SEVEN publicações acadêmicas

Applicability of additive manufacturing in traditional medical processes

Crossref doi
https://doi.org/10.56238/sevened2023.007-085

Laura Maciel de Vasconcellos Ferreira
IBMEC/MG, Production Engineering
E-mail: lauramvf@gmail.com

Carlos Alberto Silva de Miranda
IBMEC/MG, Production Engineering
E-mail: carlos.miranda@ibmec.edu.br

Paulo Henrique Campos Prado Tavares
IBMEC/MG, Production Engineering
E-mail: paulo.tavares@ibmec.edu.br

ABSTRACT

Additive manufacturing technology can be applied in several economic sectors, one of which is related to healthcare. Traditional medicine adopts imaging tests such as CT scans and MRIs to diagnose patients for diseases, injuries, and problems with internal organs. Additive manufacturing has been more widely used in production lines in various sectors, with the purpose of generating products equivalent to the products of normal production, but with lower operating costs, great customization and shorter time. As these are characteristics that attribute competitive advantage, that is, as the characteristics of low costs, high reliability, customization and shorter time represent the consumer's search nowadays, additive manufacturing becomes attractive to several companies. Specifically in the area of health, this work is characterized by an exploratory research that confirms that the use of 3D printing in the production of prostheses, especially craniofacial prostheses, is an aspect to be taken into consideration, since, in addition to the compatibility of diagnostic tests, such as computed tomography, and the possibility of using an extremely efficient biomaterial in bone regeneration, The advantages are numerous. The patient will be able to have access to a cheaper prosthesis, fully customized for their case and that uses materials that promote the reduction of infections and rejections by the body, since they are organic compounds already existing in the body. In this way, in addition to customer satisfaction with the product, the means of production in the area of medicine can be changed, in order to produce more accessible parts, which can be purchased in most cases, and can even be used in the Unified Health System (SUS).

Keywords: Additive manufacturing, 3D printing, Medical implants, Manufacturing engineering.

1 INTRODUCTION

Between the eighteenth and nineteenth centuries, the industrial revolution changed the world, so that manual labor began to be replaced by structured work with the use of machines. Such substitution is due to the fact of the constant search of investors and entrepreneurs for low costs and agility of processes. In addition, the minimization of errors and consequent rework was evident with the replacement of human labor by machines, since there were physical limitations and waste inherent to the human race. The trend of replacing machines with manual labor has grown since then, as it stands out as a great competitive advantage over the competition in a globalized world. And the recognition that a large part of the high manufacturing costs are concentrated in the development phase is at the origin of the concept of concurrent engineering or simultaneous engineering (ROZENFELD, 2006; KUSIAK, 1993).

In this context, additive manufacturing is beginning to attract the attention of various sectors of the economy, since it is a technology that stands out for being agile, less costly than some traditional processes and has the ability to develop complex geometric structures. In this way, additive manufacturing is understood as processes that were previously called rapid prototyping, precisely because of the rapid production of physical prototypes. In addition, it is popularly known as 3D printing, that is, from a software that allows the creation of geometric figures in three dimensions, it is possible to print a physical part with a certain chosen material (VOLPATO E CARVALHO, 2017; BEAMAN, 1997).

Additive manufacturing technology can be applied in several economic sectors, one of which is related to healthcare. Traditional medicine adopts imaging tests such as CT scans and MRIs to diagnose patients for diseases, injuries, and problems with internal organs. Similarly, additive manufacturing has been more widely used in production lines in various sectors, with the purpose of generating products equivalent to the products of normal production, but with lower operating costs, greater customization and shorter time (BEAMAN, 1997).

As these are characteristics that attribute competitive advantage, that is, as the characteristics of low costs, high reliability, customization and shorter time represent the consumer's search nowadays, additive manufacturing becomes attractive to several companies. Thus, the possibilities of using prostheses made of materials with low rejection by the body in reconstruction surgeries or implants are being studied.

Specifically, in order to use additive manufacturing in traditional medical processes, there must be the identification of the ideal materials and the type of approach that best apply to each process. In this context, there is the concept of biomaterials, defined by WILLIAMS (1987) as a substance or combination of two or more substances, pharmacologically inert, of synthetic or natural nature, which are used to improve, augment or replace, partially or totally, tissues and organs.

The medical-hospital sector, mainly linked to orthopedics, has the participation of design and engineering in activities that include biomechanics and three-dimensionalization through informatics, which allows a more detailed analysis and helps designers and orthopedists to develop new fixation systems, prostheses and materials, being able to reach the customization and production of dedicated and exclusive pieces.

This article aims at an exploratory analysis, which aims to establish the relationship between a CT scan and the 3D printing process, taking into account the type of biomaterial compatible with the process and that presents the lowest possible rejection rate by the patient's body. The case addressed for study will be based on an example of a craniofacial prosthesis.

