Chapter 27
Comparison Analysis Between Different Technologies for Manufacturing Patient-Specific Implants

Georgi Todorov, Yavor Sofronov, and Krasimira Dimova

Abstract The demand for improved, fast and effective way to produce patients-specific implants has led to the developing new technologies in Implantology. The increasingly advanced development of methods for materialization of products used in Medicine allows the introduction of new materials with better characteristics and more efficient usage of the resources for manufacturing. The Virtual Prototyping and Rapid Prototyping technologies are used in the manufacturing process of the products such as personalized implants and prostheses, dental implants and joint implants, intervertebral discs, medical instruments and devices for fixation and guidance. Applying those technologies improves the process of designing and producing patient-specific implants. Actually, the goal of the process is to minimize the extra removal of tissues and to improve the precision of the process suggesting exact Prototyping technology for personal case. The research compares in few aspects the manufacturing technologies of cage type spinal implant. A patient-specific cage type implant is in the area of interest of the paper especially a comparison of the manufacturing technologies for producing it.

Keywords Technologies · Manufacturing · Patient-specific implants

27.1 Introduction

In the field of Implantology not only surgical implementation it is important part of the process but the implant's manufacturing. With the developing the Medicine more and more technologies are involved in the innovations. Nowadays, Virtual and Rapid prototyping are developing as research areas that use basic engineering principles for solving complex problems in the human body in a medical environment. The physical prototyping could be accomplished with additive technology—in the current research were chosen SLM and FFF technology or subtractive technology. In

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certain clinical cases, the additive technologies are very suitable for creating patient-specific implants, and it is possible to select a suitable material for producing, which must be biocompatible [1]. At the other hand Subtractive technologies might be better option in some clinical cases. Additive technologies, both metal and plastic printing, continue to expand their design capabilities, improving the functions and complexity of implants. Traditional methods, such as machining, are also being improved especially the control and precision, but for some cases and parts, which have a complex geometry, they still require a wide range of machines and highly qualified personnel. The aim of the research is make comparison analysis between different technologies for manufacturing of cage type spinal implant considering the implants material, complexity, dimensions and other factors and using Virtual prototyping [2].

27.2 Methods and Materials

For the aims of the research was used a 3D model of cage type spinal implant. With some of the existing Additive and Subtractive technologies and the help of CAM (Computer Aided Manufacturing) software and a 3D slicing software were evaluated the implant's precision and cost. For the current case was chosen the optimal material and technology for producing. The materials in Implantology should have specific characteristics like bio-compatibility, strength, corrosion resistance, fatigue strength. The most common materials in Implantology are titanium alloys and plastics, rarely used material is ceramic. For the research are compared Ti6Al4V, PEEK (Polyether ether ketone) and ceramic [3]. With increasing the complexity of the part its cost is increasing too, both in Subtractive manufacturing and in Additive manufacturing. But in Additive manufacturing there is a point beyond which the levels of complexity and customization is free, which make the technology more suitable for complex shapes as its shown on Fig. 27.1 [4]. The total number of required parts is a key design consideration when selecting a manufacturing technology [5]. The patient-specific implants require unique design for that reason the Additive technology is competitive to Subtractive technology in that case. In cases where are required large number of parts the Subtractive manufacturing might be more suitable as it shown on Fig. 27.2.

These advantages of the Additive manufacturing include less material consumption, increasing design complexity, opportunity to produce direct assembly, variety of materials [8]. Also applying Subtractive manufacturing technology results in a lot of raw material waste, which is often expensive titanium alloy [9]. One of the flaws of the Additive process is quite rough surfaces, which could require additional finishing operation like sanding or blowing [10]. The right chose of technology depends also on number of required series, the complexity of the shape, the material and technical requirements.

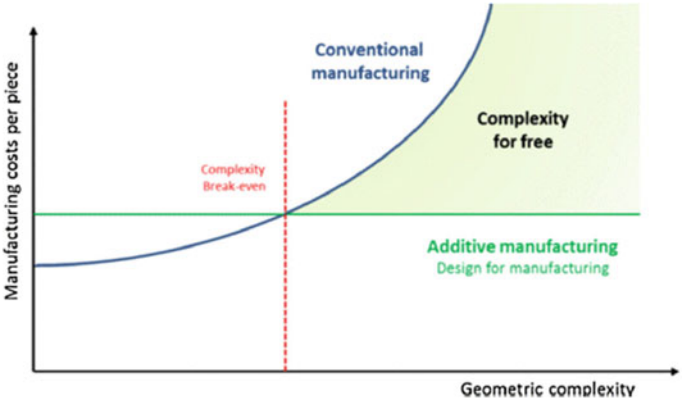
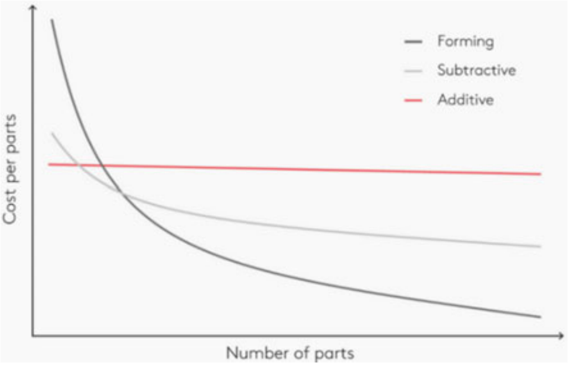


