Design and manufacture of orthopedic corset using 3D digitization and additive manufacturing

I Molnár 1, L Morovič 2
1,2 Slovak University of Technology, Faculty of Materials Science and Technology, Institute of Production Technologies, Department of Machining and Forming, Jána Bottu 2781/25, 917 24 Trnava, Slovakia

1 ivan.molnar@stuba.sk, 2 ladislav.morovic@stuba.sk

Abstract. The paper discusses the use of 3D digitization and additive manufacturing technologies in the field of medicine. The paper focuses on design and manufacture of an orthopedic corset. Described are the methods of designing and manufacturing of orthopedic corsets according to the individual requirements of the patient at present, and a more detailed description of the design and manufacturing process using 3D digitization and additive manufacturing. The paper introduces three variants of corset design and manufacture, with the description of the materials selected for use. The main purpose of the paper is to describe the process of the effective design and manufacture of orthopedic corset using 3D digitization and additive manufacturing technologies.

1. Introduction
At present, the methods of 3D digitization and additive manufacturing are increasingly used in various sectors of industry, with increasingly widespread use being made in the field of medicine. In the medical field, the development and use of 3D digitization and additive manufacturing influences several factors, which are advances in technology, improving health infrastructure or investing in science and research.

The purpose of this paper is to describe the design and manufacture of the individual orthopedic corset using 3D digitization and additive manufacturing. This orthopedic aid was chosen for the dissertation thesis with the title „Research of design and manufacture of orthopedic aid by 3D digitization and Rapid Prototyping“. The orthopedic corset was chosen in collaboration with the Neoprot company, which designs and manufactures individual orthopedic and prosthetic aids in Slovakia. The choice of orthopedic corset was made on the basis of requirements for saving manufacturing material, shortening of manufacturing time, introducing a new design and creating an effective methodology of design and manufacture of individual orthopedic corset [1].

2. 3D digitization and additive manufacturing
The purpose of 3D digitization is to convert real physical objects into their digital form. This fact is used in medicine to obtain computerized patient data that serves, for example, to determine the exact diagnosis or to make computer adjustments for the manufacture of various medical aids and models [2].

The following part of the paper describes the 3D scanning of the human body with the method of active triangulation (structured light), which subsequently serves as a basis for making an individual
orthopedic corset [3]. This method of 3D digitization is based on obtaining the coordinates of points represents the surface of the scanned object (cloud of points) or component by transmitting light patterns from the light projector to the scanned object’s surface. The patterns on the surface are captured by the sensor’s of the cameras (CCD (Charge Coupled Device) or CMOS (Complementary Metal-Oxid Semiconductor) sensor) and the exact position of the scanned points is then calculated on the principle of triangulation ‘figure 1’ (a) [1,3].

![Figure 1. Principle of active triangulation (a) and Fused Deposition Modeling (b) [1].](image)

At present, the several methods of additive manufacturing (AM) are used in the field of medicine. These are mainly Selective Laser Sintering (SLS) [4], Selective Laser Melting (SLM) [5], Poly Jet Modeling (PJM) [6], Stereolithography (SLA) [7] and Fused Deposition Modeling (FDM) [6,7].

The following part of the paper describes the principle of AM method FDM ‘figure 1’ (b) used for the manufacture of individual orthopedic corset. FDM is one of the most common AM in practice.

Fused thermoplastic fibers are extruded from the tip of a heated nozzle that moves in the X and Y axes. Thin fibers are deposited on a platform that has a significantly lower temperature, which ensures fast cooling of the melted thermoplastic. After the platform has been reduced to a precisely defined thickness of one layer, another layer is deposited. In this way, a component is created.

The height of individual layers ranges from 0.05 to 0.3 mm, depending on the quality requirements of the resulting surface of the component. In this method, depending on the complexity of the component, it is also necessary to use the support material [8].

3. Current methods of design and manufacture of an individual orthopedic aids

At present, there are several methods used for designing and manufacturing of individual orthopedic aids, the use of which depends on the patient's state of health or, respectively, the state of his / her injury, which is the consequence of the need to use an individual orthopedic aid. The orthopedic aids are determined by a specialist after a medical examination and the extent of the injury.

