

# BRIGT

**Erasmus+ strategic partnership for Higher Education**

**BOOSTING THE SCIENTIFIC EXCELLENCE AND  
INNOVATION CAPACITY OF 3D PRINTING METHODS**

**IN PANDEMIC PERIOD**

## **e -TOOLKIT 4 METHODOLOGY OF DESIGN AND RAPID MANUFACTURING OF MID- SURGERY SUPPLIES IN OTOLARYNGOLOGY (Fused Filament Fabrication and Vacuum Casting)**

<b>Project Title</b>	<b>Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period 2020-1-RO01-KA226-HE-095517</b>
<b>Output</b>	<b>O2 – BRIGT e-toolkit manual for digital learning in producing medical parts by 3D printing methods in the context of the pandemic</b>
<b>Toolkit</b>	<b>e-Toolkit 4 Methodology of design and rapid manufacturing of mid-surgery supplies in otolaryngology (Fused Filament Fabrication and Vacuum Casting)</b>
<b>Date of Delivery</b>	<b>November 2021</b>
<b>Authors</b>	<b>Filip GÓRSKI, Remigiusz ŁABUDZKI Magdalena ŻUKOWSKA, Mate BABIC</b>
<b>Version</b>	<b>Final Variant</b>

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

## Content

1.	Introduction .....	3
2.	Theoretical background .....	5
2.1.	Otolaryngology .....	5
2.1.1.	Oral tongue anatomy .....	5
2.1.2.	Cancer of the tongue .....	6
2.1.3.	Diagnostics .....	7
2.1.4.	Tumor removal surgery .....	7
2.2.	Medical imaging .....	8
2.2.1.	CT imaging .....	8
2.2.2.	MRI imaging .....	10
2.3.	3D printing in preoperative planning .....	11
3.	Work methodology .....	15
3.1.	Design methodology .....	15
3.2.	Manufacturing methodology .....	17
3.3.	DICOM medical imaging .....	18
3.4.	Segmentation of anatomical structures .....	18
3.5.	Processing the 3D mesh .....	20
3.6.	Design of matrices .....	21
3.7.	3D printing .....	25
3.8.	Casting of models .....	27
3.9.	Clinical evaluation .....	33
4.	Conclusions .....	36
	Acknowledgements .....	36
	References .....	36

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

## 1. Introduction

Otolaryngology is one of the branches of medicine dealing with the diagnosis and treatment of disease problems arising within the head and neck. This range also includes ailments related to the tongue and salivary glands [1]. Cancer of the tongue is one of the most common malignancies in the oral cavity. A tongue tumor can grow relatively quickly and spread deep into the muscles of the tongue [2]. It is recommended that the resulting lesions undergo tumor resection [3]. This procedure involves radical removal of the tumor, and the operation is highly demanding due to the difficulty of accessing the tumor, it may lead to trismus or massive bleeding.

After tumor resection, a cavity remains, which must be reconstructed using the patient's tissues. Failure to accurately reconstruct the language is associated with the following problems such as difficulty swallowing, problems with articulation, which can lead to psychological problems.

Proper preoperative planning is essential for successful tumor resection and tongue tissue reconstruction. Exercises on an individualized language model can significantly improve the work of medical personnel in preoperative planning.

The answer to the need for thorough preoperative planning is to create a personalized object that reflects the shape, size and mechanical properties of anatomical structures. One-to-one creation of an individualized model is possible and cost-effective thanks to the additive manufacturing technique. It is a modern technology that allows for accurate reproduction, low costs, even of small objects.

The subject of the work is to present the methodology of designing and rapid production of intraoperative aids in otolaryngology. This paper presents the analysis and selection of medical data processing tools, programs for their design, and a comparison of the manufactured intraoperative tools using various methods of additive technology or the use of different materials.

One of the initial assumptions of the work is the analysis and selection of medical data processing methods as well as the analysis of design tools and techniques for the rapid production of intraoperative aids. After the compilation of data, a project of intraoperative aids will be carried out with the use of various techniques of rapid production. The obtained models will be analyzed and assessed with the participation of medical personnel. On the

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

basis of the above-mentioned activities, the last step will be to develop a standardized methodology of conduct and recommendations for further development.

The forms of individual goals include:

- theoretical part, this chapter is devoted to the description of the most important terms mentioned in this work and to the presentation of the achievements so far in the field of intraoperative planning with the use of incremental techniques,
- a methodological part to present the concept of the project and to present the action plan in a descriptive and graphic manner,
- a validation part, containing the general assessment of the produced models, presenting the results of a survey conducted with the participation of medical personnel and comparing the data from 3D scanning of the resulting models with their virtual designs in order to capture shape change errors.

The input data used in this study were medical imaging performed by magnetic resonance imaging of a patient referred for a tongue tumor resection.

This toolkit is based on cooperation between engineers from Poznan University of Technology and doctors from Poznan University of Medical Sciences. It has been presented with great detail in a master's thesis cited in the acknowledgement section.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

## 2. Theoretical background

### 2.1. Otolaryngology

Otolaryngology, also known as otorhinolaryngology, is a science dealing with the diagnosis and treatment of diseases of the ears, nose and nasal sinuses, larynx (voice box), oral cavity and upper pharynx (mouth and pharynx), as well as structures of the neck and face [4]. Traditionally, in medical practice, treating the ear has been equated with treating the eye. With the development of ENT at the end of the 19th century, the relationship between the ear and throat was known, and otologists became involved with ENT specialists [5].

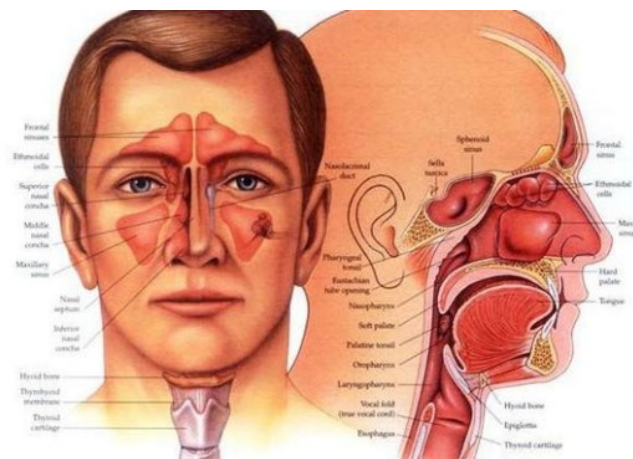


Fig. 2.1 Anatomical representation of otolaryngology [4]

#### 2.1.1. Oral tongue anatomy

The tongue (Latin lingua) is a muscular organ in the mouth of vertebrates. Language is the organ of communication, speech, and articulation, and is the main structure that shapes and controls food during chewing and swallowing. It is a complex muscular structure covered with a specialized layer of mucosa, anatomically composed of twin structures such as muscles, veins, arteries and nerve supplies that connect to each other in the lingual septum [6].

The tongue is covered with moist pink tissue called the mucosa. Small bumps called papillae give the tongue a rough texture. Thousands of taste buds cover the surfaces of the nipples. The taste buds are a collection of nerve-like cells that connect to the nerves that go to the brain [7].



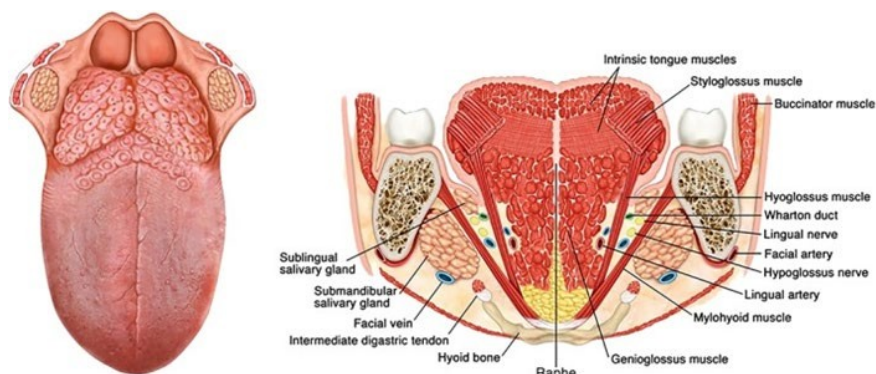


Fig. 2.2 Graphical representation of the anatomy of the tongue [8]

The tongue is anchored in the mouth with a net of hard tissue and mucosa. The loop that holds the front of the tongue down is called the frenulum. At the back of the mouth, the tongue is anchored to the hyoid bone [9].

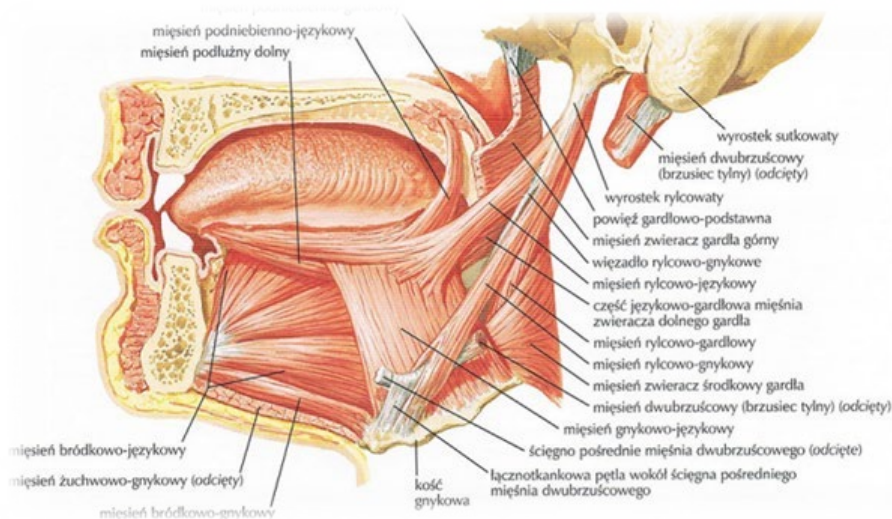


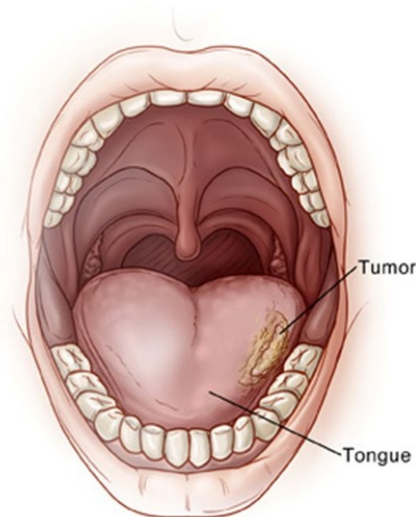
Fig. 2.3 Anatomical representation of the lateral side of the tongue

### 2.1.2. Cancer of the tongue

Oral cancer appears as a growth or pain in the mouth that does not go away [10]. Oral cancer, which includes cancers of the lips, tongue, cheeks, floor of the mouth, hard and soft palate, sinuses, and pharynx (pharynx) can be life-threatening if not diagnosed and treated early on.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Oral cancer is treated in the same way as many other cancers - with surgery to remove cancerous growths, followed by radiation therapy and / or chemotherapy (medications) to destroy any remaining cancer cells [11].



