RESEARCH REGARDING THE ANATOMICAL MODELLING OF A WRIST ORTHOSIS FOR 3D PRINTING APPLICATION

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ABSTRACT: The aim of this research is to study the possibility to develop an anatomical model of a wrist orthosis by using additive manufacturing technology. This paper represents a further research of the study "Cercetări privind dezvoltarea și fabricarea unei orteze personalizate pentru încheietura mâinii" and an optimization of the previously obtained model by using Autodesk Fusion 360 software. The improvements made to the last orthosis model were: the possibility to empirical modify the shape and dimensions of the splint, the possibility to create a Voronoi pattern and to adjust it according to the functional and aesthetical needs and creating a closing solution for the orthosis, fact that will make wearing it easier. The further research directions include the designing of a parametrical model of orthosis, testing more solutions for the fixing system and implementing generative modelling.

KEY WORDS: anatomical modelling, additive manufacturing, Fusion 360, Voronoi, 3D printed orthosis

1. Introduction

An anatomical model is a representation that copies with high accuracy the shapes and outlines of the human body. Those models are used in the medical industry, firstly, for learning and secondly, for better understanding the right way to approach a medical problem (preoperative planning).

As it can be easily observed, the human body has a complex geometry that is hard to reproduce. One accessible solution to recreate this type of geometry is the additive manufacturing. AM represents the process of creating an object using a technique of adding layer upon layer by using a 3D representation of the object. This technology is already used for the fabrication of medical devices and models because it offers some big advantages, such as rapid prototyping, variety of materials, the possibility to create complex geometries and accessible costs. [1]

The medical field which is deeply improved by using additive manufacturing fabrication process is orthopedics: AM is used to produce orthosis, prosthetics, or orthopedic implants.

This paper represents a research regarding the anatomical modelling of a medical device that ease the recovery of a body part that we use in almost all our daily activities, sometimes even without noticing it: the wrist. The aim of this research is to analyze the possibility to model an anatomic wrist orthosis (by using *Autodesk Fusion 360,* a CAD software that is free for personal use) that can be edited, modified according to the patients' needs and 3D printed.

2. Current stage

Medical reports inform that orthosis for the wrist are treatment for medical conditions such as: fracture, dislocation, tendonitis, carpal tunnel syndrome, pot-operative, etc. So that, the splint for the wrist must provide stability, allow some mobility, but not in an excessive way, correctly align the wrist and the hand and resist to the external forces. Living with a hand splint may take time to get used to, so medical specialists and engineers are trying to develop and constantly improve solutions to ease the problems of the patients. The following part of the paper presents some of the last solutions for designing additive manufactured orthosis [2].

One study [3] has presented the possibility to create a personalized 3D printed orthosis by using SolidWorks software. To design the 3D model, there was used anthropometric measurement of patients' hand and a file of a scanned arm, which served as a guidance. The pattern was generated as a sketch of holes of random sizes and position. The orthosis was made of PLA and used a Velcro fastener.

Another solution [4] that has been developed is a 3D CAD software specially created for generating 3D customed models of orthotics (fig. 1 a). The software uses **.ply* or **.stl* files which are prepared and simplified. Then, there are drawn and trimmed the curves that represent the contour of the future splint. In the end, there are generated patterns or lattice structures and there are attached accessories such as fasteners or other details.

Fig. 1. a. Wrist orthosis created by Mediace3D [4]; b. Wrist orthosis created with Xkelet software [5]; c. Wrist orthosis realised with Rhino 3D and Grasshopper [6]

There is another software, Xkelet, that ease a lot the designing process for the medical personnel. The software keeps a rigorous evidence of the patients' personal data. Also, Xkelet can scan the hand and recommend the most suitable orthosis according to the lesion and the hand geometry. Another innovation of the orthosis produced in this way is the helicoidal cut, that according to the designers, improves the resistance of the product to possible impacts and increases the stability of the union between two pieces. Further, the openings are designed to assure comfort and to facilitate access for the realization of the cures and the closing system allows the solving of post-inflammatory processes (fig. 1 b). [5]

Other study [6] tried to make the entire process even more accessible, so that it will not be necessary for the designer of the orthosis to have previous knowledge of how to use a CAD software. The first step is to acquire the data by 3D scanning. For the 3D designing there were used two software Rhino 3D and Grasshopper. They were able to develop a parametric CAD model that was printed with a FDM printer. The orthosis was made of two parts, used four screws as fasteners and had a Voronoi pattern (fig. 1 c).

According to a previous research [7], additive manufacturing can be used to create custom made orthosis by following three main steps:

1. 3D scanning
2. Postprocessing of the data
3. 3D printing

For the first step, there was used a 3D scanner and the image needed to be postprocessed with a special software; for the second step there were used the 3D sculpting software *Autodesk Meshmixer* and also, *Blender;* for printing the product there was used PLA (Polylactic Acid) and the FDM printing technology (fig. 2).