At present, the following three methods of designing and manufacturing of the individual orthopedic aims are mainly used. Corsets as well as other orthopedic aids can be produced by the next methods:

- design and manufacture of gypsum / “light gypsum” orthopedic aid,
- design and manufacture using 3D digitzation and CNC milling,
- design and manufacture using 3D digitization and additive manufacturing [9].
The use of these methods of designing and manufacturing of an individual orthopedic aids has been found based on a literature review in the field of medicine. Currently, the above mentioned methods are used, the choice of which of them depends on the case, respectively, type and extent of injury to the patient [10].

The gypsum and “light gypsum” based methods are entirely manual methods of designing and manufacturing of individual orthopedic aids. The other two methods work with the use of computer aided systems, which are computer aided design and computer aided manufacture software. The gypsum individual orthopedic aids are made of a plaster, a handy and relatively „dirty” way of applying of plaster bandages on the injured place on patient body. The „light gypsum” individual orthopedic aids are made of a resin that hardens similar as gypsum after contact with water [1]. The ‘figure 2’ describes the above mentioned methods of designing and manufacturing of individual orthopedic aids. The highlighted is the method by which the article is dealt with more closely.

**Figure 2.** Methods of designing and manufacturing of individual orthopedic aids [2].
3.1. Design and manufacture using active triangulation and Fused Deposition Modeling
In the design and manufacture of individual orthopedic corset two ways of designing and manufacturing can be made:

1. design and manufacture of a 3D model of the individual orthopedic corset,
2. design and manufacture of a „2D” model of the individual orthopedic corset.

3.1.1. 3D model of individual orthopedic corset. 3D model of the individual orthopedic corset is created using CAD software according to the data obtained by 3D scanning a model that will be designed and manufactured in the shape and size according to the particular patient, and then it is possible to use after manufacture.

Variants created on the basis of the 3D scans were designed as 3D models of corsets. These two variants were created, based on their own pattern and on the basis of the polygonal mesh pattern. The above mentioned two variants of corsets are seen in the following ‘figure 3’ [1].

![Figure 3](image)

**Figure 3.** Variants of 3D models of the individual orthopedic corsets.

Variant A was created in software Autodesk PowerSHAPE. In the first step, it was necessary to create curves on scan model by means of a dynamic section. Subsequently, it was possible to create surfaces between the curves. Therefore, reverse engineering was used to create the corset 3D model. Because it was a rather complicated area in the back, it was necessary to create a larger number of curves so that the software could be counted and packed between the curves. The next step was the cropping of the created surfaces. The digital surfaces had to be cut to the desired shape of the corset, which was possible
by creating further curves copying these surfaces. From these curves, additional areas were created, this time perpendicular to the corset surfaces. Using the cutting tool, the separation of the areas between them at the points of contact was achieved.

In this design and manufacture variant, emphasis was placed on minimizing material consumption, saving manufacturing time and resulting in lower production costs, while maintaining the strength and hence the functionality of the device.

In variant B, the corset was created using software Autodesk Meshmixer. The surface model from software Autodesk PowerSHAPE has to be re-introduced into the polygonal mesh. Subsequently, this mesh was reduced from 128,000 triangles to 6,300. The reduction was performed to reduce the size of the model file and thereby increase the speed of the modeling itself. Mesh reduction generally reduces the shape and dimensional accuracy of the model, but in this case it will not affect the future functionality of the model (corset).

After the reduction, the mesh was exported in the STL format into software Autodesk Meshmixer in which was possible to further reduce the number of triangles of the mesh and to work exactly to the required number and size of the given triangles. These processes were performed using the crossover functions, as in the previous case, and then by the triangle number reduction function. In the last step, it was possible to create a STL corset model, which is automatically generated according to the number of triangles in the mesh [1].

As has already been mentioned, the corset manufacturing will be made by FDM method. In case of the printed elements require improve surface properties, finishing operations are recommended [11,12].