*Fig. 2.4 Oral cavity with cancer of the tongue [11]*

### 2.1.3. Diagnostics

The diagnostic test begins with an interview with the patient and an otolaryngological examination, i.e. an examination performed by an ENT doctor. Diagnosing a tumor in a person with tongue cancer is very difficult as pain, drooling and tongue immobilization are common. It is also difficult to detect metastases and determine the resection area [12]. In order to accurately diagnose the patient, modern imaging methods such as MRI or CT should be performed [13].

### 2.1.4. Tumor removal surgery

The term "glossectomy" is used to describe various surgical procedures for resection of tumors in the tongue [14].

Over time, the technical methods of tongue cancer resection have evolved. In the last century, most early and intermediate stage cancers of the tongue have been treated by partial glossectomy with a margin of approximately 0.5-1 cm from the macroscopic borders of the tumor [15]. At the beginning of this century, the more common approach was a broad resection with a larger free margin of macroscopic (1.5–2 cm) [16].

Today we can better plan the removal of tumors from the tongue thanks to a better understanding of the superficial and deeper local spread of the tumor along muscles, nerves

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

and vessels. Improving imaging techniques that allow surgeons to assess the involvement of each muscle, nerve, and veins in the tongue.

Complete tumor resection is an axiom of oncological surgery. Oral cancer ablation is difficult due to its anatomical, functional and aesthetic nature. Anatomical surgical planning plays an important role in achieving complete resection. The use of cross-sectional imaging, anatomical features and spatial awareness of the tumor is extremely important in planning oral cancer resection.

Usually, an indispensable step in removing a tongue tumor is also excision of the muscles and mucosa. After the procedure, a cavity remains, which is reconstructed with the patient's own tissues. A flap is collected in the form of a skin fragment with vessels from the neck, forearm or thigh. Once the wounds have healed and the rehabilitation process is complete, the patient can move his tongue, swallow, and communicate properly [3].

## 2.2. Medical imaging

### 2.2.1. CT imaging

Computed tomography scan is a medical imaging technique used in radiology for the non-invasive acquisition of detailed body images for diagnostic purposes. Personnel performing computed tomography are called radiologists or radiology technologists [17, 18].

CT scanners use a rotating X-ray tube and a row of detectors placed in a gantry (peri) to measure the attenuation of X-rays by various tissues inside the body. Multiple X-ray measurements taken from different angles are then processed on a computer using reconstruction algorithms to produce tomographic (cross-sectional) images of the body. The use of ionizing radiation sometimes limits its use due to its adverse effects. However, CT can be used in patients with metal implants or pacemakers for whom MRI is contraindicated [19].





*Fig. 2.5 The course of the CT examination [20]*

During the test, data is entered into the computer's hard drive. The information obtained from the x-rays is processed by computer to obtain an easy-to-read image. With the help of a complex analysis, taking into account the amount of radiation absorbed during the irradiation of the object from a given side, black and white images are generated showing the cross-sections of the examined organ. Moreover, computer processing is possible to obtain a spatial reconstruction of given organs. Each of the sections is divided into small parts - voxels, representing a fragment of the imaged volume. Each voxel is assigned numerical values proportional to its absorption of radiation [21].

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

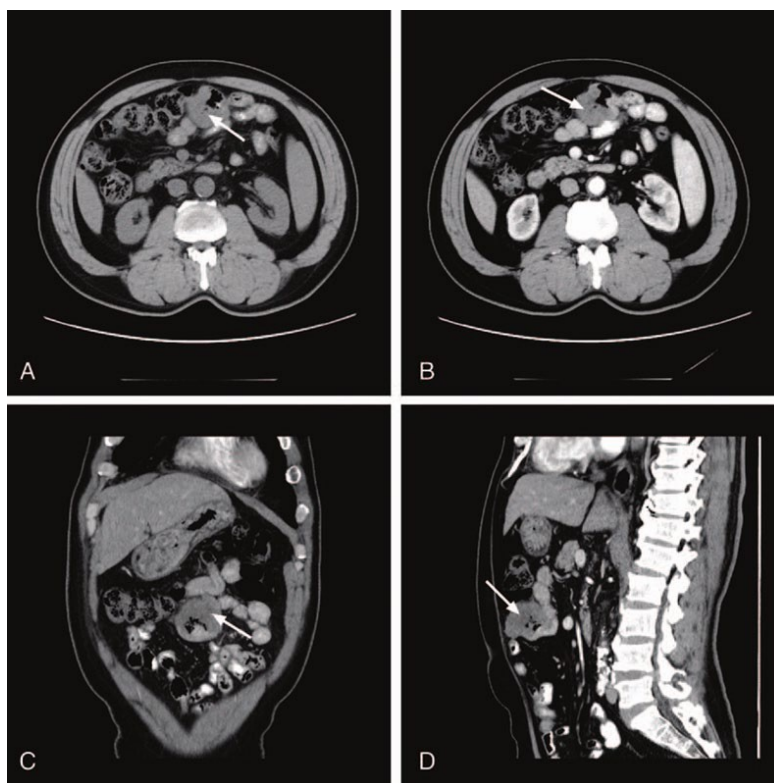


Fig. 2.6 Example of CT imaging result [22]

### 2.2.2. MRI imaging

Magnetic resonance imaging is a technique used in radiology to create images of the anatomy and physiological processes of the body. MRI scanners use strong magnetic fields, magnetic field gradients, and radio waves to generate images of organs in the body. During this imaging, no harmful X-rays or ionizing rays are produced, which distinguishes them from CT and PET scans [23].

MRI imaging enables excellent soft tissue differentiation, contrast, high spatial resolution and does not use harmful radiation. These features make MRI a valuable tool in the clinical and surgical environment, particularly useful in the diagnosis of neoplastic lesions [24].

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

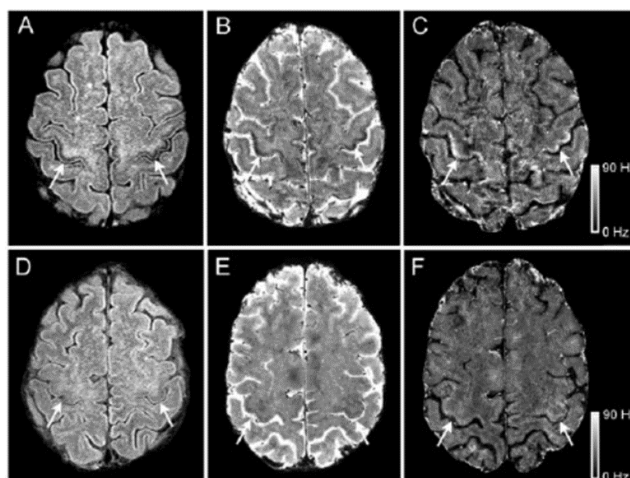


Fig. 2.7 Result of MRI of the brain [25]

### 2.3. 3D printing in preoperative planning

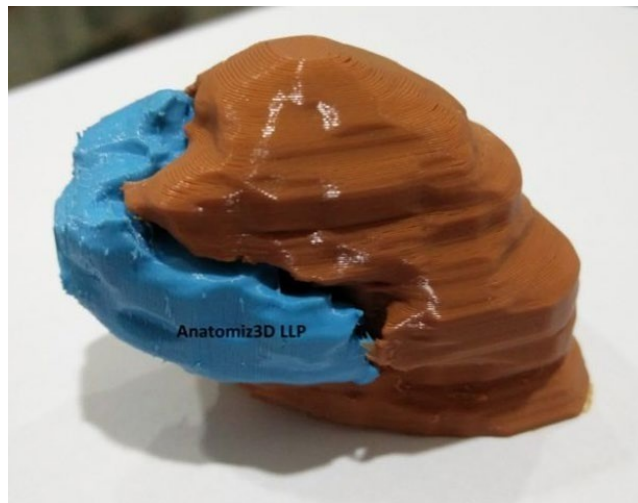
At the Greenberg Women's Health Center in the Ottawa Hospital, Maureen was treated. She had nearly 50 fibroids and did not want to undergo a hysterectomy, a complete removal of the uterus, so that she could become pregnant in the future. To this end, doctors contacted the hospital's 3D printing laboratory. Based on medical imaging data, a model was printed using acrylic and plastic. Multiple fibroids in the uterine cavity made printing very difficult and each had to be identified to recreate the exact anatomy on a 3D-printed model. Doctors commented that having the 3D model was tremendously helpful and provided a good visual aspect. The model and images from the imaging were also used during the operation itself, as the doctors could rotate the image of the uterus at any angle and degree so that they could see the object from different perspectives, which was helpful during the operation. The 3D-printed models not only help surgeons, but also help patients like Maureen understand their disease and prepare for surgery. For patients, seeing a 3D model of the problem inside their body makes it tangible and real. The operation was a success and the hospital is already working on similar projects to provide women with alternatives for complicated surgeries [26].

