COBEM 2023 27TH INTERNATIONAL CONGRESS OF MECHANICAL ENGENEERING

ABCM Brazilian Society of Mechanical Sciences and Engineering
27th ABCM International Congress of Mechanical Engineering
December 04-08, 2023, Florianópolis-SC, Brazil

COB-2023-0137
THREE-DIMENSIONAL IMPRESSION OF MODELS OF THE HUMAN MANDIBLE AND MANDIBULAR IMPLANTS

Felipe Estevão da Silva
felype_estevao@hotmail.com
André Crivellaro
andrecrivellaro7@hotmail.com
André Boregio Madey
madeiy@hotmail.com
Rafael Ferreira Gregolin
rfgregolin@gmail.com
Faculty of Engineering, Mechanical Engineering Course, Federal University of Grande Dourados (UFGD), Dourados (MS), Brasil.

Bruno Fontoura da Silva Colman
brunocolman@gmail.com
Ruís Camargo Tokimatsu
ruis.c.tokimatsu@unesp.br
Dept. of Mechanical Engineering, Paulista State University (UNESP), Ilha Solteira (SP), Brasil.

Abstract. *This paper shows how the technological advent of computational imaging tools and the use of computed tomography, combined with additive manufacturing, significantly influence cases of trauma in bone regions, with emphasis on mandibular trauma. It shows the difficulties encountered in the development and manufacture of a customized implant, due to the complexity of the bone geometry. This work seeks to manufacture in a 3D printer a model of the human mandible from a CT scan together with the development of a customized implant, showing the methodology of transforming DICOM files (CT scan) into a three-dimensional file of the human mandibular geometry. The goal is also to print the models of the mandible and the customized implant in order to perform a physical simulation of the coupling of the implant in the mandible. The results show the possibility of using additive manufacturing to develop customized implants, being an efficient and more attractive process, compared to conventional commercial prostheses, for doctors and patients, by producing customized prostheses adapted to the geometry that will receive the implant.*

Keywords: *Additive manufacturing, 3D Imaging Software, Oral and Maxillofacial Implants, ...*

1. INTRODUCTION

The technological advent of tomographic image acquisitions, allied to computer graphics and rapid prototyping, has had a great influence on the advance and development of new procedures in the field of medicine and biomechanics. At any given moment, novelties appear in the health areas that qualify the actions of prevention, diagnosis, and treatment of diseases. It is in this context that these tools contribute to positive prognoses, being of great relevance in this area.

The use of additive manufacturing (or 3D printing) has been an innovation in several fields, mainly in the industrial sector, however, its application is also in the health areas. In this sense, with the application of these resources for orthopedic treatments, several benefits have already been achieved, as they allow faster and safer treatments. Research and studies do not cease, bringing more and more innovations that facilitate the professional's work and increase patient satisfaction (Delvechio *et al.*, 2021).

The integration of the technologies of medical image acquisition and manipulation, CAD (Computer Aided Design), and rapid prototyping systems, together with the creation of multidisciplinary teams, has led to good results in the medical field. The prototypes resulting from this integration are now being used to simulate surgical procedures in advance, allowing the prediction of complications and problems that may occur during and after more complex interventions. These prototypes have also been used to make customized implant molds. Unlike machining processes, which subtract material from the blank to obtain the desired part, rapid prototyping systems generate the part from the gradual joining of liquids, powders, or sheets of paper. Layer by layer, from cross sections of the part obtained from the 3D model, rapid prototyping machines produce parts in plastics, wood, ceramics, or metals (Stoetzer *et al.*, 2011).

With advances in medical modeling software and with the help of additive manufacturing or 3D printing, it is now possible to design and manufacture implants with better precision, understanding the patient's needs, and also in less time. With this, the implementation of integrated techniques can also save a lot of money on medical expenses and renew the

quality of life for many people (S. Singare and Lu, 2009).