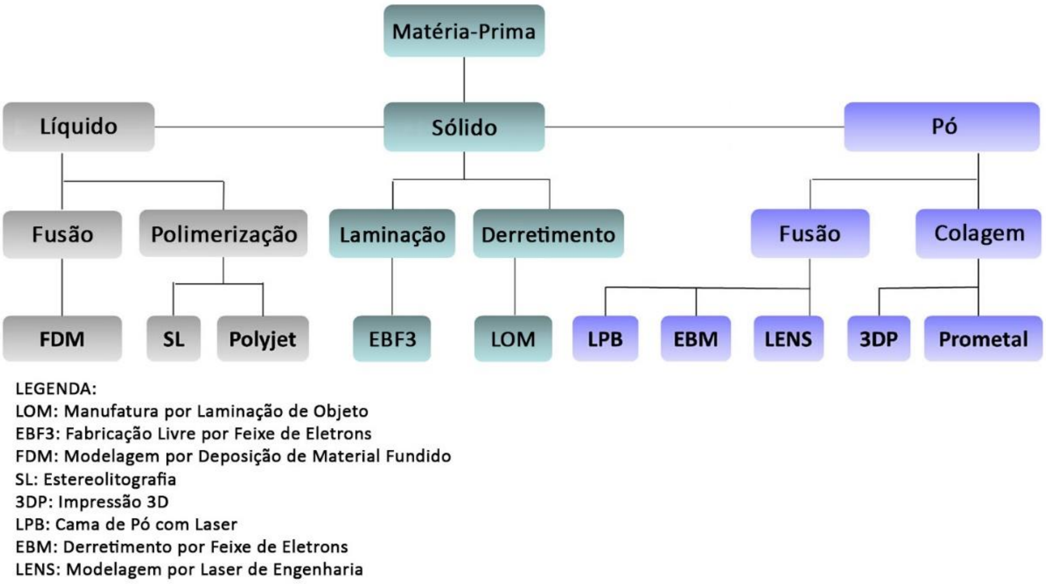
2 TYPES OF ADDITIVE MANUFACTURING TECHNOLOGIES

There are several ways to manufacture products through additive manufacturing (MONTEIRO, 2014; PHAM & GAULT, 1998). And the processes to be addressed in this work consist of the processes of stereolithography (STL), fused material deposition (FDM) and selective laser sintering (SLS) (Figure 1).

The process of Stereolithography (STL) occurs in such a way that a laser beam passes over a surface of a liquid photopolymer, which is sensitive to ultraviolet radiation, hardening when exposed. The beam travels along a certain path and, after finishing hardening a layer of photopolymer, a platform that supports the part descends a few tenths of a millimeter to start the process again with the liquid from the tank.

After printing, the material supports must be removed and, if necessary (depending on the type of material), there must be a UV oven curing.

Figure 1 – Types of additive manufacturing technologies



Source: Monteiro, 2014.

Another faster and more accurate way is to use laser beams working from the bottom up while the support platform rises as the layers are created. In this way, several lasers work together to trace the shape of the part with high resolution. However, as this technology can only print with a single type of material per piece and as the photosensitive polymers used are not yet as resistant as those used in the injection of plastics, the costs and complexity in the maintenance of this type of technology are significant, which opens up opportunities in the development of a market for low-cost models that use UV lasers (MONTEIRO, 2014; MELLO, 2006; PHAM & GAULT, 1998).

The molten material deposition (FDM) process works in such a way that a material in a plastic state is deposited on a platform through an extruder nozzle, which deposits the material on the entire contour of the section and, after it is finished, begins to fill the contour content in back and forth movements. As soon as the first layer is completed, the nozzle rises a few tenths of a millimeter and the second layer begins, and continues so on. The advantages of this process consist in the variety of materials that can be used (any material in a plastic state and that can be compressed by a nozzle to be extruded) and in the lower prices due to its simplicity of operation and ease of finding components on the market (MONTEIRO, 2014; MELLO, 2006; PHAM & GAULT, 1998).

The selective laser sintering (SLS) process is a technology that directs a high-powered laser beam onto a surface deposited with a powder, which is sintered to form a solid layer. After the first layer is made, a roller with the material deposits a new layer of powder, starting the process again. In this way, the process continues, layer by layer, until the part is finished. The advantages related to this process consist in the fact that the unmelted powder (unlike liquids) naturally serves as a support for cantilevered points in the part and can be reused in other works and, in addition, there is a wide variety of materials that can be used in this technology. However, the surface quality of this type of process tends to be porous due to the material used as raw material. In addition, it is a hot process, so you must wait up to a day for it to cool down and the piece can be removed from its interior (MONTEIRO, 2014; MELLO, 2006; PHAM & GAULT, 1998).