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



*Fig. 2.8 3D model of the uterus with myomas [27]*

In India, a patient with a tumor of the tongue was cured at the HCG Cancer Hospital, which specializes in the treatment of malignant tumors, thanks to the use of 3D printing. A 53-year-old woman had an extensive malignant tumor of the tongue, which was much larger than expected prior to the medical imaging analysis. As the team had difficulties in planning the operation, it was decided to use the Anatomiz 3D software to design a model and then print it.



*Fig. 2.9 Printed model of the tongue with its tumor [28]*

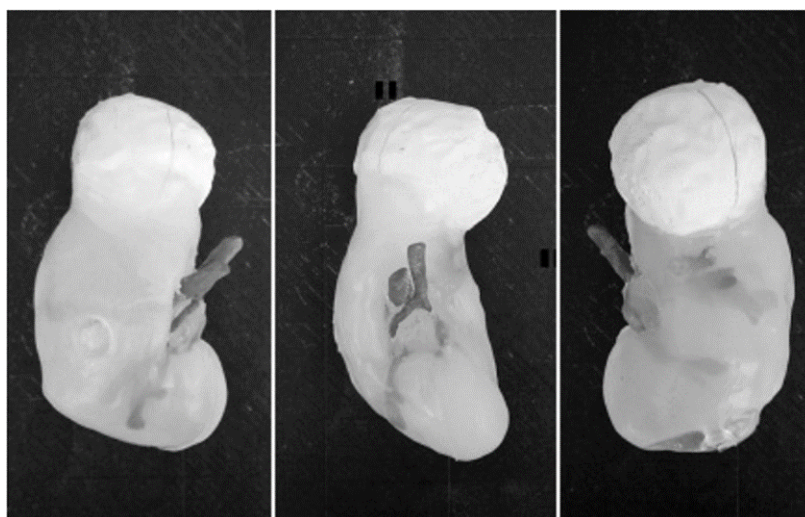
For this, flexible materials were used and two separate, matching parts in different colors were printed and folded together. The model helped to understand the anatomy, depth, size and position of the tumor compared to the tongue. As a result, the staff was better prepared,

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



and the patient himself was properly acquainted with the course of the surgery thanks to the presentation of the printed models [29].

At the Poznań University of Technology, in order to create an appropriate intraoperative aid, an anatomical model of the kidney was designed, together with its tumor and blood vessels, which were then produced using rapid prototyping techniques. Models were also designed on the basis of medical imaging and then processed in dedicated programs. However, in this case the final model was not completely printed, here a mold, tumor and blood vessels were produced by rapid prototyping techniques. The printed parts were attached to a matrix and then covered with a silicone material resembling the structure of the kidney after solidification. The model reflects the personalized nature of the organs and tumor of a given patient [30].



*Fig. 2.10 Finished kidney model [30]*

In the Małopolska Ultrasound Workshop, models are used to diagnose fetal heart defects developed by Dr. n. med. Marcin Wiecheć and the company GRID in Krakow. Examination of the fetal heart is very difficult because the organ contracts with a high frequency, which is difficult to interpret only by ultrasound, and the fetus often changes its position, making it difficult to diagnose any heart defects. Initially, during the first training trials, the doctors used only 2D and 3D images made with the use of ultrasound. However, this message was found not to influence doctors sufficiently. To stimulate the imagination of gynecologists, it was decided to create 3D models that can be further unfolded thanks to the introduced magnets. It should be added that these models not only have a positive impact on the education of

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



doctors, but also patients, and in this case parents are able to understand the problem in a much better way, which was not easy only when presenting 2D diagrams or images [31].



*Fig. 2.11 3D model of the fetal heart [32]*

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

### 3. Work methodology

#### 3.1. Design methodology

MIMICS is a medical engineering software based on 3D images that converts an image into a 3D model and allows you to scale objects. Opportunities for participation in this program range from research and development to major clinical operations [33].

3D Slicer is computer software designed to solve advanced problems related to image processing, with an emphasis on clinical and biomedical applications. Development platform for rapidly building and implementing custom solutions for research and commercial products using free and open source software [34].

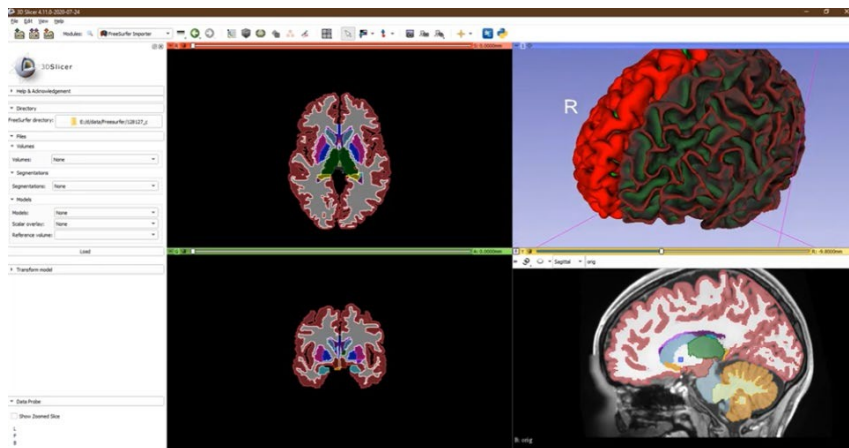


Fig. 3.1 Introduction to the 3D Slicer program [34]

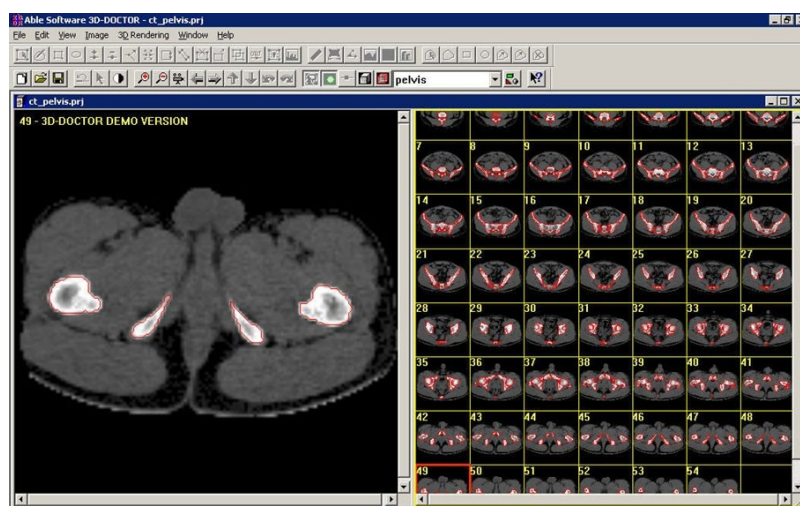


Fig. 3.2 Presentation of the program in the demo version of 3D-Doctor [35]

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

InVesalius is a free medical software for generating virtual reconstruction of structures in the human body. Based on two-dimensional images obtained with computed tomography or MRI equipment, the software generates virtual three-dimensional models corresponding to the anatomical parts of the human body. After building 3D DICOM images, the software allows you to generate STL files. These files can be used for rapid prototyping [36].

For research purposes, the InVesalius program was used in this work. It meets all the requirements needed for the research, allows you to change the format and segment the structure in 3D. The program is available in a free version and its use is very intuitive.

Meshmixer is a prototype design tool based on high-resolution dynamic triangle meshes. We are exploring new possibilities for this surface representation for interactive design and manufacturing in the context of a practical system that we make available to the public.

Blender is a free and open source 3D computer graphics toolkit used to create animated movies, visual effects, art, 3D printed models, motion graphics, interactive 3D applications, virtual reality, and computer games. Blender features include 3D modeling, UV unwinding, texturing, raster graphics editing, rigging, and skinning, fluid and smoke simulation, particle simulation, soft body simulation, sculpting, animation, match moving, rendering, motion graphics, video editing and composing [37].

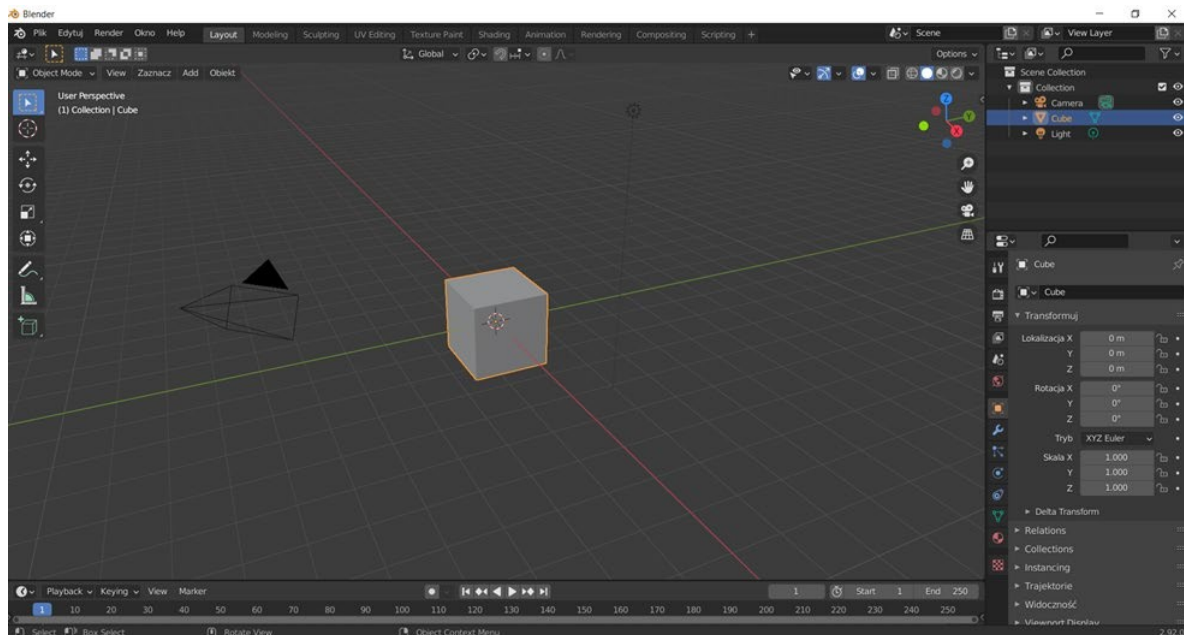


Fig. 3.3 Blender software window view

Due to the ease of use, the Meshmixer system was selected for the purposes of the study.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

