RAPID PROTOTYPING AS AN AID IN MEDICINE

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ABSTRACT: Modern times brought modern techniques and we are taking part in a huge process of evolution regarding any main field of our daily lives. Engineering, medicine, economics and many other main fields faced optimization processes that, in a way or another, made our lives more comfortable, more practical and more efficient, trying to achieve the three main needs: precision, quality and short manufacturing times. In this paper I would like to sintetize the main benefits of rapid prototyping used in the field of medicine and medical engineering, based on the close approach beetwen engineering and modern medicine due to up to date nonconventional technologies, in this case aditive manufacturing or 3D printing. Also, I will present case reports regarding an active element used in medicine and designed and manufactured by a 3D printer – a shoe insole, and a passive element also used in medicine, more specific in clinical research as a continuous glucose monitoring system sensor holster.

Keywords: Rapid Prototyping, Optimization, Medical Engineering, Efficiency

1. INTRODUCTION:

Technologies evolved in such a manner that our daily lives quality have been improved. As been said previously, the close bound between fields that were another times quite unrelated, have become more evident. Based on up to date techniques, the field of medicine requires new solutions that engineering is capable to deliver. This close bound proves that the medical act has faced some improvements, ranging from a more quick and efficient diagnose to complementary and evolved rehabilitation. The main goal is to help those in need in a more efficient way and, why not, to save lives in some circumstances. Rapid prototyping made a big step toward the optimization process mainly because of its flexibility and adaptability for any given situation. Redesigning and manufacturing in a cell that it's available in a small place have never been more suitable than now. [1,2,4]

2. RAPID PROTOTYPING

Rapid prototyping (RP) represents a technique that reproduce quickly a model of a physical part designed in a computer aided design (CAD) program using data from it and manufacturing it layer by layer using a 3D printer as a part of additive layer manufacturing.[2,3]

This process faced huge improvements since its creation in 1980 and has been nowadays a very important contribution for medicine because has significantly improved the ability to fabricate physical models with precise geometries using computer-aided designs (CADs) or data from medical imaging technologies.

Rapid prototyping is benefical in the field of medicine, as the technology used allows to manufacture complex shaped anatomical parts directly from scanned models or data obtained via medical imaging. Also, due to improvoments of biocompatible materials it's more easy for this manufactured components to be accepted by the human body in case we are talking about implantology or an associated field where the models must be compatible with human tissues.[1,3]

There are many Rapid Prototyping techniques, based on the improvements the technique faced in the past years, each one having its own applications and limitations for manufacturing different models.

Figure.1 – Rapid prototyping cell – Inspire S200 3D printer and a laptop used for the computer aided design software and the manipulation of the 3D printer

The 3D printer used in this case it's based on the FDM principle, a fused deposition modeling device that carries an extrusion head in the XY plane being feed with a plastic filament through heating elements which heats it to a semi-molten state. The filament is then fed through a nozzle and deposited onto a platform to form each layer. The latest FDM system includes two nozzles, one for the part material and one for the support material. The principle of the Fused Deposition Modeling is represented in Figure 2.[1,2]

The materials used by the 3D printer are mainly acrylonitrile butadiene styrene, known as ABS or polylactic acid known as PLA.