3 3D PRINTING PROCESS PLANNING

First, it is necessary to understand the main characteristics of the parts used and the materials that will be produced from the additive manufacturing process (FERREIRA et. Al., 2001). The first feature consists of the stair step effect, which can be understood as a deviation between the geometry of the 3D orientation and the one that will be obtained at the end of the process. The construction axis is the so-called Z axis, which is located vertically, and this deviation is observed on all surfaces inclined with respect to this axis. Reducing the thickness of the predetermined layers reduces the scale step effect, but does not eliminate it, since there is a minimum limit thickness (VOLPATO AND CARVALHO, 2017; FERREIRA et. Al., 2001; BEAMAN, 1997). Another characteristic is the deviations and dimensional errors in the orientation direction (Z-axis), since the height of the part used may not be multiple of the thickness of the layer used. Therefore, the dimension will undergo some changes. The anisotropy of the material is also an important characteristic, as the mechanical properties of the material produced by additive manufacturing are different when this same material is produced in the traditional way. This is due to manufacturing by adding layers and also because there are preferred directions on the XY axes. Normally, parts in which layers are added by the Z axis are less resistant than parts in which layers are added by the XY axis (GRIMM, 2005). Finally, another feature is the base and support structures. The concept is based on the addition of additional material in addition to the volume of the part to act as a base and/or support structure in order to fix the part on a build platform, preventing it from moving in manufacturing; it serves as an anchor to prevent warping of the workpiece; avoid damage during platform removal and compensate for unevenness (VOLPATO and SILVA, 2017; GRIMM, 2005).

In order to carry out a good process planning for additive manufacturing, in order to improve dimensional accuracy, surface finish and mechanical properties of the manufactured material and reducing manufacturing costs and times, specific tasks must be performed. Such tasks consist of: reading one or more 3D geometric models; orientation and positioning of geometry in the construction volume; application of the scale determined according to the process; computational slicing of geometry; calculation of the base and support structures; calculation of the filling for each layer according to the strategy and parameters of the process and generation of data to be sent to the technology (VOLPATO and SILVA, 2017; FERREIRA et. Al., 2001).

Basically, the steps of the additive manufacturing process consist of obtaining the geometric model, process planning, manufacturing and post-processing, so that, at the end of this sequence of phases, the part is obtained. In addition, process planning can be divided into four steps: orientation, positioning, and scaling; base and support structures; Slicing and planning of the trajectory or geometry of the contour and/or fill. (VOLPATO and SILVA, 2017).

In the stage of obtaining the 3D geometric model of the part, the geometry is prepared in the appropriate format for specific additive manufacturing technologies and in the STereoLithography (STL) and addictive manufacturing format (AMF) standards. This step is performed in CAD and in computer systems for processing images of computed tomography, magnetic resonance imaging or ultrasound (in the medical field) (VOLPATO and SILVA, 2017).

In the planning of the process, there is the beginning of the processes of orientation, positioning, application of scale factor, slicing, calculation of the base and support structures, calculation of trajectory and/or geometry of the contour and/or filling of the layers and generation of data to be sent to the additive manufacturing machine. All these tasks, with the exception of the calculation of the base, are necessary in all additive manufacturing technologies, and are performed by a CAM (computer aided manufacturing) system (VOLPATO and SILVA, 2017).

Also within the planning of the process, there is the process of choosing the orientation for manufacturing, which consists of the decision of how the part to be produced should be oriented in relation to the main axis of manufacturing (Z axis). Through this step, you can define the regions of the part that will be most affected by the stair step effect and anisotropy, as well as the precision of the details. In addition, the number of layers and the amount of support material required are determined, and it affects the dimensions, finish, and properties of the part, as well as the manufacturing time and cost. The scale factor is considered in the choice of orientation, in order to compensate for the contraction and distribution of the parts in the construction volume. In this way, there can be a production of a greater number of pieces simultaneously (VOLPATO and SILVA, 2017).

After the manufacturing orientation has been chosen, the placement in the build volume must be determined. Additive manufacturing technologies have batch process characteristics (the greater the number of parts that are manufactured in the same cycle, the lower the unit cost of each part), which involves a longer time to prepare the equipment or remove the part within safety parameters. The construction volume of the equipment is defined as the largest volume that can effectively be used to build a part and the shape is usually characterized by a parallelepiped with the dimensions of the base in the XY plane and height in the Z plane. 2017; FERREIRA et. Al., 2001).

Next, a scale factor must be applied to the 3D model in order to obtain the dimensions of the part as close as possible to the previously designed measurements. The need for the scale factor can be explained by the fact that the material can shrink in most additive manufacturing processes, especially in the final cooling of the processing. The scale factor is not always the same in all manufacturing directions due to the various forms of processing and its definition depends on a calibration process, i.e., an experimental process that determines the overall contraction of the material in each axis (VOLPATO and SILVA, 2017; MELLO, 2006).

Defining the basis of the support structure is also an important task. The reduction in the number of support structures depends on the orientation of the model in the most stable way possible at the base and with the least number of regions that require a base. From the identification of these regions, the geometry of the support used should be defined using the minimum possible use of resources. With the reduced number of structures, the processing time is shorter, so the total time in production will be reduced and, with the rationed use of resources for the support geometry, the cost of the process also tends to decrease (VOLPATO and SILVA, 2017; FERREIRA et. Al., 2001).