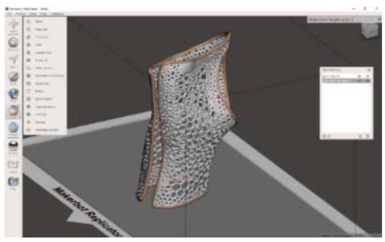


Fig. 2. Wrist orthosis made of PLA by using Meshmixer software [7]

In the following part of the paper there are presented the improvement made to this product.

3. Modelling and manufacturing the orthosis

3.1. Using a CAD software

The inconvenient that the previous 3D model presented was the fact that surface and shape could not be modified in *Meshmixer*. Thus, to solve that problem, it was decided to use a CAD software to design the model. There was chosen *Fusion 360* because it was more suitable for designing complex surfaces.

The first step was to introduce in Fusion 360 the 3D scanned hand (**.obj* file) to be used as a model to the new design (fig. 3).

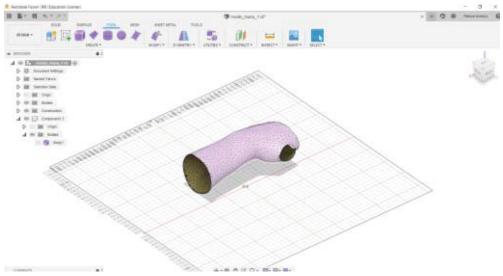


Fig. 3. Introducing the *.obj file in Fusion 360

To obtain a model as similar as possible to the scan, it was used *Form* menu that allows the t-splines modelling. T-spline represents a mathematical model for defining freeform surfaces.

It was easily observed that the shape of the hand can be approximated by a cylinder, so there was defined a primitive cylinder shape on the YX plane, with the dimensions approximately equals with the hand's dimensions. The cylinder had 8 diameter faces and 6 height faces (fig. 4 a). After that, each face and edge were scaled, translated, or rotated until it was obtained the shape that better fitted the hand scan (fig. 4 b).

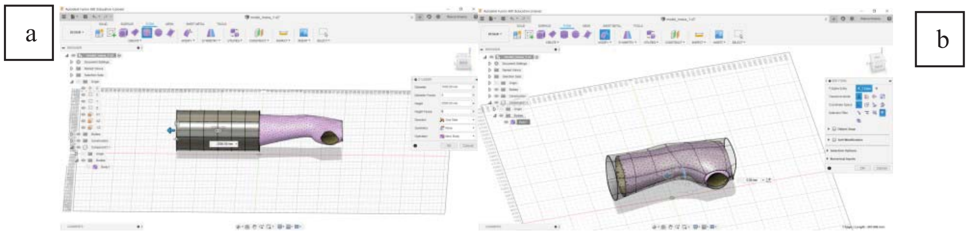


Fig. 4. a. Defining the cylinder; b. Modelling the shape of the orthosis

This process represented one step ahead because now it is possible to empirically modify the shape, the surface, and the dimensions of the 3D model of the orthosis. Before using Fusion 360, it was impossible to adjust the scan, the only changes that could have been made were Boolean operations, measuring and adding a pattern.

3.2. Adding volume and patterns

For the printing process there cannot be used a t-spline surface, there is needed a volume. To obtain that, there was used the *Convert* option and there was chosen the type *T-Splines to Brep* (fig. 5 a). After that, there was obtained a surface. There was used the *Thicken* option from the *Surface* menu to create volume fig.5 b). The product is going to be 2.5 mm thick so that it can be light and comfortable to wear and be resistant and confer protection in the same time (fig. 5 c).

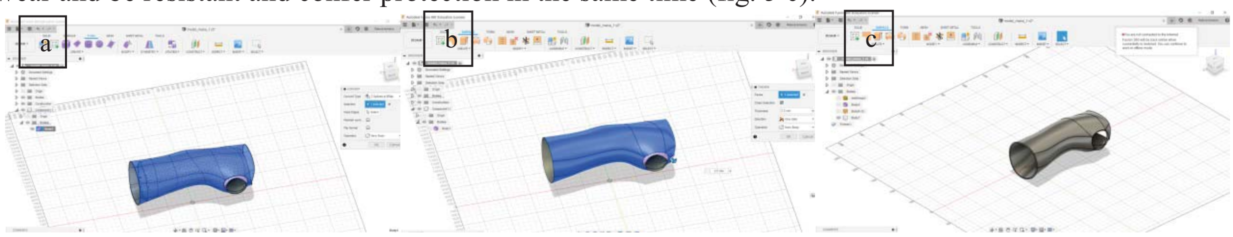


Fig. 5. a. Converting T-splines to surface; b. Converting surface to volume; c. The result of conversion

In the actual shape, without any openings (besides the one for the thumb), it is difficult for the patient to put the orthosis on the hand. In addition, it can worsen the medical problem and harm the skin.

