Search for the optimal method of making reticular neck telescopic implants

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Abstract. The production of individual implants, intended for a specific clinical case, is increasingly used in medicine. The next stage in the development of implants is the creation of a non-monolithic mesh structure of the implant body. This allows to reduce its weight without loss of mechanical characteristics, and the main thing is to fill the free intergrid space with bioresorbable material, which will be replaced by cells in the future. The creation of a reticular three-dimensional structure of the implant is a complex technical task and requires the search for new ways of production. In this paper, a comparative study of the possibilities of selective laser melting and casting on burned-out models of telescopic implants obtained by 3D printing methods is carried out. Various production methods produced prototypes of telescopic cervical implants and carried out their technical and economic analysis. It is established that the best quality of products is observed by Selective Laser Melting technology.

Introduction
The development of medicine is strongly associated with the development and implementation of new technical devices and technologies. It was the development of new robotic instruments of operation that greatly expanded the capabilities of surgeons, and the discovery of superconductivity made it possible to produce affordable for general use MRI systems. At the moment, it is the relationship between medicine and technology that allows solving new problems of human health [1,2,3]. The latest trend of individual approach in the treatment of patients is becoming increasingly widespread. This applies to the individual selection of drugs based on genetic analysis, and in particular the creation of individual implants. In addition to the individuality of the implant site, there is a need to create a retina mesh body. This is necessary to reduce the weight of the structure and fill the bioresorbable material of the intergrid space. In the case of using standard production and molding methods, the creation of this product type is a complex technological task [4,5]. The use of additive technologies solves this problem. In the additive manufacturing of individual implants, there are two methods: creating models for subsequent casting or direct manufacturing of finished individual implants from metal powders. The most correct is the direct production by selective laser melting of metal implants, thereby reducing the number of manufacturing stages. However, from laboriousness view obtaining a certificate-permission to use this method for medical purposes, it can not be used in the short term. But there remains an open question of the
possibility of casting a three-dimensional mesh structure of the implant body [6,7]. Therefore, the task was set, to compare and find the optimal method of manufacturing individual cervical telescopic implants. Namely, how many complex designs can be obtained with the help of SLM-technology and the combined technology of casting burn-out SLA- and DLP-models.

One of the common injuries is spinal injury. The greatest danger is a fracture or dislocation of the cervical spine. It is important to replace the damaged vertebra correctly. This is achieved only with the installation of individual telescopic implants, with the possibility of changing the upper platform location in the vertical and horizontal directions. Therefore, the comparison of SLM and the combined method of casting SLA- and DLP-models was carried out in the work.

Main part

To create an individual implant, you need to obtain digital data of the fracture site or dislocation. The surgeon decides to install a telescopic cervical implant. Obtaining a three-dimensional model of the fracture site is possible only in installations receiving a object layered structure, such type of equipment include tomographs. Digital data obtained with CT, MRI are needed to create a three-dimensional virtual model. Determine the location of installation and cervical implant attachment. Only after receiving this information will it be possible to begin modeling the geometry and calculating the component dimensions of the telescopic implant. With 3D Slicer software, the CT data was processed and 3D model of the patient cervical spine in STL format was created. In the MeshMagic program, we load the STL file of the fracture site and standard size models - blanks of telescopic cervical implants. We adapt the workpiece model to the fracture site. As a result we have individual three-dimensional virtual implant model in the STL format, presented in Figure 1.

Fig. 1. A mesh virtual model of the cervical implant assembly.

To produce a burned-out model, we used a 3d printer ProJet 1200 equipped by pico projector with a resolution 585 dpi in the X-Y, and Z-step height of 30 μm. This setting applies to the DLP (Digital Light Processing) family of 3d printers. At the heart of the DLP-system is a special device - a DMD-chip (Digital Micromirror Device). This is a complex structure that belongs to the so-called class of microelectronic mechanical systems (MEMS - Micro-Electronic Mechanical System). As a source of light can act as a light bulb (incandescent, luminescent or LED), and lasers. The wavelength extends from the ultraviolet to the infrared range. The device has the form of a micromirror matrix. Each micromirror is 10 microns in size. They are able to reflect both the invisible and visible spectrum of light and reflect light in one of two directions. The direction is determined by the angle of rotation. Direction itself is set by loading the bit "0" or "1" in the memory location. Each cell receives an independent bit stream with a frequency of several kilohertz, as a result of which we have a useful image on one of the outputs, and at the other output there is a light absorber. The GeomagicPrint program splits the printed object into layers with the specified thickness. A photopolymer is poured into the printer's bath with a transparent bottom. At the bottom of the bath the metal substrate is immersed, receding from the bottom to one (first) layer of the product. It turns out in the gap between the substrate and the bathroom is a liquid photopolymer. The projector, located under the bathroom, projects the picture of the first layer onto
the bottom of the bath and, thanks to UV radiation, only the plastic that gets the image from the projector freezes. Then the working table rises one more layer and again a new layer is glued, which is attached to the previous one. As a result, a three-dimensional object from the liquid photopolymer grows layer by layer. The material used was the VisiJet FTX Green photopolymer from 3D Systems. It has the following properties: heat resistance - up to 93 °C, dynamic viscosity (mPa s): 100 - 130 (30 °C), burn-out - ash residue 0.01%.