This is followed by the slicing step, which can be directly or indirectly. Direct shape slicing occurs directly on the mathematical surfaces of the CAD and therefore provides more accurate results by avoiding errors arising from indirect shape. This, in turn, works with the use of a triangle mesh and is more used in practice. First, there must be the definition of the thickness of the layer, remembering that the quality of the surface finish of the piece is so much better the lower its thickness. However, the construction time is longer, since there will be a greater number of layers (VOLPATO and SILVA, 2017).

Subsequently, there is the planning of the contour and/or fill path, which is defined as the path that delimits the visible external surfaces of the part. These are planned for the purpose of processing the material within the boundary limits of the workpiece and the possible supporting structures. Thus, this trajectory planning is directly related to the type of 3D technology used (VOLPATO and SILVA, 2017).

Then there is the manufacture of the part itself in the additive manufacturing equipment, which is usually automatic and unassisted, in which an operator is needed only at the beginning, set-up moments and at the end. Therefore, for better use of time and technology, there is the use of the strategy of producing at night. Some technologies can be used in offices, due to the low emission of noise and heat at the time of production, and others require a more appropriate environment (VOLPATO and SILVA, 2017; MELLO, 2006).

Finally, there is the post-processing stage, basically seen as an additional step necessary in each technology to control the quality of the parts produced. It can involve everything from manual actions to going through additional processes, such as machining and furnaces (VOLPATO and SILVA, 2017, MELLO, 2006).

4 BIOMATERIALS AND THEIR APPLICATIONS

A biomaterial is a substance or combination of two or more substances, pharmacologically inert, synthetic or natural in nature, which are used to enhance, augment or replace, partially or entirely, tissues and organs. To Azevedo et. Al. (2007), are any substances or combinations of substances, synthetic or natural, that can be used for a period of time, in whole or in part, as part of a system that treats, augments, or replaces any tissue, organ, or function of the body. The first generation of biomaterials was based on the search for inert materials, which would be ignored by neighboring tissues, without causing any inflammation or infections at the site. Later, researchers introduced the concept of bioactivity as the ability of some materials to bind to living tissues without the formation of fibrous layers that separate them from that same tissue. In this way, another class of biomaterials emerged: bioactives.

The criterion for selecting these biomaterials is based on the application for which they are intended. These can be synthetic polymers, metals, ceramics, and natural macromolecules (biopolymers) that are manufactured or processed for use in medical devices that come into contact with organic systems and molecules. These materials should be free from producing any adverse biological responses for the purpose of reducing infections. That is, the material must be non-toxic, non-carcinogenic, non-antigenic, non-mutagenic and non-thrombogenic. Such restrictions must exist in order to avoid infections and biodegradation in the patient's body.

In addition, high biocompatibility (the ability of a material to perform with an appropriate tissue response in a specific application) has made polymeric materials the main solution in the biomedical field and in the development of permanent or degradable implant devices. When any implant material is inserted into the body, several layers of proteins are created, which adhere to the surface of the implant and control the initial adhesion of cells through enzymatic processes. In this way, the interface with the implant is determined. According to Oliveira (2005), the adequacy of the material has a fundamental relationship with the integration of the material with the organism (host).

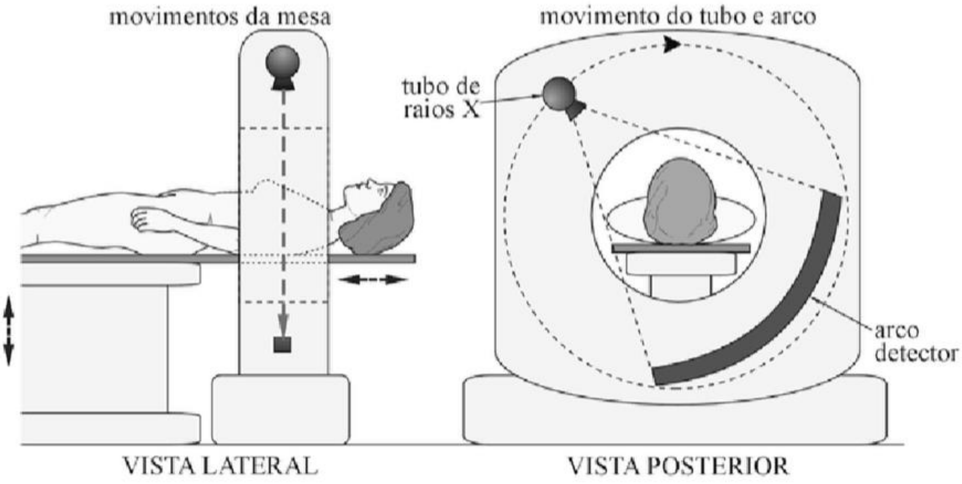
In general, biomaterials have several applications, such as hydroxyapatite, metals and metal alloys (such as titanium and its alloys), and polymers. Hydroxyapatite helps in the coating and bone implants and, among the bioactive materials, stands out for its similarity with calcium phosphates present in the mineral phase of bone, so it is studied for clinical purposes. However, its clinical use is limited, as it undergoes a slow biodegradation, around 4 to 5 years after implantation. As there must be the replacement of a bone in formation, the resorption of the biomaterial is a fundamental characteristic. When hydroxyapatite is implanted near the bone, it acts in two stages, the first as a prosthesis and the second as a support for tissue regeneration. It demonstrates a high degree of biocompatibility with both hard and soft tissues, especially for bone grafts (CARVALHO, 2010; OLIVEIRA, 2005). Due to its pores, hydroxyapatite allows the development of tissues inside it, with interconnection between the pores, favoring nutritional transport in the tissue and increasing the speed of growth. Metals and metal alloys, such as titanium and its alloys, are also extremely important in the medical field, with several applications, such as orthopedic implants, fracture plates and nails, and bone repair screws (OLIVEIRA, 2005). Alloplastic grafts are made up of synthetic or organic materials modified in laboratories, such as titanium. Its biocompatibility ensures successful implants in humans (PARR, STEFLIK & SISK 1993).