### 3.2. Manufacturing methodology

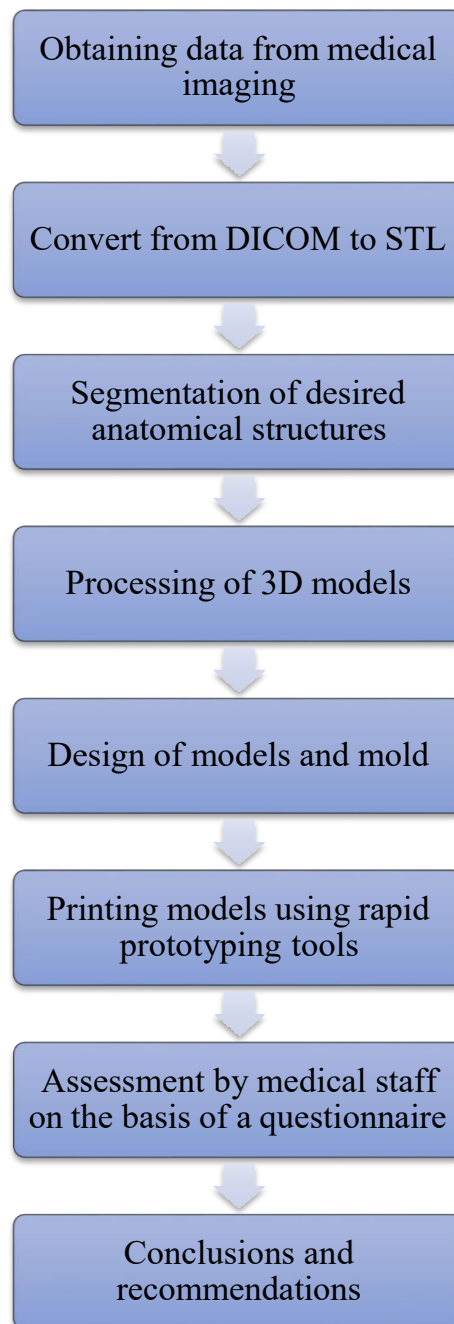


Fig. 3.4 Diagram of the organization of the conducted research

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

### 3.3. DICOM medical imaging

On the basis of cooperation between the Poznań University of Technology and the Clinical Hospital of Heliodor Świącicki of the Medical University of Karola Marcinkowski in Poznań, the data provided in the form of DICOM from MRI imaging for the conducted research was one of the patients. These photos show an MRI of the head, and the area of interest is the tongue and the tumor of the tongue. One of the first steps was to import data from imaging to InVesalius 3.1. It enabled the conversion of the file from the DICOM standard to the STL format and setting the parameters, the thickness of a single layer is 1 mm.

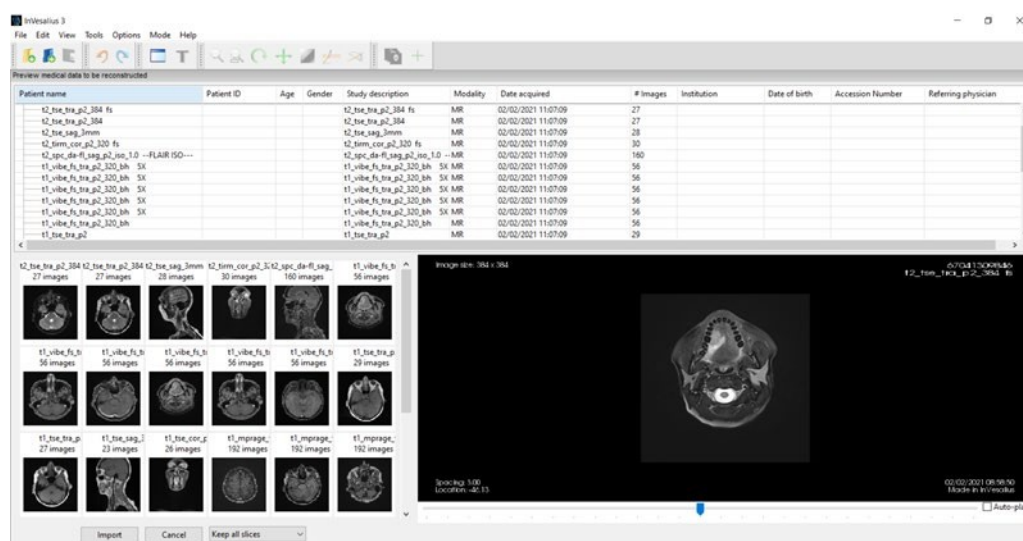


Fig. 3.5 Data import in InVesalius 3.1.

Data import to the program allowed to generate images of the skull as a 3D model, which made it easier to locate and measure the structures of the tongue and its tumor. The malignant neoplasm of a given patient is located on the right side of the tongue, however, the complete diagnosis of the lesion was relatively difficult, therefore a radiological consultation was performed for this purpose.

### 3.4. Segmentation of anatomical structures

Then in InVesalius 3.1. the segmentation of the structures of the tongue and its tumor was carried out. Various taskbars appear on the screen after the data is imported. On the left side you can see the image manipulation tools and on the right side there are windows showing the same three-dimensional image in 3 different planes. There are sliders next to each of the

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



windows, which are used to change the viewed cross-section. Below is a 3D image of a patient's skull with a tongue tumor.

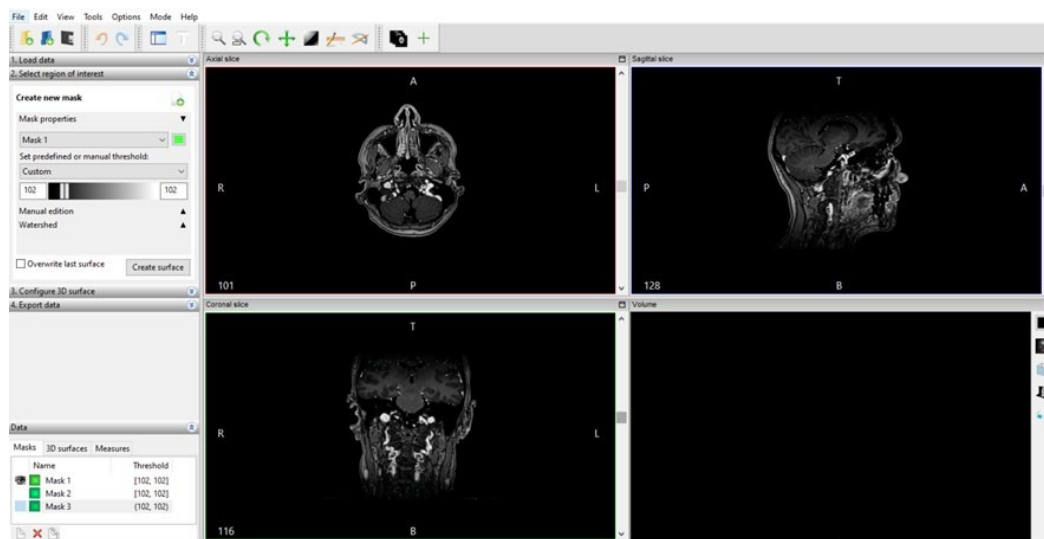


Fig. 3.6 Presentation of imported files in the InVesalius program

In order to segment the structures, it was necessary to set the appropriate mask properties, so as to manually perform the segmentation, layer by layer, of anatomical structures such as the tongue and the tumor of the tongue. For this purpose, the predefined or manual threshold has been selected as custom in the properties of the mask, so that in the further happiness of segmentation, you can only change the type and size of the brush or the erasing element.

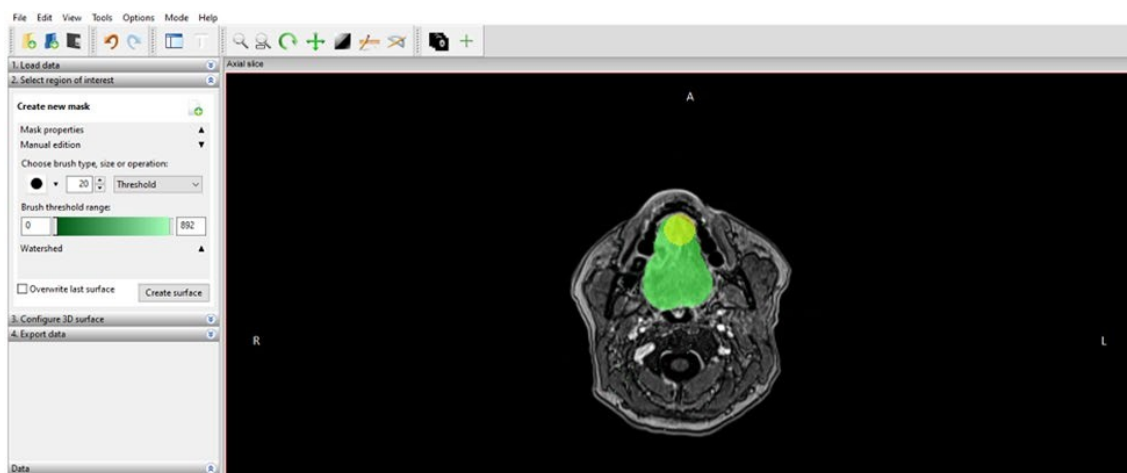


Fig. 3.7 Screenshot taken during tongue segmentation

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

The effects of the work described above are presented below:

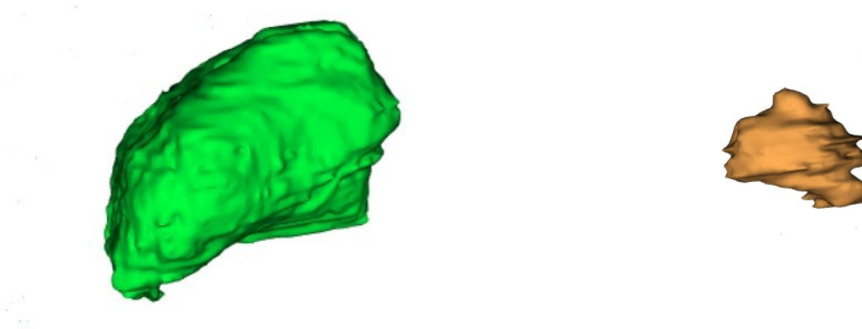


Fig. 3.8 On the left side there is a segmented model of the tongue and on the right side is its tumor

Since the segmentation was based on the isolation of structures layer by layer, the models are characterized by significant inequalities. These structures are not yet suitable for printing or for creating casting matrices, so the next step will be to process the model.