With regard to the jaw region, this area is still very challenging due to the strict requirements that are placed on the patients by the complex anatomy, the external profile and the optimal restoration of oral functions. Despite these challenges, the mandible is of paramount importance to the body as it is related to mastication, and other equally important functions such as swallowing, speaking and breathing, as well as defining the aesthetics of the lower third of the face (Lacerda *et al.*, 2018). That said, the main objective of the present article is the reconstruction of part of the patient's mandible, as well as the elaboration of a customized implant.

2. OBJECTIVE

This work aims to perform the computational modeling of the mandibular region through a computed tomography and manufacture, in 3D printing equipment, models of the human mandible and their personalized implants, suitable for the patient. Performing a surgical simulation fixing the implant made in 3D printing material (PLA, ABS, PETG) to the patient's mandible built by the same method, thus allowing a previous analysis of the patient's surgery.

3. METHODOLOGY

The study was designed using computers, software and 3D printers located at the Engineering Faculty of the Federal University of Grande Dourados (UFGD). The modeling of the implant and mandible have already been done in previous works allowing the fabrication of the parts in the current work.

To create the 3D model of the mandibular region using computed tomography, after importing the patient's images, it was necessary to previously clean the image using the 3D generation software (InVesalius). In this case, it is necessary to filter the image so that only the mandible is reconstructed in the 3D software. Thus, at first, the entire mandible must be reconstructed. After this step, the modeling of the mandibular prosthesis and implant must be done and the mechanical stresses imposed must be studied. Using 3D imaging software, it was possible to filter and edit the human mandibular image, making use of InVesalius, MeshLab, Rhino 6, Meshmixer and SolidWorks.

3.1 Cleaning and Selection

The InVesalius software was used to clean and select the region of interest in the mandible. To do this, the image was cleaned using the threshold selection tool, and a bone filter was placed so that only these were selected by the mask. This is possible because the software has a segmentation feature, thus allowing to select from the image only those pixels whose intensity is within the threshold defined by the user. There are also pre-defined threshold values according to the type of tissue, as is the case with the bone filter that works based on the result of the grayscale colors obtained in the CT scan. This filter works by selecting a threshold value range of colors in the grayscale spectrum as shown in Fig.1, then simply select the filter and the mask will select the bone regions automatically.

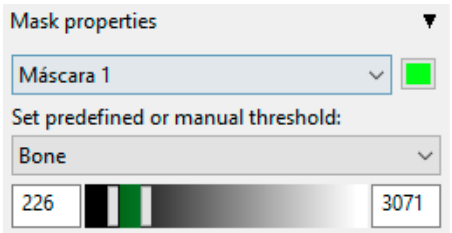
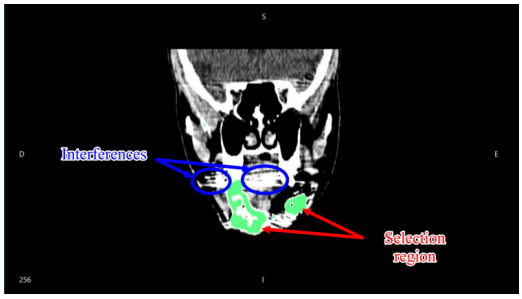
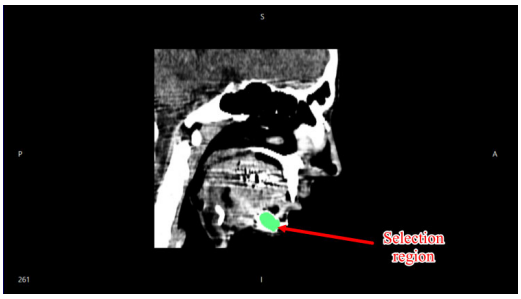


Figura 1: Threshold value range.

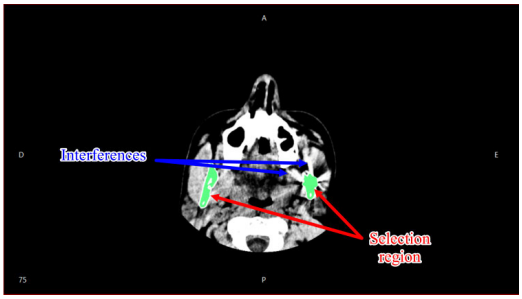
For more precise adjustments and finishing, threshold selection and manual adjustments were performed on each layer in the lateral view only. On the frontal and superior views, the interferences caused by light refraction on dental implants were removed, also manually with threshold adjustment, as they had the same color threshold as the bones and were captured in the automatic selection. This can be seen in Fig.2.