5 CT SCAN EXAM

CT scans are diagnostic tests characterized by images of a cutting plane that make it possible to study the structures found inside the body. These images can belong to different cut planes, such as the frontal, axial, lateral and inclined planes, and do not overlap. The Computed Tomography device is the device used to generate such images, by attenuating X-ray beams (CHEW et. Al. 2016; MOURÃO, 2015; BOYD, 2011).

Conventional tomography is a technique performed by X-ray machines whose tube emits beams while moving along a certain axis. Meanwhile, the image registration film moves in the opposite direction, in a synchronized manner and on the same axis. Between the film and the X-ray emitter is the object being studied. The chosen cutting plane is where the image will appear sharpest, since this plane remains at rest when the reference frame is the X-ray emitter and the film. The beams absorbed by the body of the object under study pass through different places, recording different information about the entire surface of the film. If the beams pass through the same point in the plane, they will be recording the same images, and if this occurs continuously, the image quality is good. The images recorded on the support axis through which the chassis and the X-ray tube move appear more clearly, and on this axis the anatomical section of interest to be recorded is determined. (MOURÃO, 2015). The CT scanner enables the acquisition of an image of an axial anatomical section with the aid of a computer. (CHEW et. Al. 2016; MOURÃO, 2015; BOYD, 2011). Unlike conventional tomography, the CT method uses an X-ray tube that emits radiation as it moves in circular trajectories around the patient, in order to generate the image, which does not take place directly on the radiographic film, but is captured by detectors positioned on a screen that moves in opposition to the radiation source. as shown in Figure 2.

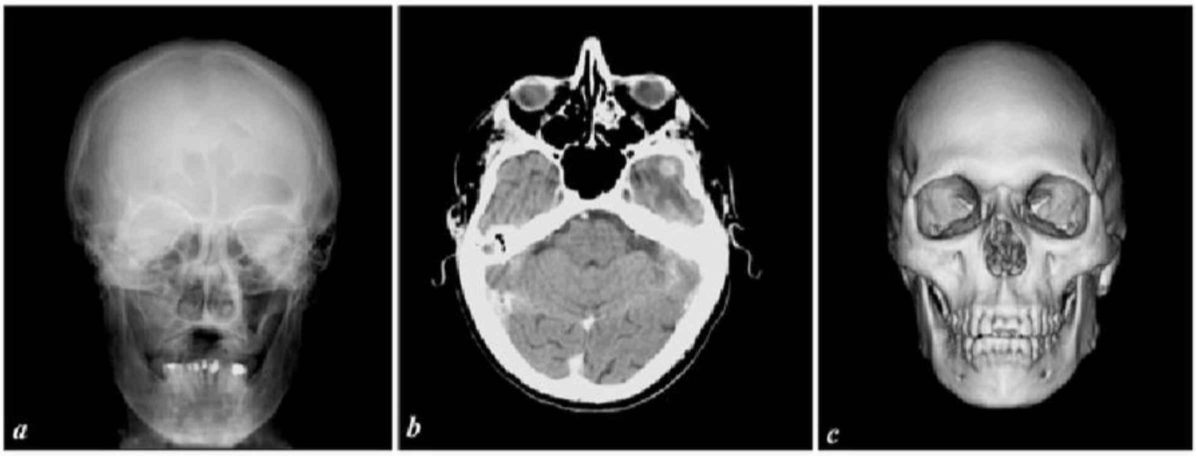
Figure 2 – Positioning of a patient in a CT scanner. Side view with table shifts and posterior view with movement of the X-ray all around the patient.



Source: Mourão (2015)

Figure 3 shows three diagnostic images of a head. One generated in conventional X-ray machines (a) and two (b and c) in Computed Tomography (CT) machines. It should be noted that the image generated in the X-ray equipment does not differentiate between the tissues, making it difficult to identify the soft tissues (brain tissue, eyeballs, cartilage, etc.). In the case of CT, this differentiation is possible, with no interference from posterior structures, as shown in Figure 9 (c), which optimizes diagnostic procedures (MOURÃO, 2015).