### 3.5. Processing the 3D mesh

In order to make the models as real as possible and to facilitate the printing of individual models, they were processed using the GOM Inspect Suite system. For this purpose, several functions were used, such as smoothing, selecting surface triangles, closing holes interactively/automatically. The most frequently used function when machining models was smoothing, you can find it by opening the operation options and going to the mesh, as shown in the figure below

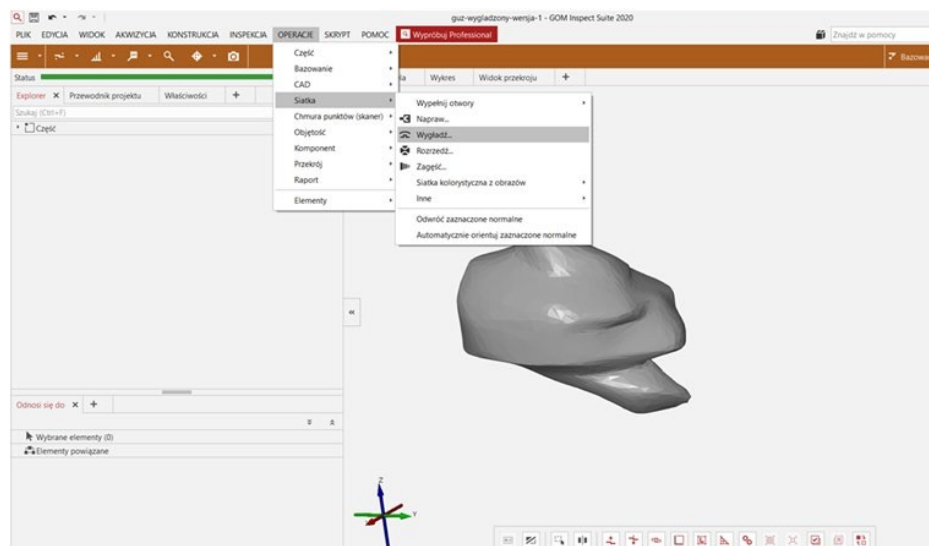


Fig. 3.9 GOM Inspect Suite

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

The results of the operations performed for both models are presented below:

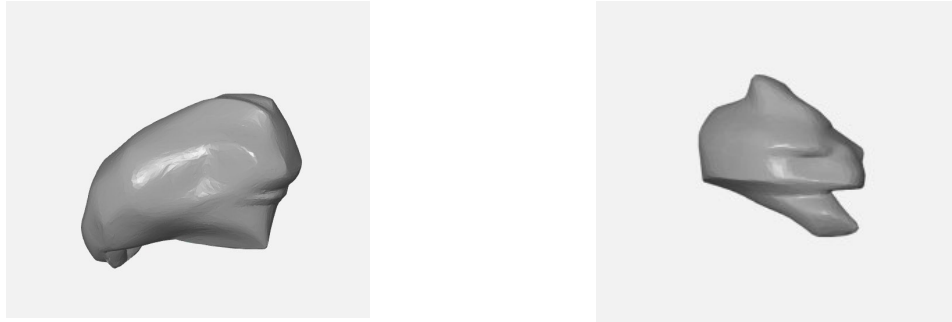


Fig. 3.10 The final effect of machining the models from the left tongue on the right tumor

### 3.6. Design of matrices

The last of the design elements was the preparation of molds for the tongue with the tumor and the tumor itself. For this purpose, the Meshmixer program and the STL models designed at that time were used. In both cases, the first step was to import the designed models. Then, overflow and venting channels with a diameter of 6 [mm] were added to each of the models, located in the tops of the models, and infusions placed on the side and in the center of the models for the tongue form with a tumor with a diameter of 11 [mm], for the tumor the diameter was the same dimensions every transfer, that is, it measured 6 [mm]. For this purpose, the cylinder-shaped objects already in the program were added, and then they were sized and positioned in the appropriate places using the transform function in the edit function tools.

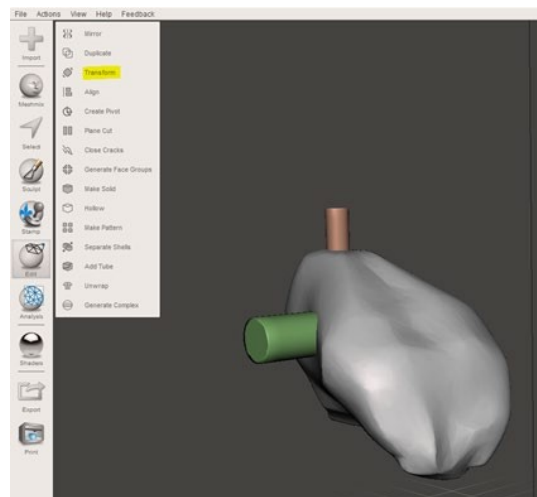


Fig. 3.11 Designing an overflow using the transform function

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

After creating the infusion and overflow, you had to select these elements together with the model, open the edit option in the taskbar again, but this time the Make Solid option was selected, setting Solid Accuracy and Mesh Density to the maximum possible values as in Figure 5.7, if the object had any kind of holes this function could be performed. Setting these functions was required so that the next operation, which will be subtracting models, could be performed correctly.

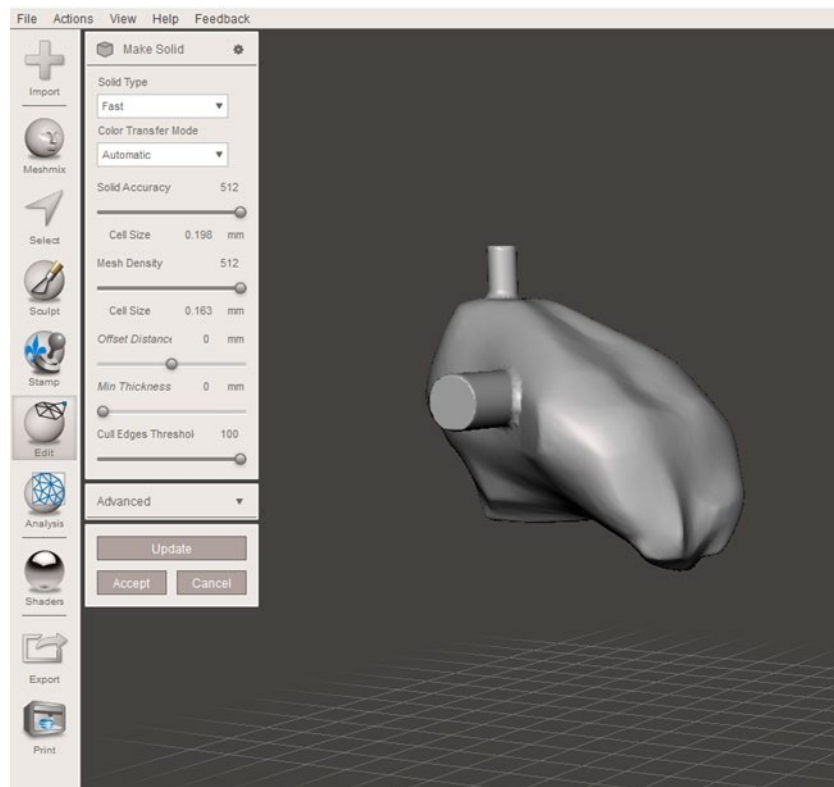


Fig. 3.12 Design of the die core

Once the die core was prepared, a casting box had to be prepared. For this purpose, the shape was again obtained from the objects proposed by the Meshmixer program, and in the Meshmix options, both the tongue and the nodule were selected as cuboids. The main goal of designing the boxes was to keep the volume as small as possible, so that the printing was not time-consuming and financially optimal. The initial dimensions of the cuboid in the case of the tongue were 57x72x70 mm, and in the case of the tumor, the dimensions of the cuboid as well as its final dimensions of the form were 25x30x35 mm. The created objects also had to be subjected to the Make Solid function and set the aforementioned parameters.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

When two objects were created for both the tongue and the tumor - a cuboid and a form, it was time to subtract one model from another. The program enables such an operation using the Boolean Difference function. For this purpose, in the Object Browser panel, the object was first selected, from which the next selected object was to be subtracted, as shown in Figure 5.8.