(a) Front view.



(b) Side view.



(c) Top view.

Figura 2: Views used for mask cleaning and adjustment.

Once this was done, the *.STL model was obtained as shown in Fig.3:

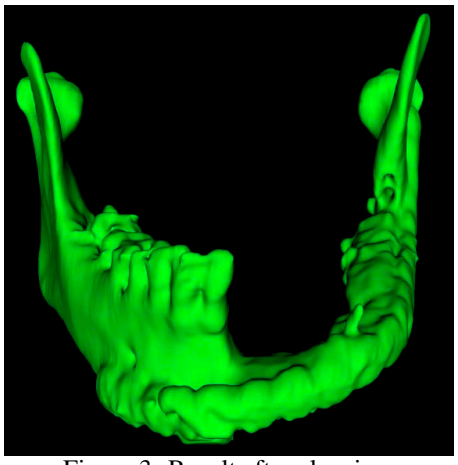
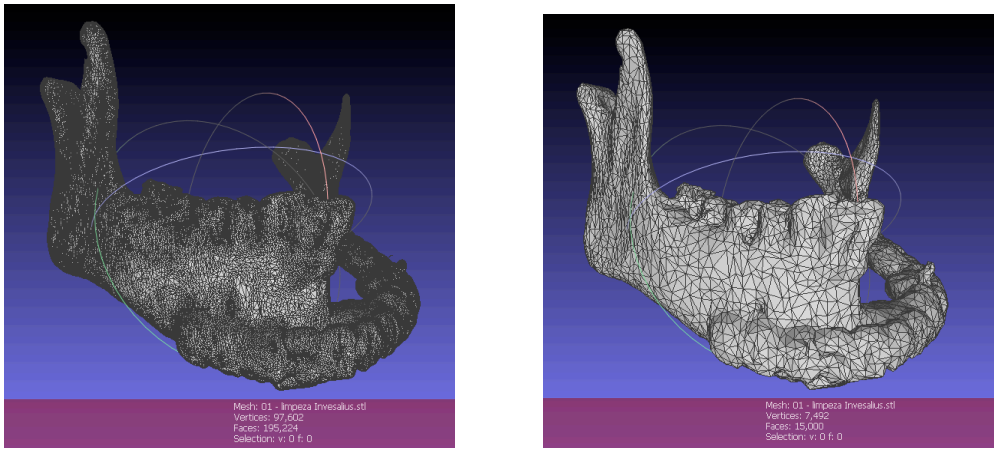


Figura 3: Result after cleaning.

After that, for an easier mesh edition, the MeshLab software was used in order to reduce the triangles that compose it, reducing this to 40000 triangles. This is still a reasonably high value, but it is necessary so that there is no loss in quality and no significant geometric distortions, resulting in Fig.4.



(a) Original mesh (195224 faces). (b) Reduced mesh (15000 faces).

Figura 4: Mesh reduction.

Subsequently, using the Rhinoceros software, the left side of the patient's mandible modeling was removed. To do this, the faces of the mandibular ramus along with the patient's existing prosthesis were removed using the Rhinoceros tool "delete mesh faces". Then, as the mesh was open, due to the removal of faces, the tool "fill all holes in the mesh"was used, resulting then in the image that is shown in Fig.5.