Figure 3 – Radiological images of the head. (a) frontal radiography; (b) axial cutting; and (c) front view.



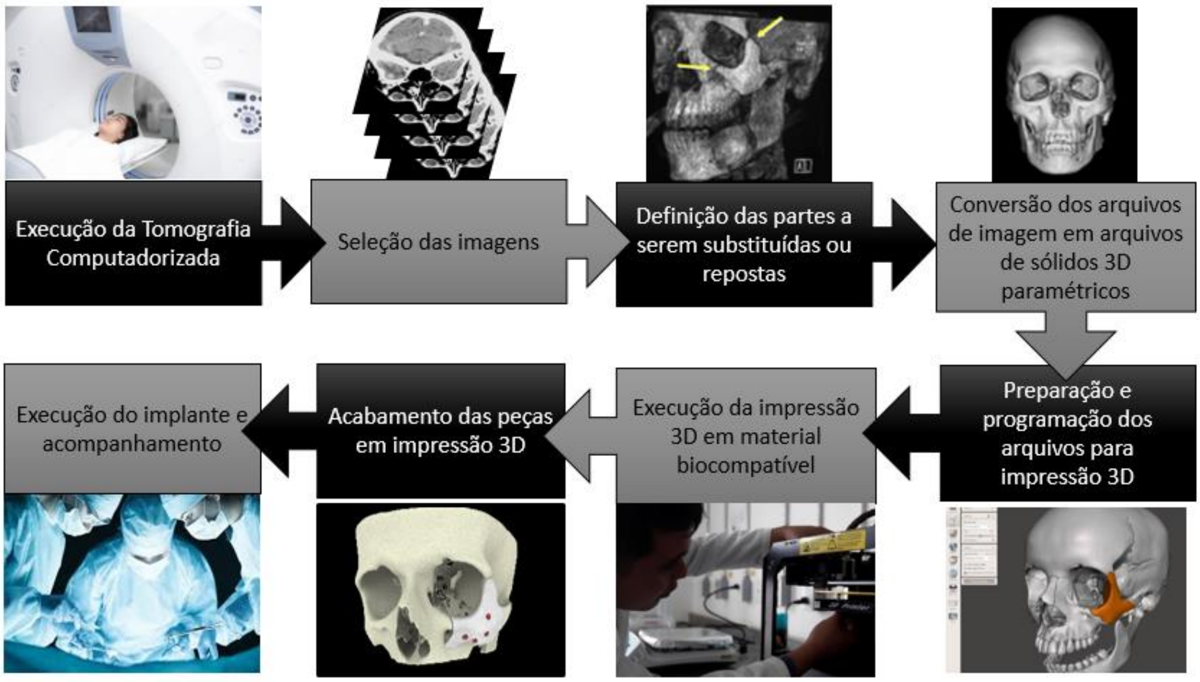
Source: Mourão (2015)

The computed tomography machine makes it possible to obtain an image with the aid of a computer. According to MOURÃO (2015), the method uses an X-ray generator tube that emits radiation while moving in circles or semicircles around the object of study. Instead of generating the image directly on the film, the radiation that passes through the object is captured by detector devices positioned opposite the X-ray source. The images are then reconstructed through various measurements at the system's positions in relation to the object and the data are converted into digital signals, which are sent directly to the computer. Because very flat beams are used to irradiate the volume, only a thin slice of the volume is irradiated at a time. The detectors pick up a portion of the beam that has passed through the object and generate an electrical signal, which is converted into a digital signal and sent to the computer. After acquiring a large number of measurements, the computer processes the information received to determine the portion of the beam absorbed and, subsequently, it will be able to construct a digital image that will represent the slice. In this way, it is possible to construct a computerized structure from several slices obtained by irradiation in the object of study. The colors and intensities of gray presented in CT scans depend on specific factors such as the X-ray absorption rate of each slice (CHEW et. al. 2016; MOURÃO, 2015; BOYD, 2011).

6 DEVELOPMENT AND DISCUSSIONS BASED ON EXPLORATORY RESEARCH

In order to develop an exploratory research based on the information obtained in the bibliographic reference of this work, and using as an example a case of craniofacial prosthesis, it is possible to plan the 3D printing process, as proposed in Figure 4 below.

Figure 4 – Proposed flowchart for the production system of bone system prostheses using 3D printing technology



Source: The Authors

As mentioned earlier, there must be tasks to be performed for the manufacture of the part, in order to ensure low time and costs and to ensure dimensional accuracy and mechanical properties. Such tasks make up the steps of the additive manufacturing process and will be analyzed for a case of craniofacial prosthesis.