Fig. 27.1 Cost of the part considering its complexity in traditional and in additive manufacturing [6]

Fig. 27.2 Cost per parts considering the number of parts [7]



The involved additive technologies in the research are: SLM (Selective Laser Melting), FFF (Fused Filament Fabrication) and are compared to the CNC technologies. The study compares the manufacturing technologies by which the cage could be accomplished using only different Virtual systems for CAM and software for slicing:

- SLM technology—Selective Laser Melting is method which melts metallic powder with laser to produce metal with unlimited complex shape. Its main advantage is the independence with respect to material selection [11]. It is a complex thermo-physical process which requires delicate process determination to achieving high precision [12]. The first step is importing the generated STL file of the implant in a slicer software where is chosen the technology and the material, in the current case- the used material is Ti6Al4V. The material is often used because of its corrosion-resistance, wear resistance and a good osseointegration. The main parameters of the process as power of beam, scan strategies, layer thickness and other. The metal shrinking should be considered and the positioning of the implant. Figure 27.3 shows the first layer and the support structure of the implant. The software gives the opportunity to calculate the resources including the cost of material, the cost for manufacturing and cost for extra operations. The time for printing is shown also.

- FFF technology—Fused Filament Fabrication—the process includes a nozzle which extrudes a thermoplastic material, layer by layer. The used materials are main and supporting, as the supporting is low-melting material. The main privileges of the process are printing flexibility, variety of materials, and easy material switch [13]. The generated STL file from a 3D model of the cage is inserted in other slicer software, where it is defined material PEEK, the support structures are generated. Figure 27.4 shows the first layer of the implant and its positioning.
- CNC machining—Computer Numerical Control machining is a method for producing metal parts where code is written to control the machinery in the process of subtraction. The code determines the whole machining process. As main factors that could limit the CNC manufacturing process are tool access and clearances, and also the level of geometry complexity [7].

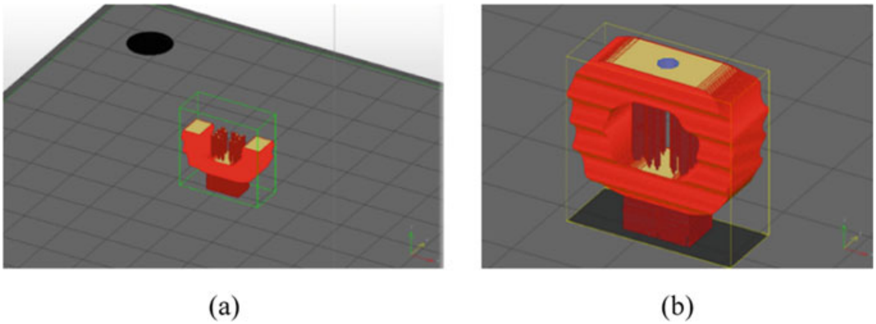

(a) (b)

Fig. 27.3 **a** Support structure of the implant and **b** visualization of 3D printed implant

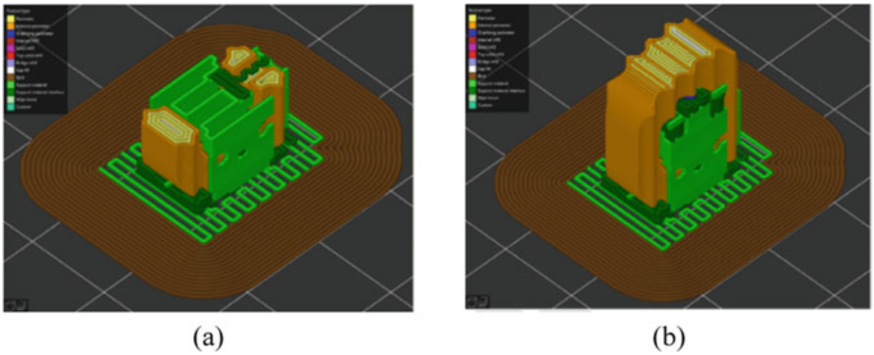
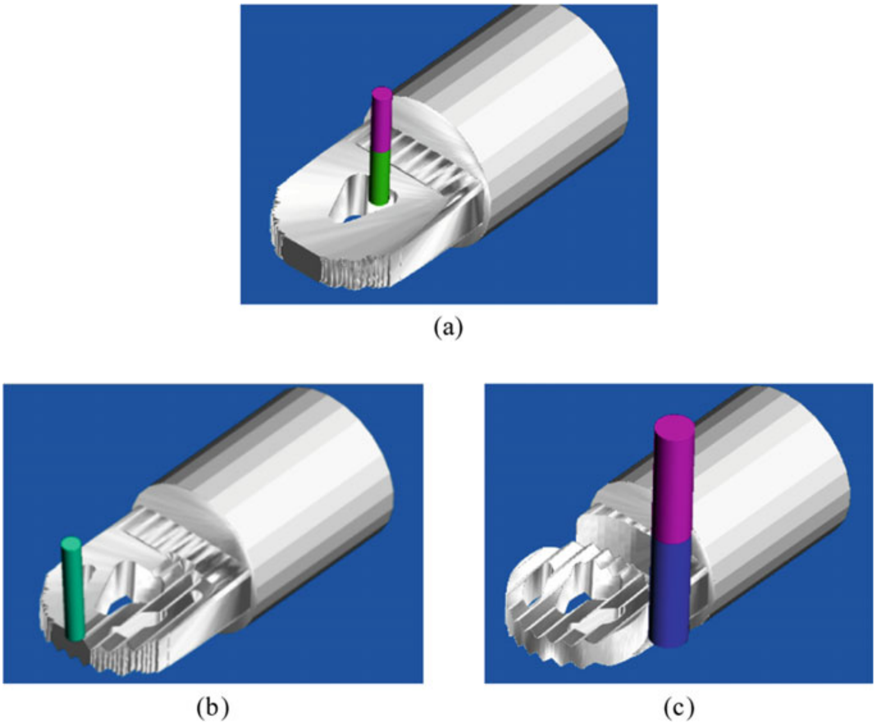