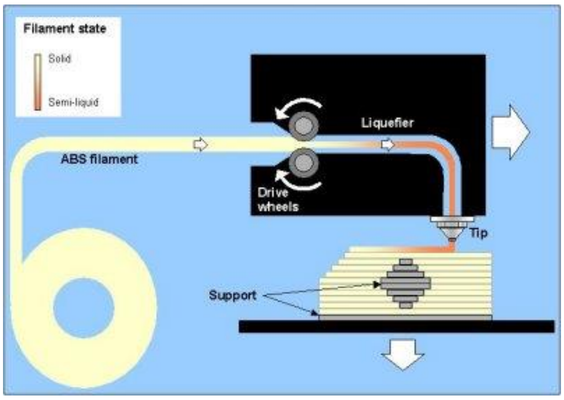

Figure.2 – Working principle of a Fused Deposition Modeling 3D printer

3. MATERIALS

In the case of medical applications, the rapid prototyped models can be fabricated with a variety of materials, and the selection of material depends on the purpose of fabrication. However, some medical applications (surgical tools or medical implants) require models which have the ability to be sterilized or remain compatible with human tissue-like biomaterials. A biomaterial can be classified as any material used to manufacture devices that replace a part or a function of the body in a safe and reliable way. Metallic biomaterials are mainly used in areas of high static or cyclic stress and are well suited for medical implants such as cranial plates and acetabular implants. Ceramic materials are typically solid inert compounds and are used where resistance to wear is of primary importance, such as dental implants and crowns, whereas medical-grade polymers are used in various medical applications where stability, flexibility and controlled porosity are demanded, such as tissue repair, drug delivery devices and medical implants.[1]

The materials used for different models are limited by the printer because not all types of material can be processed on any kind of printers. Plastics can be used for elements used for medical recovery as well as auxiliary items for different medical devices. Ceramic and metallic materials are way more hard to work with and need special types of 3D printers that use sintering to build the desired item.[1,2,5,6]

Table.1 – Materials used for medical applications

Metals	Ceramics	Polymers
316L Stainless Steel	Alumina	Ultra-high molecular weight polyethylene
Titanium Alloys	Zirconia	Polyurethane
Cobalt Chromium Alloys	Carbon	ABS
Ti6Al4V	Calcium phosphate	PLA

4. MODEL FABRICATION

3D printing machine needs CAD information to fabricate a physical model, so for that purpose rapid prototyping process can be divided into two phases: virtual and physical. As mentioned earlier, first comes the virtual phase, which consists of using image processing tools that involve data acquisition and image processing, to create a virtual model through dynamic and interactive simulation. The fabrication of the physical model is the second phase (physical). Data acquisition is the process in which high-resolution images of human anatomy are captured by using medical imaging technologies such as computerized tomography, magnetic resonance imaging and others. After data acquisition, images are processed by softwares, then the output (virtual model) is transferred in the STL file format to the rapid prototyping system for fabricating a physical part.

5. RAPID PROTOTYPING APPLICATIONS IN MEDICINE

As the technology faced progress, medicine also faced challenges which require help from major fields of engineering, like mechanical engineering, electrical engineering, science of materials, all this to deliver optimal solutions for patients and, in some cases, to save lives.

To start from the bottom, a first application that uses rapid prototyping in medicine it’s creating models of external or internal structures of human anatomy for didactical purposes. Because the models can be made from different colours they can be used as teaching aids in medical education or research. This kind of models can be distribuited to medical school or museums for a better ilustration of the functions and structures of human body.[1,2,6,7,8]

A main field of application represents the design and development of medical devices and instrumentations. This types of devices are mainly used in the clinical research area, where the design and functionality must be improved and optimized in a rapid manner to bring the best version of the product on the market. Here we can include hearing aids, sensors, different holsters for sensors and derived products, tools and many others. Due to swift evolution of electronics and transmision methods, devices needed optimization of their sizes to be more confortable to be worn on a daily basis. Devices as continuos glucose monitoring systems, that need to be worn by the patient for days or weeks, were reduced in size for a more comfortable fit and a more ergonomic shape to be carried for longer periods of time without jeopardizing its functionality.[1,2]

Figure 3 – Dexcom G4 continuos glucose monitoring device used in the clinical research for patients with Diabetes Mellitus

Rapid prototyping can be used for customized implant design due to ability to fabricate customized implants and fixtures and also of the inherent advantage of this technology to fabricate complex forms and geometries in a very short time. Medical imaging combined with computer aided design software it makes possible to manufacture implants and fixtures that are precisely designed for every patients needs and requirements.(Figure.4)[1,2,8]

Figure.4 – Dental implant

Prosthetics and orthotics are major fields with many improvements over the past time due to the rapid prototyping processes involved in the optimization of protheses. The ability to quickly fit a prothesis to a patients unique proportions is a great advantage and to include in the design the specific characteristics of the patients anatomy represent the main benefit of the mentioned technique.[1,2]

Patients specific characteristics, dimensions and alignments are included in the 3D model developed in the computer aided design software, allowing the implementation of a biomechanically correct geometry that improves fit, stability and comfort.