As shown in Figure 4, after obtaining and selecting the images through computed tomography, the first task consists of creating the geometry, when one or more geometric models are read, since the method of scanning bones, cavities and desired organs is performed in slicing similar to the slicing used in the construction of the three-dimensional part by additive manufacturing. The precise measurements obtained through the diagnostic examination, which are image files, must then be converted into solid, parametric three-dimensional models through CAD modeling software, where they can then be edited and have their parts selected for future printing. At this point, files are converted into 3D-printable formats, such as STL (Stereolithografy) and IGES (Initial Graphics Exchange Specification).

The second task is to transfer the converted file to the machine via a direct connection, network, or USB stick. After the transfer, it is necessary to observe whether the size, position and construction orientation are correct. In the case of the construction of a craniofacial prosthesis, the orientation should be made in the X and Y axis, as explained above. The printer needs to have its work parameters well defined, such as the restrictions of the type of material that should be used, the power source, the thickness of the layer, the production times and speed.

From the point of view of manufacturing, manufacturing methods based on the technology used were presented. Taking into account a case of construction of a craniofacial prosthesis, the best manufacturing model and technology to be used should take into account the cost-benefit ratio and the availability of the technology. Another selection criterion should be the compatibility of the biomaterial with the printing process, with regard to the maintenance of its properties, whether in the melting temperature and mechanical forces of the FDM process, or in the presence of ultraviolet light, in the SLA process, for example.

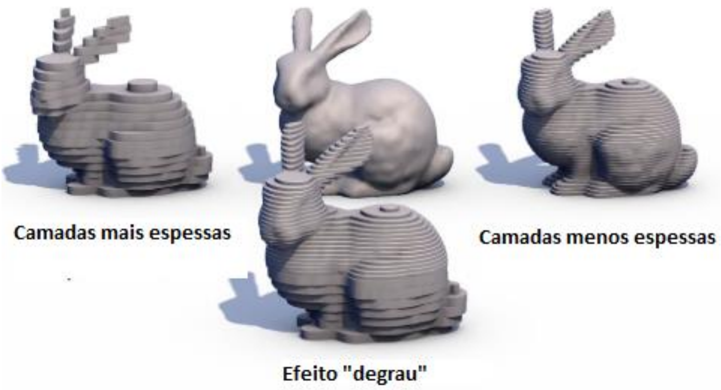
With the end of the construction of the part, there must be an interaction with the machine for the removal of some parts of the construction and measures to do this safely and without damaging the part must be taken before manufacturing. Removing the material must be extremely cautious, as the support and the workpiece itself may be fragile. An example is the construction of internal locks to secure the part to the construction shaft.

Finally, there must be post-processing, a task performed when the piece needs cleaning or finishing work, in order to make the piece acceptable to its final consumer or for its purpose. A craniofacial prosthesis must be made with a gigantic precision of measurements so that it can fit perfectly on the patient without major problems. Therefore, even with the measures taken to improve and reduce the error caused by some manufacturing effects, there must be a surface finish to ensure accuracy of measurements and product quality.

The first aspect to be analyzed is the stair step effect, which can compromise the quality of the final product if the layers used have great thicknesses (Figure 5).

As it is a craniofacial prosthesis for medical application, the chosen process must reduce as much as possible the irregularities that the stair step effect causes. Therefore, the print layers on the Z-axis should be as thin as possible. In addition, as the thickness measurement influences a variation, on the Z axis, of the desired dimensions for the part to be built, it is necessary to analyze whether the minimum measurement of the layers is multiple of the ideal size for the part.

Figure 5 – Step effect. Related to the thickness of the 3D printing layers.



Source: The Authors

If the measurement is not multiple, there will be a variation in the dimension of the piece in the Z axis. The anisotropy must also be analyzed so that the material has greater resistance to mechanical forces, since it is a craniofacial prosthesis, that is, there will be the replacement of part of the skull, characterized by an extremely hard bone with functions of protection of the internal organs. Therefore, one should opt for the addition of layers by the X and Y axes, since the addition of layers by the Z axis results in less resistant materials. In addition, support structures must be in place to prevent warping and part movements during manufacturing, in order to prevent handling damage, compensate for unevenness and use as few resources as possible to reduce manufacturing costs. Finally, the ideal biomaterial for the process is taken into account. The best use for a craniofacial prosthesis would be to replace bone tissue by consuming the biomaterial used by the body, without causing rejections by the patient's body. Therefore, there must be great biocompatibility, which makes polymeric materials as a solution for medical purposes, as long as they do not produce adverse biological reactions. In this context, hydroxyapatite can be considered as a good biomaterial for this purpose, since it helps in the covering of bone tissues and implants and stands out for its similarity with calcium phosphates present in the mineral phase of bone. In addition, hydroxyapatite is reabsorbed by the body and is a material that is extremely biocompatible with bone tissue.

7 FINAL THOUGHTS

The use of 3D printing technology for the production of parts in the most diverse areas will be increasingly common, since such technology may be able to achieve the desired precision with the reduction of costs and processing time. In the field of production engineering, such reductions in costs and manufacturing times are essential for companies to achieve their profit margin or productivity goals. Logistics as a whole benefits, so that costs previously used in the production of a part can be transferred to other areas of the production line according to need. In addition, the decrease in manufacturing time can be an essential competitive factor for the company.