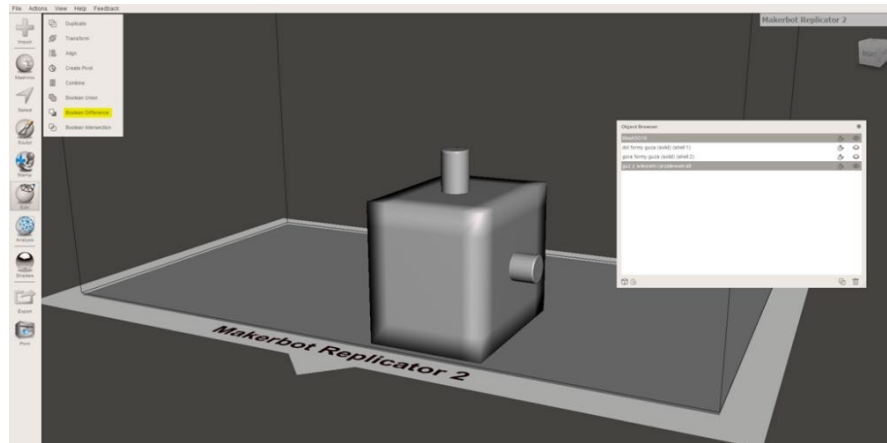


Fig. 3.13 Using the Boolean Difference function to obtain the form of a tumor

In the case of the tumor matrix, the cuboid had too much unsuitable volume, so it was transformed. With the plane cut operation available in the edit functions, the volume of the mold was reduced as shown in the figure below.

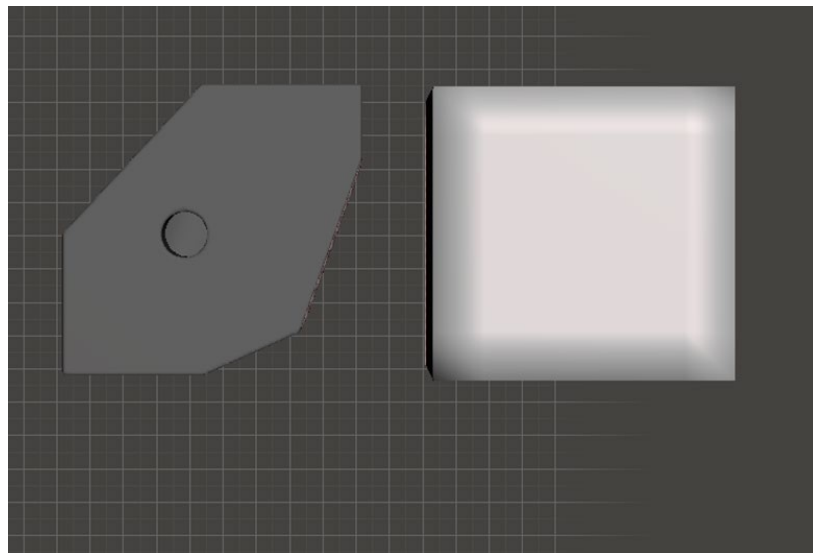


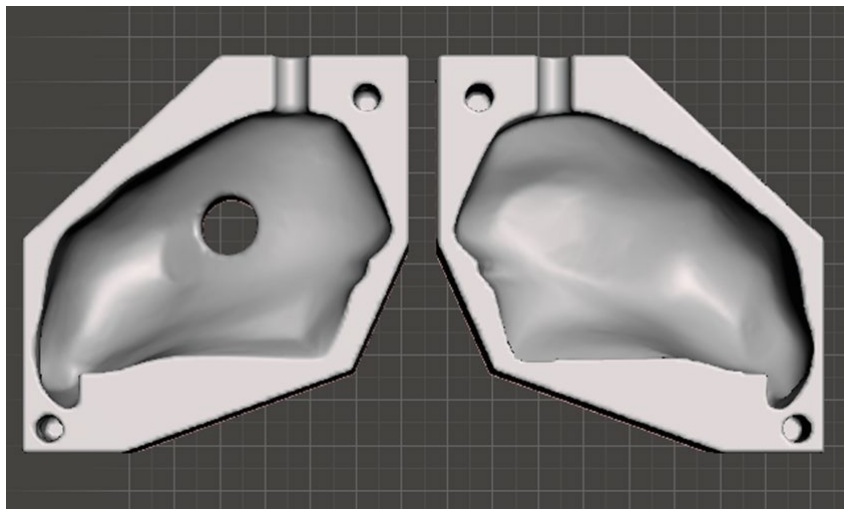
Fig. 3.14 Comparison of the optimized object with its initial version

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



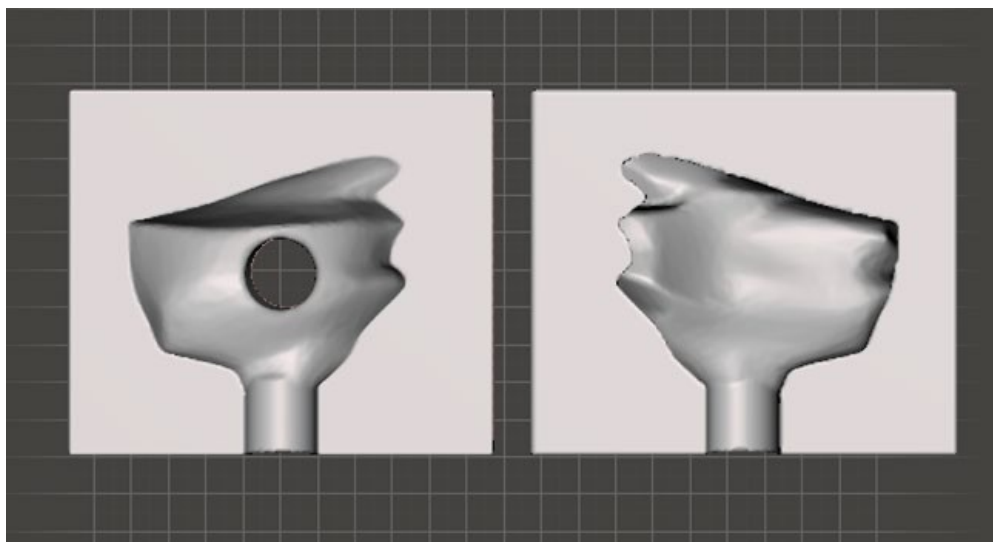
The final step was to use the plane cut function again to separate the molds into two parts so that the resulting castings could be easily removed. For this purpose, the division of the facilities was carried out through the overflow and venting channel.

This is how the designed and ready-to-print casting models look like for a tongue with a bump:



*Fig. 3.15 Casting form of a tongue with a tumor*

Below are casting molds designed to cast a tongue tumor:



*Fig. 3.16 Tongue tumor matrix*

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

### 3.7. 3D printing

In order to print the previously described models, the objects were imported into PrusaSlicer 2.3.3. Formerly known as Slic3r Prusa Edition and Slic3r PE, the program is an open source, feature-rich, frequently updated tool that gives you the ability to export printfiles for Original Prusa 3D printer [38].

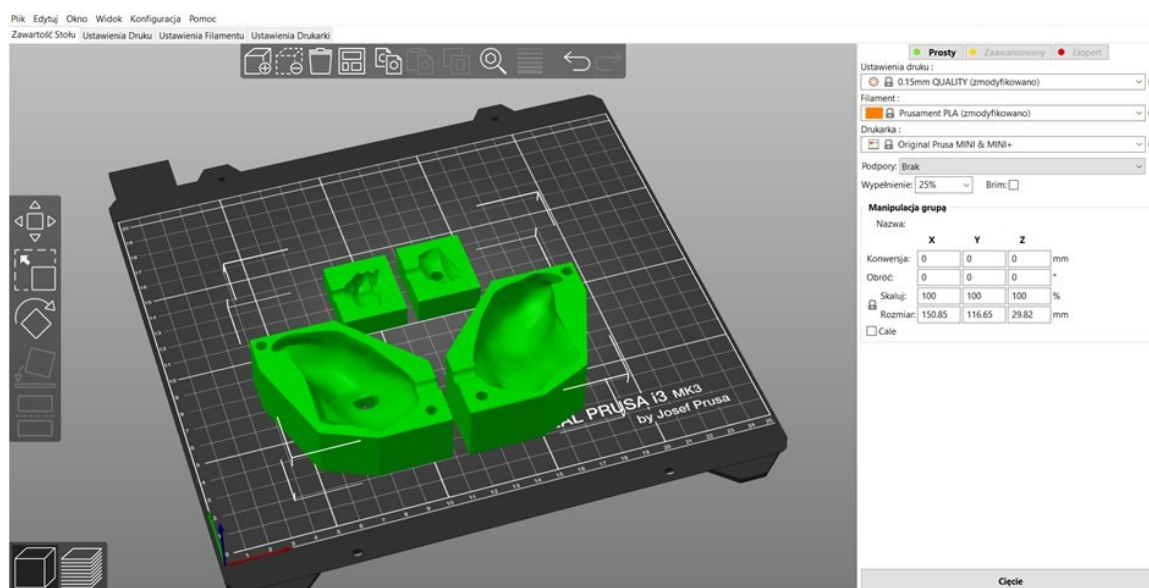


Fig. 3.17 Screenshot of PrusaSlicer with casting molds [38]

The table with the printing parameters of the above-illustrated forms is presented below:

Parameters	Values
Material	PLA
Filling	25%
Thickness	0,15 [mm]
Printing time	9 [h]
Volume	524,73 [cm <sup>3</sup> ]