The technology of laser stereolithography is based on photoinitiated laser radiation or the emission of mercury lamp polymerization of the photopolymerizable composition (PPC). In a container with a liquid photopolymer, a mesh platform (elevator) is placed on which the prototype is "grown". Using this technology, a three-dimensional object projected on a computer is synthesized from liquid PPC by successive thin (0.03-0.2 mm) layers formed by laser radiation on a moving platform. The 3D model of the object is preliminarily converted from the STL-file format into a set of stratified sections with the required height step, the array of which is recorded in the executable file with the SLI extension. This file is a set of two-dimensional vector data that provides sequential laser beam orientation control by means of mirrors in the process of object synthesis, commands to turn on the laser and move the platform. A laser is activated that acts on those parts of the polymer that correspond to the target object walls, causing them to solidify. After that, the whole platform is dipped a little lower, by an amount equal to the thickness of the layer. After the printing is completed, the resulting object is immersed in a bath with special compositions to remove excess and cleaning. And, finally, the final irradiation with powerful ultraviolet light for final hardening. Like many other 3D prototyping techniques, SLA requires the construction of support structures that are manually deleted when printing is complete.

On the RSPro 600 (Uniontech) and ProJet 1200 printers, mesh samples of polymeric telescopic cervical implants were grown on simulated models, the photographs of which are shown in Figure 2.

![Fig. 2. a) gating system from SLA-models, b)33 gating system from DLP-models.](image)

The construction of the gating system begins with the establishment of each unit according to the feeder. Elements of the implant are supplied with sprue channels with a diameter of 5 mm. The channels number depends on the number of units cast. After building a gating system, it must be weighed. Based on the known mass of wax, the required amount of metal is determined. The calculation is made by the following formula: \( M_{Me} = m_{wax} \times 10 + 5 \) g. Starbond CoS dental metal was used in the experiments, the following composition of Co - 59%, Cr - 25%, W - 9%, Mo - 3.5%, Si - 1%, other components (C, Fe, Mn, N) - maximum 1.5%. Ultimate tensile strength (Rp0.2) 650 MPa. The tensile strength is 910 MPa. The maximum elongation is 8%. The modulus of elasticity is 200 GPa. Vickers hardness 280 HV 10. Density 8.8 g / cm³. Solidus-liquidus interval
is 1305 - 1400 °C. The casting temperature is 1500-1550 °C. The thermal expansion coefficient is 14.0 μm / m °C.

In the second stage, the Yeti Expansion refractory molding (90 g) is prepared and kneaded with Yeti Liquid (22/20 ml) + distilled water (0/2 ml). To avoid the formation of air bubbles, a vacuum mixer Fox 88 from OMEC (Italy) was used. The kneading time was 30 seconds, the blade rotation speed was 400 rpm, and the pressure in the bowl was 0.8 Bar. The casting of the gate was made on a vibration table VB 1.1 with 2 vibration frequencies of 3000/6000 min⁻¹. After the molding mass has been filled in, wait 30 minutes before the molding material solidifies completely. The resultant hardening of the molding mass should be heated in the muffle furnace. In the experiments, the method of shock heating of the flask was used. In particular, the Programix 50 Ugin oven was preheated to a temperature of 900 °C. A mold was used with an X6 size, the minimum warm-up time was 60 minutes. To effectively cast the metal, the crucible with the metal is also heated in a muffle furnace. In the next step, the heated crucible is placed in a casting chamber. The metal is heated by means of high frequency currents. Further, from the muffle furnace, a heated flask is extracted and vertically fixed to the crucible cover and pressed down from above with a clamping mechanism. After that, the vacuum chamber cover is closed, and the evacuation process of air begins with simultaneous high-frequency metal heating. During the heating process, the metal melts, resulting in the formation of a molten metal in the crucible, which is covered with an oxide film on top. At the rupture moment of the oxide film, the caster performs a casting process, namely, a vacuum-casting chamber is rotated, and compressed air is pumped at a rate of 3 bar/s to a pressure of 3.6 bar. As a result of the overturn, the metal from the crucible is poured into the flask and pressurized by excess pressure. The pressure provides the possibility of spilling metal into channels with a thickness more than 0.1 mm. In the experiments, a fore-casting installation was used. The vacuum-casting chamber is in an inverted state for 30 seconds, during which time the metal cools and crystallizes. Molding box must be cooled at room temperature, and mechanically clean the metal frame from the molding mass. A sandblasting unit was used, in which sand particles stream with a grain size of 250-300 μm, bombarded the surface of the sprue system and cleared the molding mass.