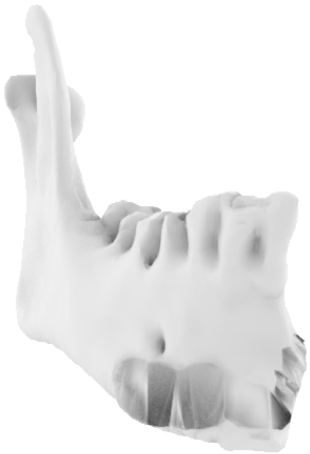
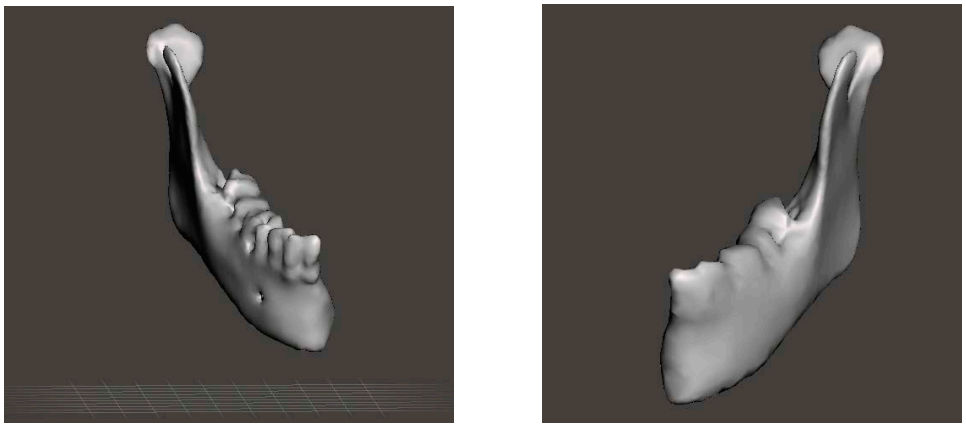


Figura 5: Result after face removal and filling.

3.2 Modeling

Manual mesh editing tools were used, for which some simplifications were made with case study bias. The left side of the patient's mandible was completely created by mirroring the healthy right side. Initially, tools available in the Meshmixer software were used to smooth the mesh of Fig.5, which ended up in a lateral mandible faithful to the real one, according to Fig.6.



(a) Characteristic side. (b) Side of the prosthesis.

Figura 6: Both sides of the jaw.

Note also that in Fig.6b, the resolution was reduced, because it is the prosthesis, and does not require a faithful mirroring of the characteristic remaining side of the patient's jaw.

After this step, and taking into account the non-symmetry between the sides of the mandible, SolidWorks software was used to make an extruded cut in the region of the teeth. This was done taking into consideration the fact that the prosthesis should only be made in the mandibular region, as the teeth would be made with other materials and a dental professional. This cut resulted in the image shown in Fig.7.

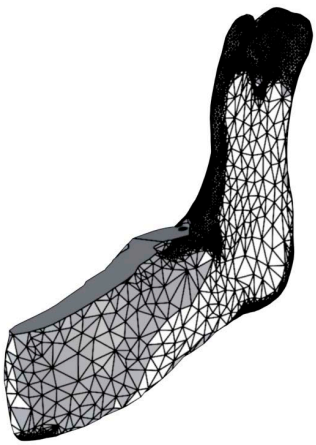


Figura 7: Adjustment made to remove the tooth chain.

After removing the teeth with the extruded cut, it was necessary to return the model to the Meshmixer to remove the sharp corners that this tool produces, resulting in the image shown in Fig.8, which is the geometry of the prosthesis before the anatomical adjustments required for the patient. For these adjustments, the original side of the mandible was used as the basis for the computational positioning of the prosthesis, thus making a Boolean union between the original side and the prosthesis in order to obtain a proper fit between the mandible and the prosthesis, as shown in Fig.9.

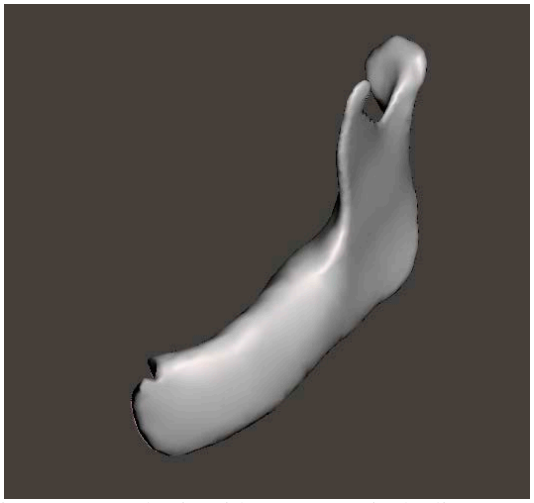


Figura 8: Prosthesis without anatomical adjustments.