3.1.2. „2D” model of individual orthopedic corset. On the basis of the outputs and information (time for design of the corsets, manufacturing time, quantity of building and support material) obtained from the previous two variants of 3D models of the corsets, the „2D” model of the corset will be designed and manufactured in the next step of dissertation thesis. The variant of „2D” model expect greater efficiency in the design and manufacture processes of the individual orthopedic corset. The benefits of this variant compared to previous two variants of 3D models are as follows:

- lower material consumption,
- shorter production time,
- higher accuracy of shapes and dimensions after shaping on the patient's body.

The „2D model” of the individual orthopedic corset is designed and manufactured in the plane, i.e. as an unfolded 3D model, is created using CAD software according to data obtained by 3D digitization (active triangulation). This model will be formed (i.e. shaped) on the body of the patient after model production.

The process consists in performing the following main steps:
1. obtaining the 3D digitized model of the desired part of the body using active triangulation,
2. edit and convert to STL format (input format to AM),
3. automated production using FDM,
4. individual orthopedic corset [1].

4. Materials of individual orthopedic corsets
Two types of materials were selected to make an orthopedic corset, namely PLA (Polylactic Acid) and PET-G (Polyethylene Terephthalate Glycol).

The reasons for choosing these materials are as follows:

- health-conscious materials that do not cause medical complications in contact with the skin,
- both materials belong to the cheapest polymers that can be purchased on a regular basis, so they are not difficult to produce,
during manufacture itself, by the chosen technology, there is no complication and no special conditions need to be created during the additive manufacture of medical devices by the chosen technology [13].

- PLA material has features that are particularly suited to the application. This material is a biocompatible polymer which, in some forms, is used for the manufacture of various medical devices, whether for external or internal use (i.e. placement in a human body). Another important feature is its forming ability, under certain conditions. This material is so soft when it is heated to a certain temperature that it is possible to shape / form it, in this case directly on the body of the patient. This shaping can be done many times in succession without breaking the coherence of the material or its degradation (variants of „2D” model) [14].

- PET-G material is a health-conscious material, has good mechanical properties (strength, elasticity) among the plastic materials used in the additive manufacturing technology. It can not be shaped to the same extent as PLA material, so the desired shape of the model can be manufactured without its further modification by molding (variants of 3D models) [15].

- The detail description of material properties and shrinking of both materials (PLA and PET-G) has been researching and described in the article [16]. On the basis of the results of the article, it is possible to assume the minimum values of the shape and dimensional deviation of these materials.

- There are currently a number of materials designed specifically for medical purposes, but only a few of them can be used for FDM technology and also their price is higher [6,7,13].

5. Conclusion

The paper discusses the processes of design and manufacture of individual orthopedic aids, mainly the method which uses 3D digitization and AM. The use of 3D digitization and AM for the design and manufacture of individual orthopedic aids is an effective way of designing and manufacturing them. With these technologies, it is possible to design and manufacture quickly and efficiently orthopedic aids, which have many advantages for the patients themselves as well as the doctors.

Using these technologies for the design and manufacturing processes has many advantages over both doctors and patients. They are:

- low material consumption,
- automated production,
- easy, comfortable, airy and visually appealing solution for the patient,
- cost savings,
- higher accuracy of orthopedic aids (by shaping the PLA material).

This paper represents part of the dissertation thesis which is being elaborated in collaboration with Neoprot company. This company is engaged into the design and manufacture of individual orthopedic aids. The result is a simple, fast, and therefore efficient process of designing and manufacturing of individual orthopedic corset with regard to its functionality, suitability for use and practical application [1].

The dissertation thesis will be dealt with already mentioned variant of design and manufacture of „2D” model of corset. It is necessary to choose the appropriate software functions and their sequence for efficient editing of the scanned data and then select the optimal parameters of manufacturing process. The aim is to create a methodology for the design and manufacture of orthopedic corset using 3D digitization and AM, with a view to the practical use in Neoprot company.

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