Figure 3 shows cast specimens of individual telescopic cervical implants.

![Fig. 3. Castings of individual telescopic cervical implants](image)

a - SLA models, b - DLP models.

At casting wire mesh there are two problems: the difficulty of molding associated with the air extraction from mesh volume and the difficulty of cleaning the molding mass is a mesh space in the implant volume. This shows the relevance of creating new, more efficient methods for pouring the
molding mass, which would allow it to effectively penetrate the interplanetary space of the implant. Otherwise, the formation of an air cavity in the intersection space and its subsequent filling with liquid metal is observed. The second demand is to develop an effective method of extracting the molding material after casting the metal. Without solving these two problems, casting implant mesh is difficult to implement.

To create metal prostheses in experiments, a Selective Laser Melting system ProX 300 3D System was used. Figure 4 shows a diagram of the inner chamber, whose length is 1500 mm, height 800 mm. The chamber is hermetic and allows creating an atmosphere of inert gas, on the left is a metal roller for applying powder, it has the ability to move horizontally throughout the chamber. In the middle of the box with powder, inside which the movable piston is located, on the right there is a construction zone consisting of a movable piston with a platform and a laser system installed above it. The cycle of layer construction consists of the following stages: lifting of the central piston by 60 microns, descent of the working platform of the construction by 40 microns, movement of the roller through the central box with the transfer of excess powder to the working platform of construction, laser scanning of the powder. During the scan, combustion products can be generated, which are carried away by the flow of gas into the dust container.

The ProX 300 is equipped with a Nd:YAG fiber laser power - 500 W, with a wavelength - 1080 nm, the laser spot area - 20 μm. The size of the construction zone is x - 250 mm, y - 250 mm, z - 300 mm, minimum product size x = 100 μm, y = 100 μm, z = 20 μm. Laser power during the melting supports 100 W, during the melting product - 150 W, the scanning speed is 380 mm/s. Stainless steel powder 17-4PH, dispersed from 0.5 to 40 μm, from 3D Systems was used in the experiments. Figure 5 shows prototypes of telescopic reticular implants obtained by Selective Laser Melting.
The possibility of growing an article with a layer thickness of 40 μm made it possible to reproduce the geometry of the samples with an accuracy of 15 μm. The grown samples were cut off from the surface of the construction platform. Without additional processing, it was possible to assemble the implant, which is unattainable in casting technology. The removal of powder from the interwoven space is carried out by purging with compressed air. Thus, from the point of view of achieving the required geometric characteristics and constructing a network structure, the most optimal production method is selective laser melting. The limiting factor now is casting, not SLA and DLP-technologies, which are capable of reproducing the network geometry of the implant body.

Conclusion
Comparison selective laser melting technology and the combined casting technology of burned SLA and DLP models has shown the advantages of the first. The possibilities of using the SLA RSPro 600 (Uniontech) and ProJet 1200 for obtaining a burned model of a telescopic neck implant with a mesh structure were studied. The results of the model material influence on the molding mass are obtained. There is a cracking of the flask, which indicates the need to replace the “shock” heating with a "stepped". Experimental samples of cervical implants are cast on an Inducast plant. The ineffectiveness of this technology in the manufacture of mesh collapsible telescopic implants has been established, but it can be used for structures with a thickness of 1 mm. Using SLM technology allows you to get on the platform of construction up to 100 pieces per launch. That is much faster than casting on burned models and printing time of these models. However, the high cost of an SLM installation economically limits the scope of application.

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