The automation of a production line with the use of additive manufacturing technologies is possible, considering the aspects already highlighted in this work, that the printer has autonomy in manufacturing, with no need for action for the continuity of the process.

In addition to benefits for the producer, the benefits for the buyer and the consumer are related to the precision and personalization of production. When a part is handmade, manufacturing errors are more likely to occur, which is minimized in a 3D printing process. Therefore, for the consumer, the part projected onto the geometry will be very close to the actual printed part (according to the chosen manufacturing mode). In addition, depending on the purpose of the product, the consumer will have a personalized and exclusive piece, in order to meet needs, for example, in the health area.

Specifically in the area of health, this work confirms that the use of 3D printing in the production of prostheses, especially craniofacial prostheses, is an aspect to be taken into consideration, since, in addition to the compatibility of diagnostic tests, such as computed tomography, and the possibility of using an extremely efficient biomaterial in bone regeneration, the advantages are numerous. The patient will be able to have access to a cheaper prosthesis, fully customized for their case and that uses materials that promote the reduction of infections and rejections by the body, since they are organic compounds already existing in the body. In this way, in addition to customer satisfaction with the product, the means of production in the area of medicine can be changed, in order to produce more accessible parts, which can be purchased in most cases, and can even be used in the Unified Health System (SUS).

REFERENCES

VOLPATO, N. & CARVALHO, J. Manufatura aditiva: tecnologias e aplicações da impressão 3D. São Paulo, SP. Blucher, 2017.

AZEVEDO, V.; CHAVES, S.; BEZERRA, D. & FOOK, M. Quitina e Quitosana: aplicações como biomateriais. Remap - Revista Eletrônica de Materiais e Processos. v.2.3 p.27-34. Campina Grande, 2007.

BEAMAN, J.J. Historical Perspective, JTEC/WTEC Panel Report on Rapid Prototyping in Europe and Japan. 1997.

BOYD, S. Optical coherence tomography in macular diseases and Glaucoma: basic knowledge. Jaypee-highlights Medical Publishers Inc. Panamá, 2011.

CARVALHO, P. et al. Biomateriais aplicados à implantodontia. Implant News, v. 7, n. 3, p. 56-65, 2010. Disponível em: <http://hdl.handle.net/11449/133170>.

CHEW, F.; MULCAHY, H. & HA, A. Imaginologia musculoesquelética: estudo de casos. Barueri, SP. Manole, 2016.

FERREIRA, J. M. G. C.; ALVES, N. M. F.; MATEUS, A. J. S.; CUSTÓDIO, P. M. C. Desenvolvimentointegrado de produtos e ferramentas por metodologias de engenharia inversa e prototipagem rápida. 3ºCongresso Brasileiro de Gestão de Desenvolvimento de Produto, Florianópolis, 2001.

GRIMM, Todd. Choosing the Right RP System. A study of seven RP systems,2005.

KUSIAK, Andrew. Concurrent engineering: automation, tools and techniques. New York: John Wiley & Sons, 1993.

MELLO, P. *et. al*. Comparação de Três Diferentes Tecnologias de Prototipagem Rápida em Relação a Critérios de Custo e Tempo. XXVI ENEGEP - Fortaleza, 2006.

MONTEIRO, M. A impressão 3d no meio produtivo e o design: estudo na fabricação de joias. Dissertação: Programa de Pós Graduação em Design (PPGD) Universidade do Estado de Minas Gerais. Belo Horizonte, 2014.

MOURÃO, A. & OLIVEIRA, F. Fundamentos de radiologia e imagens. São Caetano do Sul, SP. Difusão Editora, 2009.

MOURÃO, A, Tomografia computadorizada: tecnologias e aplicações. 2 Ed. São Caetano do Sul, SP. Difusão Editora, 2015.

OLIVEIRA. P. Desenvolvimento e caracterização de biocompósitos de matriz polimérica de PHB reforçados com HAP-91. Dissertação. Programa de Pós-graduação em Engenharia de Materiais. REDEMAT. UFOP. Ouro Preto, 2005.

PARR, G.; STEFLIK, D. & SISK, A. Histomorphometric and histologic observations of bone healing around immediate implants in dogs. International Journal of Maxillofac Implants. V.8, p.534-540, 1993.

PHAM, D. T.; GAULT, R. S. A comparision of rapid prototyping technologies. International Journal of Machine Tools and Manufacture, No. 38, p. 1257-1287, 1998.

ROZENFELD, H. et al. Gestão de Desenvolvimento de Produtos – uma referência para a melhoria do processo. São Paulo: Saraiva, 2006.

THRE3D. Thre3D. THRE3D - 3D Printing, Simplified., 2014. Disponivel em: <https://thre3d.com>. Acesso em: 17 de agosto 2018.

WILLIAMS, D. F., Definitions in biomaterials: proceedings of a consensus conference of the European society of biomaterials, Elsevier, New York 1987.