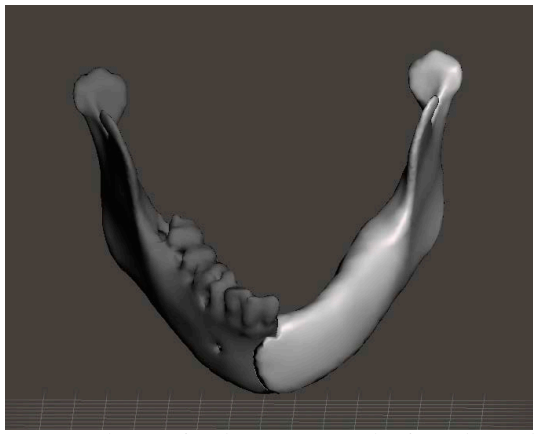


Figura 9: Boolean union between prosthesis and mandible.

After the adjustment and positioning of the prosthesis, we began the phase of creating the connecting structure between the bone and the prosthesis. It was made, using Solidworks and taking as reference the approximate curvature of the external side of the new mandible, a fixation plate that is responsible for firming the connection of the prosthesis with the bone. This plate is made with a titanium alloy (Ti6Al4V) with a thickness of 3.4 mm and with holes of 4 mm in diameter, resulting in the plate of Fig.10.

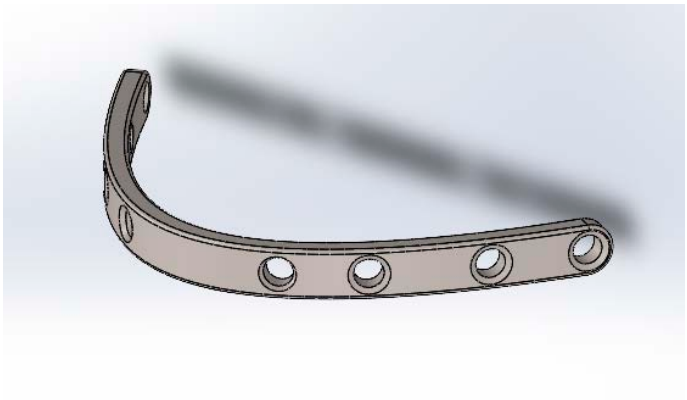
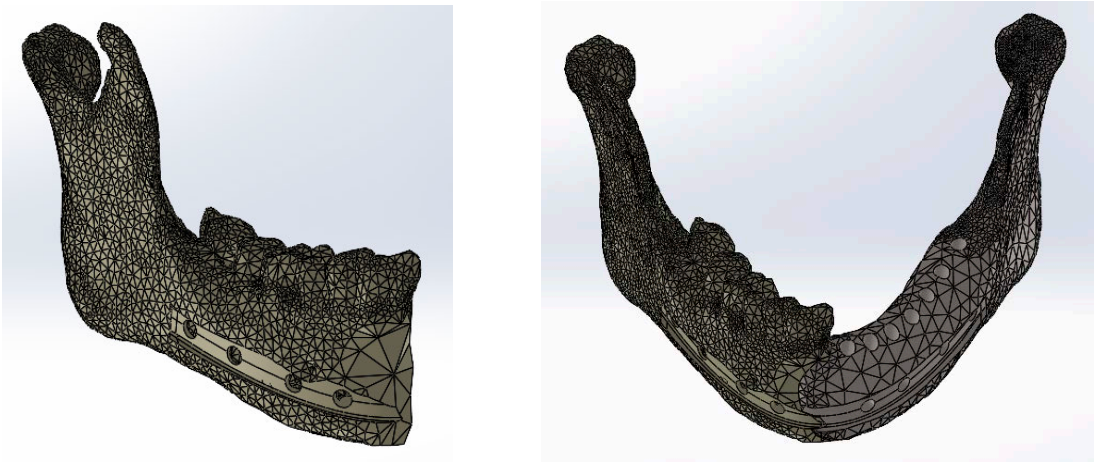


Figura 10: Titanium plate.