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

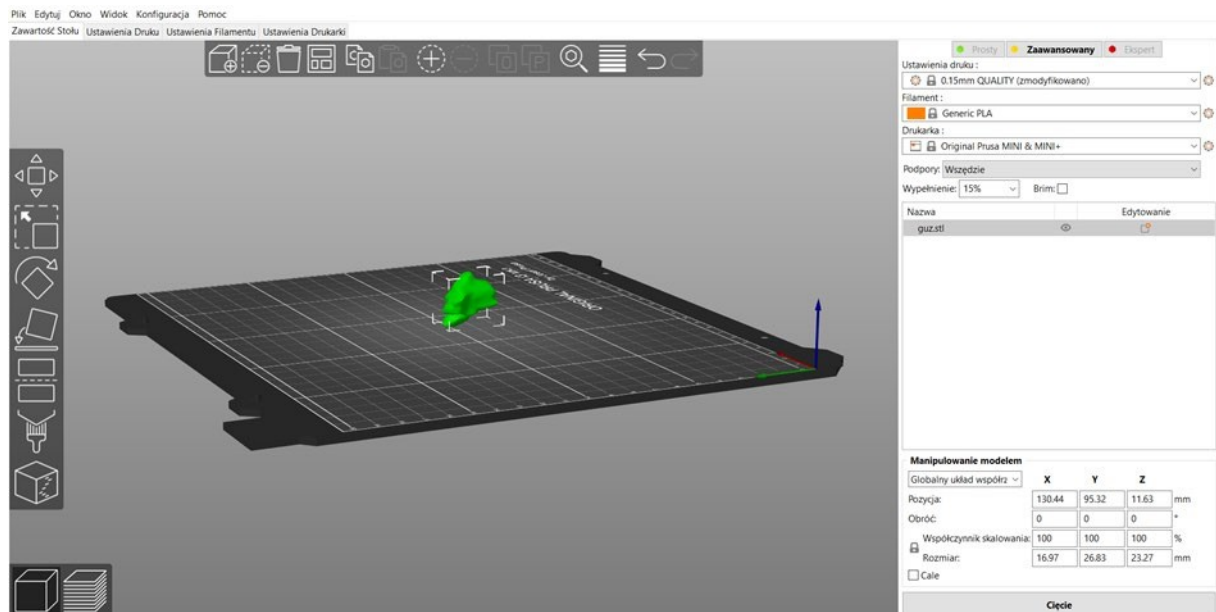


Fig. 3.18 A screenshot of the PrusaSlicer program with a bump

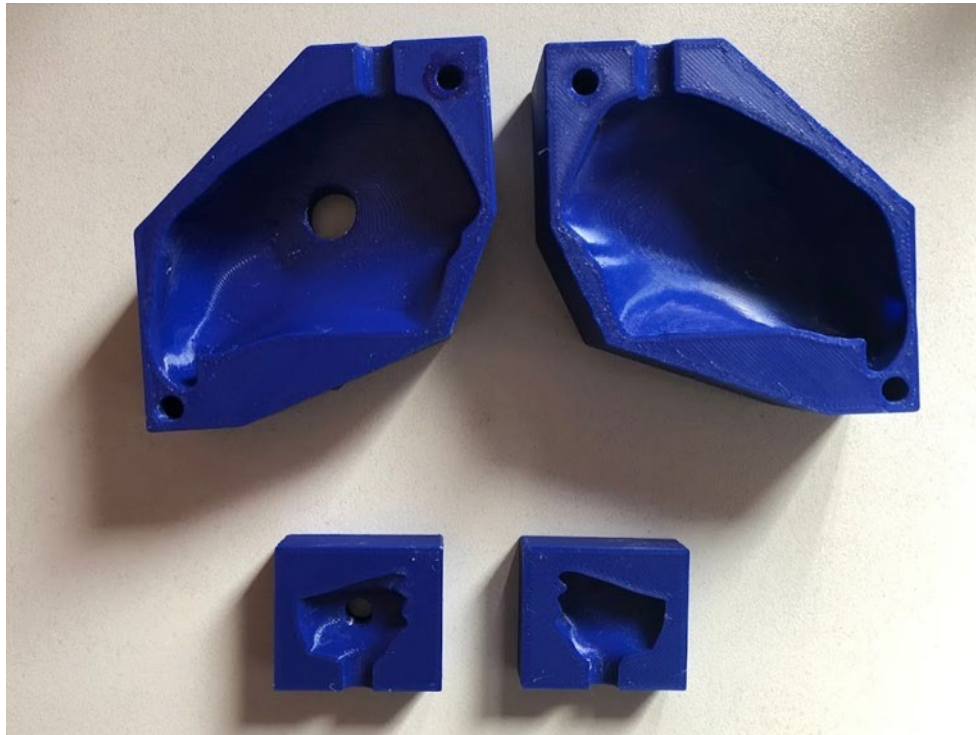
In the screenshot above, in preparation for printing, there was a lump of the tongue. The object has irregular shapes and does not contain any element that could be considered as the basis for printing. In order for the printing process to run correctly, the model had to be printed with supports. The supports were made of the same material as the object itself - Fiberlogy.

Parameters	Values
Material	Fiberlogy PLA
Filling	15%
Thickness	0,15 [mm]
Printing time	27 [min]
Volume	10,59 [cm <sup>3</sup> ]

All models were printed with the Prusa i3 MK3S printer in the 3D printing laboratory at the Poznań University of Technology.

Below is a photo of the 3D printed models, in the upper part of the picture you can see a mold of the tongue with a tumor, and in the lower part of the picture a form of a tumor of the tongue.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



*Fig. 3.19 Casting forms of the tongue and its tumor*

In the next photo, a printout of a nodule made of flexible material (Fiberflex) will be shown:



*Fig. 3.20 Tumor printout*

### **3.8. Casting of models**

After printing the casting molds of the tongue and the tongue tumor, the next step was to cast the models. The goal was to obtain three models of the tongue with their tumors, where

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



each tumor was made of different materials. In this section, we will describe the course of the foundry processes and show how various parameters can affect the final result.

The first step in all the operations was to locate the tumor of the tongue in the cast mold. As the tumor is inside the tissue, its location was arbitrary, selected on the basis of photos taken during the design. The location of the tumors in a casting mold is shown below.



*Fig. 3.21 Location of the tumor*

In each case, the molds had to be carefully secured with tape, then drain and inlet channels were installed, which were also secured against material spilling with tape. The mold, covered with an insulating layer, was placed in a vice as shown in Fig. 3.22.



*Fig. 3.22 A mold prepared for the casting process*

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



Ultimately, three different models of the tongue will be created along with its tumor. The materials were selected in consultation with the medical staff, based on the presentation of samples of various materials. The semi-finished product intended for the casting of the tongue in all cases was - Sorta Clear 12. However, the bumps will be successively made of materials such as Fiberflex (printed), Dragon Skin 10 and XTX 45 DRY (cast). A table with the properties of the given materials is presented below.

List of materials used						
Technology	Type	Trade name	Hardness [Shore A]	Colour	Additional information	
					Time life [min]	Setting time [h]
FDM	Mod. TPE	Fiberflex	90 (40D)	Black	Printing temp. 200-220°C	
VC	Silikon	Dragon Skin 10 Very Fast	10	Milk	4	0,5
VC	Silikon	Sorta Clear 12	12	Transparent	40	12
VC	Silikon	XTX 45 DRY	43	Transparent	90	12

Sorta Clear 12 is a transparent silicone rubber material that cures within 12 hours at room temperature. It cures with negligible shrinkage (0.1%) at room temperature. The manufacturer sells a material split into two substances, A as a catalyst and B as a base. Part B should be shaken thoroughly before use, and then both substances should be measured in a ratio of 1:1. The mixing process should take about three minutes and be carried out intensively. In each case, the material deaeration was referred to differently, which will be presented in more detail in the description of the given example models.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



Fig. 3.23 SORTA-Clear silicone rubber 12 [39]

In the case of the first model, the then printed tumor was attached to a casting mold with a mounting compound. It was made of Fiberflex material, without the internal filling of the model, which was to ensure greater flexibility. Then the form with the inflow and venting system was secured and mounted in a vice. Parts A and B of Sorta Clear 12 were measured and mixed as recommended by the manufacturer, however, this model did not vent under vacuum. The next day, the casting was removed from the mold and the unnecessary hardened silicone parts were removed. The result of the actions is shown in Figure 3.24.



Fig. 3.24 First model

The structure of the model was cast correctly; however many air bubbles are visible. Their presence does not significantly affect the quality of the model, but its aesthetic value.

On the same day as the casting of the first model was prepared, a model of the tongue tumor itself was also created so that it could be used the next day to prepare the second model. The tumor casting mold was secured with tape, an infusion / venting system was added and then installed in a smaller vice similar to the tongue mold. The cast material was Dragon Skin

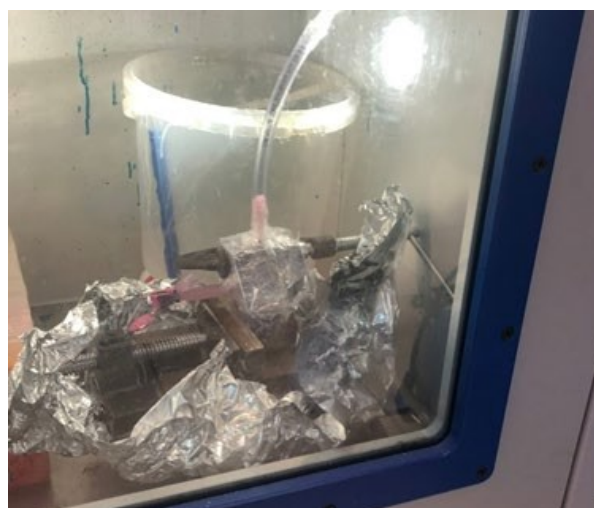
This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

10, as with Sorta clear, the manufacturer sells the base and catalyst separately, but in this case the ratio is 10:1. The substances were thoroughly mixed, the liquid was not deaerated, and after mixing, poured into a syringe, with which the material was placed in the mold and allowed to solidify. Pictures of the tumor of the tongue are presented below.



*Fig. 3.25 Tongue tumor made from Dragon Skin 10*

Once the tumor model described above was ready, it had been attached to the larger mold using a different silicone, the material was otherwise difficult to attach because silicone does not show adhesion to other materials. Then the form with the inflow and venting system was secured and it was mounted in a vice. Parts A and B of Sorta Clear 12 were measured and the red dye was added to the liquid, then mixed thoroughly until the ingredients were combined. The difference in this case was that the material already in the form was placed in a vacuum chamber to vent it.



*Fig. 3.26 Bleeding the material*

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

After the material was deaerated, the mold was allowed to stand until it reached the concentration of silicone. The next day, the model was taken out of the mold. The material did not have as many air bubbles as the previous one, but unfortunately there were significant shortcomings. However, the side with the tumor was cast correctly, which allowed for a simulated operation to proceed.