So, the next step is to cut the orthosis in two parts so that in the following stage to be created a closing system. Firstly, there is needed a sketch (fig. 6 a). On the interior side, there is designed a sketch for the future cut. The cut will be made along the entire orthosis and it will have a special form so that the two parts of the orthosis will not fall apart. With the sketch that have just been created, is going to be made the cut by using *Split* command from *Modify* tab (fig. 6 b).

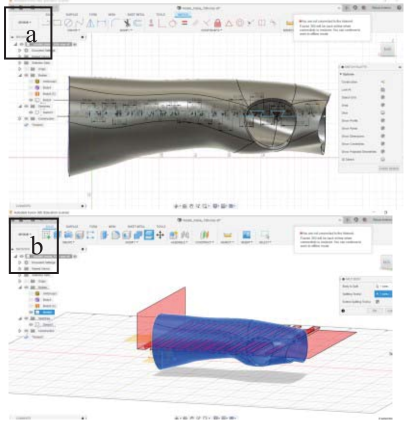
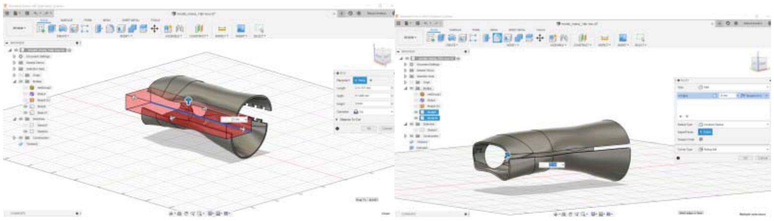


Fig. 6. a. Realizing the sketch; b. Splitting the orthosis

On the other side, the exterior one, there is going to be made a plain cut by using a box primitive form from the Create menu. The box is sized so that it can cut along the entire orthosis, with a height of approximately 23 mm (fig 7 a). Also, there is applied the fillet option to the sharpen sides to obtain soft edges (fig 7 b) that will not cause injuries or cuts when the orthosis is put on or taken of.

a



b

Fig. 7. a. Cutting the orthosis; b. Applying fillet to the edges

After that, a pattern can be applied to the future orthosis. *Fusion 360* offers the possibility to use *Voronoi Sketch Generator*. Fusion 360 generates a rectangular sketch on which there is a random pattern. The user can select the shape of the pattern (round or straight edges), the number of the pattern on the rectangle, the density of the pattern and the dimensions of the rectangle and the dimensions of the rectangle. There are presented the results obtained by using both straight (fig. 8 a) and round (fig.8 b) edges. The dimensions used for the sketch were approximated so that it can cover entirely the orthosis. After that, the pattern of the sketch was edited, so that the cuts are not too close to the margins of the orthosis and affect its resistance. After editing the pattern there is used *Extrude* command from the *Create* menu. The distance of the extrusion is not very important, but the essential condition is to assure that it is bigger than the orthosis dimensions. Another important option is to select *Intersect* type of extrusion.

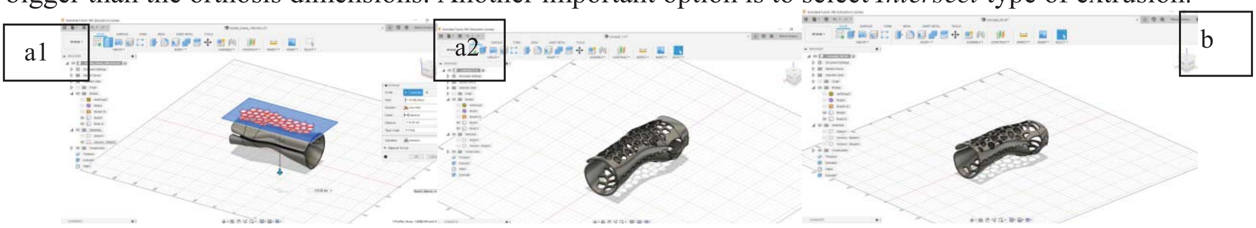


Fig. 8. a1. Generating and editing Voronoi sketch; a2. Orthosis with Voronoi pattern with straight edge; b. Orthosis with Voronoi pattern with round edges

In this step, there was obtained a pattern that can be empriricaly edited and positioned so that it will not affect the functionality or resistance of the orthosis. Those changes could not be made by using either Meshmixer or Blender software. Those only allowed the generation of a pattern that could not be either dimensioned or edited.