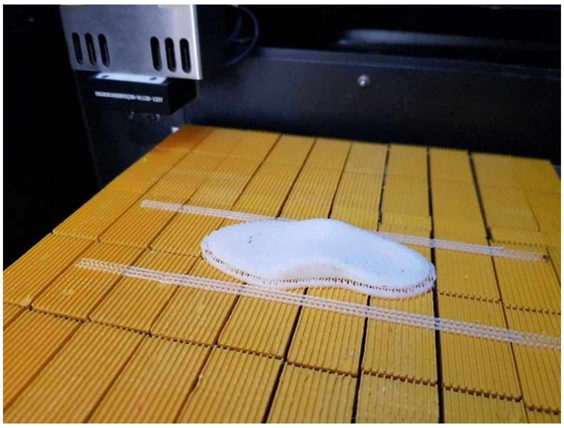

Figure.5 – Printed insole

There are always patients outside the standard range, between sizes or with special requirements caused by disease or genetics. With the aid of rapid prototyping, it becomes possible to manufacture a custom prosthesis that precisely fits a patient at reasonable cost.

Orthopedic insertions are another item that can be shaped via CAD programs and reproduced using rapid prototyping techniques, the main advantage being the possibility to change the shape of the insertion depeding on the evolution of the patient.[1,2,5,6]

6.CASE REPORTS

In the past two years I have being study coordinator for clinical research, mainly in clinical trials of Phase II and III in Diabetes Mellitus, and made contact with modern devices that could be optimized depending by the needs of the patients or by the needs of the sponsor and/or medical companies involved in research.

The first case study I did was related to redesigning the sensor holster for a continous glucose monitoring device. I made this one as a principle of work for further ideas related to optimization of medical devices.[8,9]

The rapid prototyping process can be structured on stages as the following.

- Design or redesign of the holster – Virtual Phase (Figure.6)
- Manufacturing of the holster – Physical Phase (Figure.7)

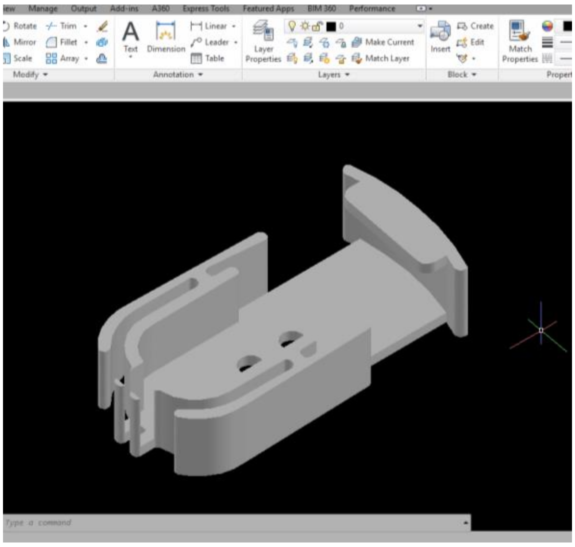

Figure.6 – Virtual Phase – redesigning the sensor holster

After processing the 3D model in the CAD software it's imperative to transfor the object into STL format to be recognized by the printer.[11,12]

Printing algorithms are made in such a way that the workpiece is not a solid form. Only the external layers are made in one piece and the inside is made in a honeycomb model, contributing for a efficient use of material without sacrificing strength.

Figure.7 – Physical Phase – 3D printing of the solid model designed in the CAD software

Another case of rapid prototyping techniques used in medicine I made in the past months was related to orthopedic shoe insoles. The main benefit for prosthetics and insertions is that adjusments can be done in a short amount of time depending by the patients or their evolution.

