounding bone tissue of the stem is stimulated a little. If the forces that stimulate the surrounding bone tissue are too high the fixation may not appear because the grown tissue might break.

Based on the simulation results from figure 5 it was decided that the case of the fixation number 1 is the ideal one because although it has the same results as case number 3 (Maximum Equivalent Stresses is 458 MPa and Maximum Total Deformation is 0.9 μm), on a long period of time, case number 3 may be resulting in bone resorption. From figure 5 it can be observed the distribution of the equivalent stresses for the case number 1 and number 3 which are graphically represented in figure 4.

Conclusion

This paper presents solutions regarding the integration process of a scaffold structure in a small tailored hip implant, which can be build by using the Arcam EBM Rapid Prototyping machine.

The simulation was a very helpful and low cost method that helped drawing conclusions about the ideal position of the initial fixation.

The tailored hip stem endoprosthesis with a scaffold structure offers a better osseointegration than the usual personalized hip stem endoprosthesis and conventional coated ones.

The results of this study demonstrate that for a stable and safe fixation it is enough to use scaffold structures in the proximal area of the stem.

In the future we will try to design other structures and to simulate them in order to determine which structures best resemble the features of the bone.

In order to confirm the truthfulness of the simulation results, future stems will be built by using the Arcam EBM S12 machine followed by mechanical testing.

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