3.3. Designing a closing system

In some cases, the orthopedist or rheumatologists recommend to the patient to wear the orthosis only a certain amount of the time (for example, wearing it only during daytime). In addition, patient must attend to frequent medical visits that require the exam of the affected wrist. This means that they should be able to easily take off the orthosis and put it back on. Thus, the orthosis must have an opening and closing system that is easy and comfortable to use. In this part of the research it was tried to improve the orthosis by adding this system. There have been made cuts along the orthosis. Also, by using *Hole* option, there have been made 3 holes on each part of the orthosis: the superior one and the inferior one.

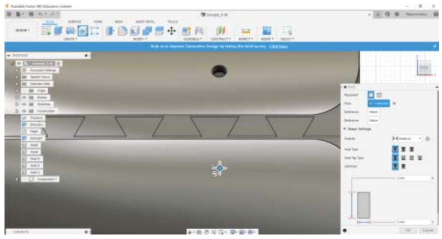


Fig. 9. Creating the holes for the closing system

There will be manufactured fixing clamps of rubber silicone to fix the orthosis on the hand. For the left part, there will be made 3 clamps from HT 33 silicone, a flexible type of silicone and for the right part there will be manufacture clamps from ZA13 silicone (fig. 10). Both types of silicone are liquid, the vulcanization is made at the room temperature (RTV). The silicone has 2 components: the base and the catalyst. Those will be mixed at a 1:1 rate and put on the model that will be reproduced.

To manufacture the clamps, there will be designed molds with the negative model of the clamp.

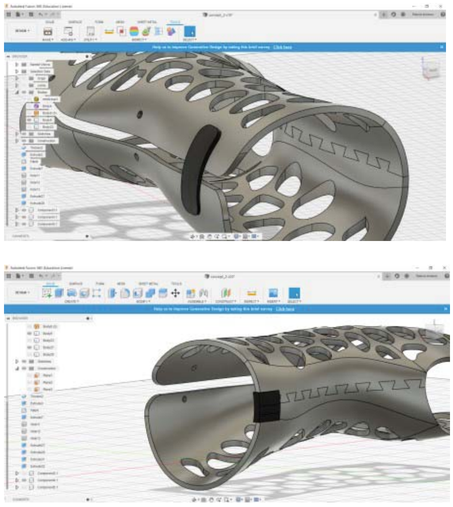


Fig. 10. Designing fixing clamps

4. 3D Printing

The orthosis design will be exported from *Fusion 360* as a **.stl* file.It will be 3D printed by using FDM technology. The printer will be *3D Kreator* and the parameters for the printing process will be selected on *Ultimaker Cura 4.5* software (presented in table 1).

Because the orthosis has a complex structure there have been created a support structure (blue in fig 11) to assure that the orthosis is correctly printed. The entire printing process will take approximately 35 hours and the mass of the splint will be about 103g.

After printing, there should be a post-processing step in which the support structure is cut off.

Table 1. Printing parameters

Parameters	Value
Profile thickness	Fine - 0,1 mm
Material	PLA
Printing temperature	210^{0} C
Print speed	30 mm/s
Travel speed	30 mm/s
Filament diameter	1,75 mm
Flow density	100%

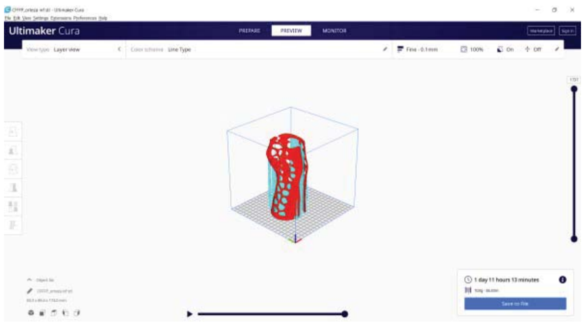


Fig. 11. Printing simulation in Cura

5. Conclusion

In this research clear improvements of the first orthosis concept were described and important progress to design a new concept was made. Even though, the product that has been manufactured is not the final one and it will need future development to obtain on optimal product.

This research contributed to the continuously development of the implementation on the additive manufacturing and CAD software in medicine. The most important aspects that were elaborated were:

- Discovering the possibility to design an anatomical modelling by using a 3D scanned image only as guide, so the entire process will not depend so much on scanned data and its quality;
- The possibility to empirical edit the shape and dimensions of the curves, fact that was impossible to do by using *Meshmixer* and *Blender* software;
- A way to create patterns that can be edited and placed on the orthosis so that they respect both the functional and aesthetic functions of the product;
- A closing system that will help the patient to easily fix the orthosis on the hand.

The progresses stated before are just a few steps toward future research directions, such as:

- Identifying the equations of the curves that describes the anatomical model of the hand;
- Creating the possibility to modify the curves parameters so that there can be used the parametrical modelling to obtain the orthosis. In this case, the production process will be even more accessible because there will not be needed the 3D scan image;
- Testing more solutions for the fixing system to make it even more comfortable;
- Creating a generative model of the wrist orthosis.

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