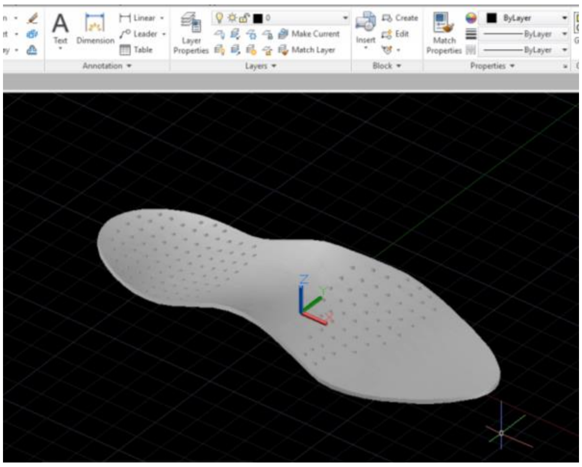

Figure.8 – Shoe insole designed in AutoCAD

Because of the limitations of the 3D printer, shoes insoles for biger sizes are harder to be done but nonetheless insertions for the same type of insole can be more easier to manufacture, especially in cases where patients are evolving at a constant rate and changes need to be done in order to fit their new anatomy and to keep the medical recovery at a high level.[11,12]

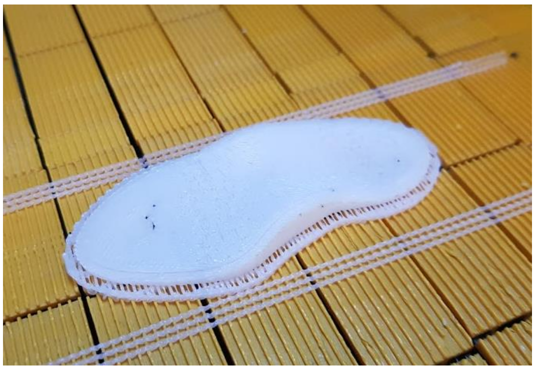
Figure.9 – Final workpiece

7.CONCLUSIONS

Up to date technologies and a fast growing demand of modern equipments used in medicine are making their way on the market. Efficiency is the word used to describe this method used to solve high level demands that are being present in our daily basis habit.

Rapid prototyping methods are combining the three key elements of the engineering – high quality, acceptable prices and good manufacturing times. Taking these characteristics into account and the capability of redesigning any product or medical device depeding on the need of the patients, we are coming close to an efficient way to fight medical issues of the modern days.

Medicine is evolving and so is engineering. Combining these two we can deliver optimal solutions resulting mainly in more profficient medical act.

Rapid prototyping takes a big place in the process of reverse engineering, in which information based on a scanned model we can modify and reproduce any item we .need for our daily lives. The time and resources saved with the help of aditive manufacturing can conclude in a efficient method of fabrication.

This technologies are not present only in medicine. Its making big steps in other fields like applied mechanics, rapid tooling, and in military research and development of modern firearms and military technologies.

The possibilities offered by the flexibility of rapid prototyping are endless, mainly because of the simple route of how we can obtain a solid part from a digital drawing format. The quality of the machined workpiece is defined by the 3D printer and by the optimization done in the computer aided design and computer aided manufacturing softwares.

Steps forward are being made in 3D printing of human tissues and organs. The main benefit of this application is that due the evolution of the stem cell manipulation that lead to creation of different organs based on the cells gathered from the patient in need. This way we eliminate the possibility that the organ will not be recognized or accepted by the body, the compatibility being almost 100%. This technique is only at begining but evolution is noticable on the market.

A very important parameter is represented by the accuracy of the 3D printer. Starting from tenths of milimeters and going up to high precisions, printers come in a big variety of characteristics, the price being directly in proportion with the efficiency and quality of the 3D printed workpiece.

Advantages are mainly represented by the efficiency of material usage and fast manufacturing times. Disadvantages are represented by high costs regarding the acquisition of rapid prototyping or reverse engineering systems. Speaking of costs, the accuracy being in direct proportion with the quality of printers results that higher costs can bring a much better result but it’s not affordable by anyone. Although becoming smaller and more efficient they still represent an aditional cost for any company that wants to introduce this kind of modern technique in their services offer.

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