In the prosthesis, which is also composed of titanium alloy (Ti6Al4V), a roughing was made to fit the plate and also the holes were drilled, both those for fixing the plate and the holes needed for dental implants posterior to the prosthesis implant, as shown in Fig.11.

Figura 11: Final prosthesis.

Similarly to the prosthesis side, the bone would need to undergo a little thinning and also needs to be drilled for the attachment of the connecting plate, thus resulting in Fig.12.



(a) Modeled bone region. (b) Fit without the plate.

Figura 12: Detail of the mandible.

With this the complete prosthesis could be obtained, and the result can be seen in Fig.13.

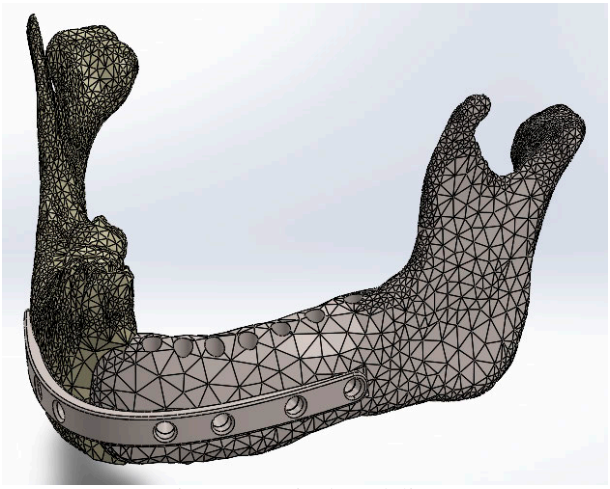
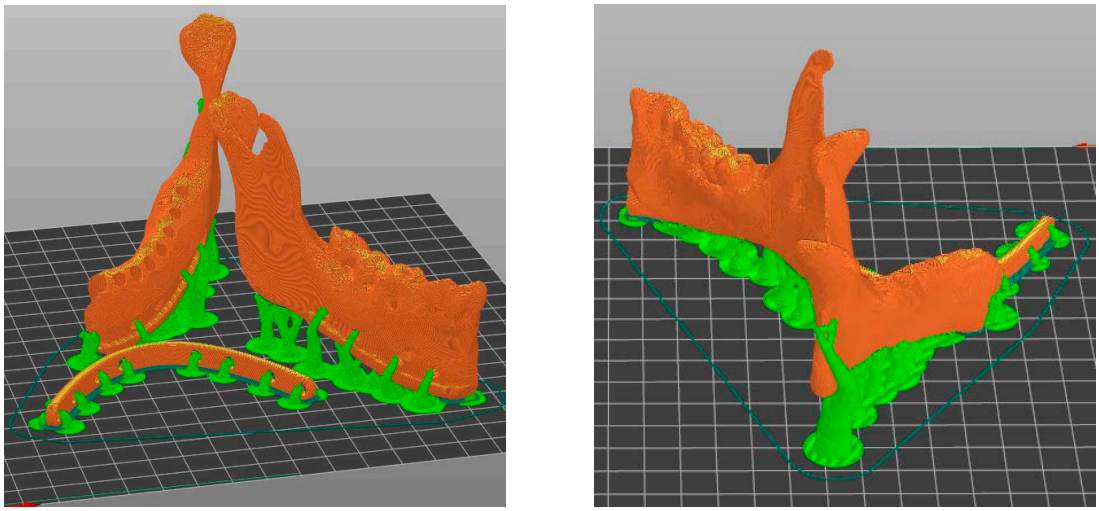


Figura 13: Final modeling.