(a) (b)

Fig. 27.4 **a** Supporting structure of the implant and **b** visualization of 3D printed implant

In current case is used a 3D model of the implant and CAM module of software. The appropriate milling machine is chosen, with 3 or 5 axis. The model's coordinate system is adjusted to the machine's coordinate system. Then it is generated a workpiece. Titanium alloy is defined as material. The technology includes few operations, as the main operations are roughing, finishing and the last CNC operation is cutting. The cutting speed for current material was 100 m/min for Ti6Al4V. The calculated time for the whole process included all operations was 134 min. Figure 27.5 shows the process of planning the CNC manufacturing using CAM software.

The CNC machining of a workpiece form PEEK is also part of the research. The PEEK workpiece has the same dimensions as the one from titanium alloy. The mode of the technological operations are different also the material cost. When applying FFF technology the PEEK material is powdered while applying CNC manufacturing the material is rod workpiece.

In Table 27.1 are compared the three cases and it was chosen FFF technology with PEEK material, which is an expensive material, but the technology allows the inside structure to be half-full, the accuracy of FFF technology is low but enough for manufacturing the implant. This additive technology is working with main and supporting material. Considering the results could be summarized that the implant's


(a)

(b)

(c)

Fig. 27.5 Visualization of the manufacturing simulation of the cage implant

Table 27.1 Comparison analysis

	Material type	Mass [g]	Material cost [€/kg]	Manufacturing cost [€]	Time for manufacturing [min]
SLM	Ti6Al4V	2	300	100	120
FFF	PEEK	3	500	40	30
CNC manufacturing	Ti6Al4V	40	150	90	134
CNC manufacturing	PEEK	12	350	70	96

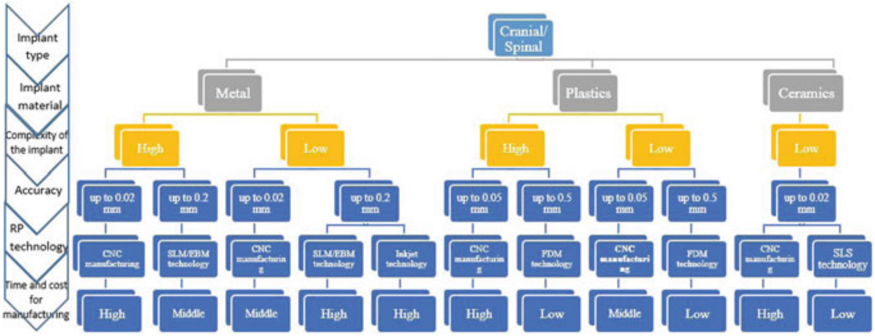


Fig. 27.6 Classification method for Rapid Prototyping choice for implants

geometry and material are the main depended factors for technology choosing. After the comparison analysis could be concluded that from current case and the use of Virtual tools was made an optimal chose for manufacturing technology, material and geometry.

The advantages that Additive manufacturing offers are manufacturing of patient-specific implant from plastics which allows complex geometrical forms with even less material. Evaluating each manufacturing features was made classification method for Rapid Prototyping choice for implants (Fig. 27.6).

27.3 Results and Conclusion

The classification method could be used in cranial and spinal cases considering the implant material, complexity, accuracy, RP technology, time and manufacturing cost. For an example was used a cage type implant and based on the classification was chosen the optimal material, technology and accuracy for reasonable cost. The research compares the pros and cons for Additive and Subtractive rapid prototyping in the process of manufacturing the implant. The major role of the comparison analysis played the applied Virtual tools which reduces the time for evaluating the manufacturing parameters. The results for current case show that the most suitable technology is SLM technology with Ti4Al6V considering the main factors. The method could be applied in cranial and spinal reconstructions in order to define the best technology for current clinical case. This classification could be used for operation planning. To summarize by the initial cage type implant it was made a classification method which could be applicable in cranial and spinal clinical cases.

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