4. RESULTS AND DISCUSSION

With the modeling ready, both of the mandible with the prosthesis and also the connecting plate, we went from the virtual model to the physical model, using the PrusaSlicer software and the GTMAX A1V2 3D printer to build the final result.

From this, it was necessary to plan the printing, having in mind a good surface finish in the additive manufacturing process. A priori the necessary properties that would serve as reference for the printing were studied, programming them in PrusaSlicer, according to the available filament, in this case PETG, according to the quality required in the printing (layer height, filling, supports, etc) and also according to the available printer, the 3D GTMAX A1V2. With this the arrangement of the models was made in an area equivalent to the printing table, the slicing of the model opting for support columns of the type "organic", these that are necessary for printing and also easy to remove. As a result of the slicing, we obtain the Fig.14



(a) (b)

Figura 14: Slicing for printing.

Finally, the printing was done and, as a result, the result shown in Fig.15 was obtained. It was not the expected result, due to the calibration of the printer that is possibly associated with temperature uncertainty or failure in the choice of parameters needed to print. However, a plausible result was still obtained, and can be used as a basis for studies in the development of mandibular implants. As a result, the printed model was fixed with commonly used screws, just for illustration, and also because the graft screw has a different geometry and material and is also difficult to access. The final result is Fig.16.

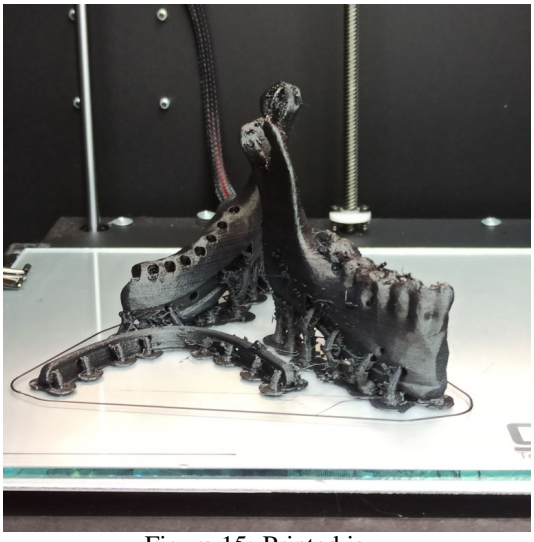


Figura 15: Printed jaw.

Figura 16: Mounted jaw

5. CONCLUSION

At the end of the study it became clear that it is possible to use additive manufacturing to develop customized implants, and that it is an efficient and more attractive process, compared to conventional commercial prostheses, for doctors and patients, by producing customized prostheses adapted to the geometry that will receive the implant. However, during the process, small dimensional differences between the models created and the geometry of the human skeleton were verified. These differences may be negligible, requiring further studies to confirm this thesis, or they may even be solved, if necessary, during surgery by the surgeon himself, minimally molding the patient's bone structure to receive the implant. A second option would be the improvement of the implant geometry, refining the models and thus avoiding any incompatibility of the impression with the proportions of the person who will wear the prosthesis in the future.

6. REFERENCES

Delvechio, V.U.B. *et al.*, 2021. "Desenvolvimento e analise estrutural de prótese de scaffolds para reconstrução mandibular".

Lacerda, I.D.R. *et al.*, 2018. "O uso de protótipos na cirurgia bucomaxilofacial: impressão 3d de uma mandíbula para o planejamento de ressecção mandibular".

S. Singare, Q. Lian, W.P.W.J.W.Y.L.D.L. and Lu, B., 2009. "Rapid prototyping assisted surgery planning and custom implant design". *Rapid Prototyping Journal*.

Stoetzer, M., Rana, M., von See, C., Eckardt, A.M. and Gellrich, N.C., 2011. "Reconstruction of defects of maxillary sinus wall after removal of a huge odontogenic lesion using prebended 3d titanium-mesh and cad/cam technique". *Head & face medicine*, Vol. 7, No. 1, pp. 1–3.

7. RESPONSIBILITY NOTICE

The authors are solely responsible for the printed material included in this paper.