*Fig. 3.27 Secondary model*

On the same day as the casting of the second model was prepared, a model of the tongue tumor itself was also created so that it could be used the next day to prepare the third model. The process of making the tumor cast was exactly the same as before, the only difference was in the casting material. Here, the semi-finished product was Dragon Skin 10, and its preparation was similar to Sorta Clear 12. Also, the base and the catalyst had to be mixed intensively in a 1: 1 ratio for about 3 minutes. The material was then transferred to the syringe and from there to the already sealed mold. After pouring, the material was allowed to solidify in the mold.

The next day, the tumor model (Dragon Skin 10) was removed and, with the help of another silicone, attached to the tongue mold in the appropriate place. Then, as a standard, a casting mold was prepared for pouring the material. In the latter case, the base with the catalyst was mixed, then a special mixing package was prepared in order to put it into the vacuum chamber. The liquid was deaerated, then poured into a syringe and placed in a casting mold. The next day, the model was pulled out and properly processed. When pouring the material, the syringe contained air which was forced into the mold along with the material, which resulted in a slight discomfort at the top of the last model.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.





*Fig. 3.28 The third model*

### ***3.9. Clinical evaluation***

As part of the planned clinical evaluation, a simulated surgery process was performed followed by a survey. The clinical evaluation was attended by two surgeons working every day at the Clinical Hospital. Heliodor Świącicki of the Medical University of Karol Marcinkowski and a medical student from the Medical University of Karol Marcinkowski.

One of the first stages of the simulated operation was the preparation of surgical instruments, which included a surgical vice, surgical tweezers, and surgical knives. Then the models were inspected and the selected area was marked with a marker, as it is usually done in the operating theater.

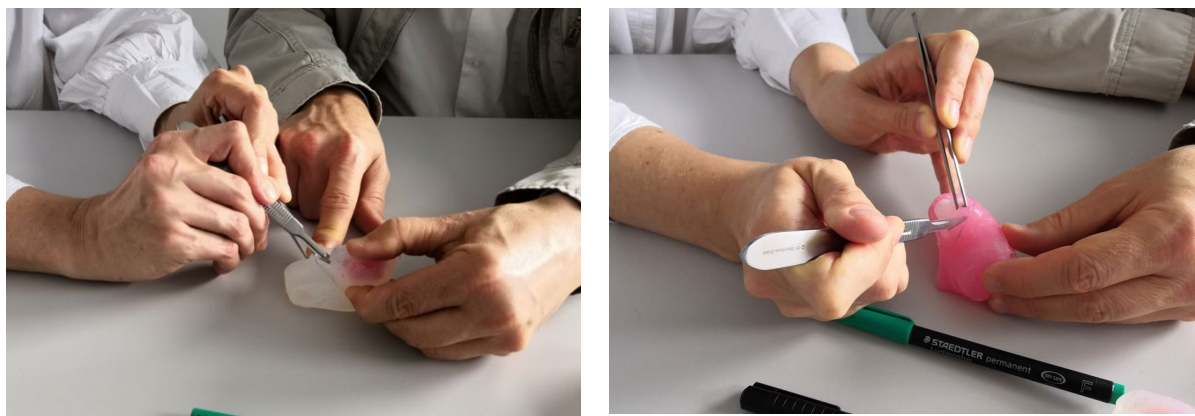


*Fig. 3.29 Operation simulation - marking*

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.



The next step was to incision the area marked at that time and then excise the tumor model (Fig. 3.30). The operation was performed jointly by two surgeons on the tongue with the tumor cast from Dragon Skin 10 silicone material and the tumor cast from XTX 45 DRY silicone material (dyed).



*Fig. 3.30 Operation simulation – next steps*

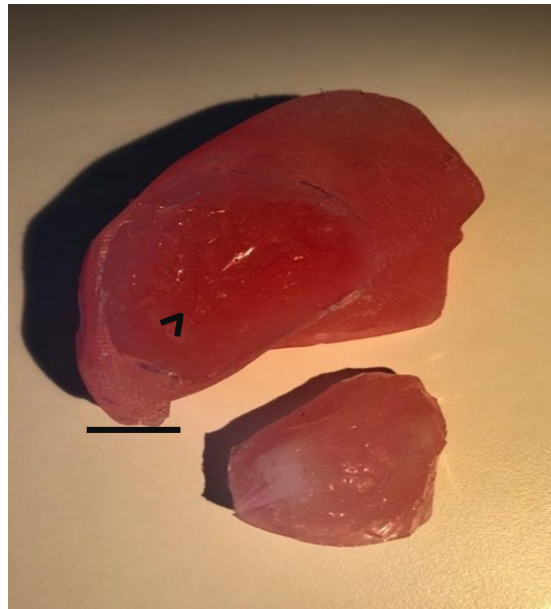
People who performed a simulated operation confirmed that the miseries are not a problem if they are not in the desired location, in this case within the tumor and its margin. The color of the silicone models turned out to be a very important factor during the planning and during the simulated operation. The transparency of the tongue model together with its colored tumor allowed a better view of the tumor visibility and its correct excision. These types of models were assessed as very good in terms of didactic value, intended for students and less experienced doctors. However, the simulated operation on the transparent model is not very realistic. The operation carried out on the colored model was closer to the actual operation, it reflects the difficulty of the operation. In this case, the tumor was excised with too small a margin and part of it remained in the tongue.



*Fig. 3.31 The tongue model together with its colored tumor*

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Remnant of a tumor model in the tongue for the stained form of the tongue (Fig 3.32).



*Fig. 3.32 Tumor model in the tongue*

To sum up, according to the doctors' assessment, the models have greater use in didactic, not entirely imaging, applications. The language banner model is perfect for exercises, and the color model is more realistic, but a less useful application will be to test the skills of a young doctor. For an experienced physician for imaging purposes, preparation for surgery and assistance during the procedure, a hard model, printed from plastic, is sufficient.

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

## ***4. Conclusions***

The module presents the role of rapid prototyping techniques in otolaryngology with the use of 3D Printing and Vacuum Casting techniques. As part of this procedure, anthropometric measurements of the patient tongue were carried out using a 3D scanner. The data provided in the form of DICOM from MRI imaging for the conducted research was one of the patients, then executed segmentation of desired anatomical structures, processing of 3D models, design of models and mold, printing models using rapid prototyping tools, assessment by medical staff on the basis of a questionnaire.

## ***Acknowledgements***

The realization of the project was possible thanks to the financing of the Polish Ministry of Education and Science. The results were obtained as a result of cooperation with surgeons from Poznan University of Medical Sciences – dr. Jacek Banaszewski and dr Agata Andruszko-Buczowska.

The study and toolkit descriptions were based on the thesis written by MSc. Renata JEZIŃSKA, entitled “Methodology of design and rapid manufacturing of mid-surgery supplies in otolaryngology”.

The publishing of this project toolkit has been financially supported by the ERASMUS KA226 project entitled “Boosting the scientific excellence and innovation capacity of 3D printing methods in pandemic period”, the implementation of the project being supervised by the National Agency for Community Programmes in the Fields of Education and Vocational Training (project reference: 2020-1-RO01-KA226-HE-095517).

## ***References***

- [1] <https://www.cmpromed.pl/otolaryngologia-czym-sie-zajmuje>
- [2] [https://www.gcm.pl/index.php/baza\\_uslug-uslug-a-56-operacje\\_nowotworow\\_jezyka.html](https://www.gcm.pl/index.php/baza_uslug-uslug-a-56-operacje_nowotworow_jezyka.html)
- [3] <https://drrysz.pl/rak-jezyka/>
- [4] <http://medical.padishahtravel.com/ent-treatment/>
- [5] <https://www.britannica.com/science/otolaryngology>
- [6] [https://www.researchgate.net/publication/330088942\\_Classification\\_of\\_GLOSSECTOMIE\\_S\\_a\\_proposal\\_for\\_tongue\\_cancer\\_resections](https://www.researchgate.net/publication/330088942_Classification_of_GLOSSECTOMIE_S_a_proposal_for_tongue_cancer_resections)
- [7] <https://www.webmd.com/oral-health/picture-of-the-tongue>
- [8] <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6590454/figure/hed25466-fig-0001/>
- [9] <https://www.webmd.com/oral-health/picture-of-the-tongue>
- [10] <https://pubmed.ncbi.nlm.nih.gov/28244479/>
- [11] <https://www.webmd.com/oral-health/guide/oral-cancer>
- [12] [https://pl.wikipedia.org/wiki/Rak\\_j%C4%99zyka](https://pl.wikipedia.org/wiki/Rak_j%C4%99zyka)



- [13] [https://www.researchgate.net/publication/325070365\\_Aktualne\\_metody\\_diagnostyki\\_obrazowej\\_raka\\_jamy\\_ustnej\\_-\\_badanie\\_TK\\_MRI\\_DWI-MRI\\_oraz\\_PETTK](https://www.researchgate.net/publication/325070365_Aktualne_metody_diagnostyki_obrazowej_raka_jamy_ustnej_-_badanie_TK_MRI_DWI-MRI_oraz_PETTK)
- [14] Sigal R, Zagdanski AM, Schwaab G, et al. CT and MR imaging of squamous cell carcinoma of the tongue and floor of the mouth. *Radiographics*. 1996;16:787-810
- [15] Royster HP, Lehr HB, Raventos A, Demuth WE. Management of patients with squamous cell carcinoma of the tongue. *Ann Surg*. 1961;154:563-572
- [16] Calabrese L, Tagliabue M, Maffini F, Massaro MA, Santoro L. From wide excision to a compartmental approach in tongue tumors: what is going on? *Curr Opin Otolaryngol Head Neck Surg*. 2013;21:112-117
- [17] <https://www.mayoclinic.org/tests-procedures/ct-scan/about/pac-20393675>
- [18] <https://web.archive.org/web/20141109192141/https://www.arrt.org/Patient-Public/Patient-Page>
- [19] [https://en.wikipedia.org/wiki/CT\\_scan](https://en.wikipedia.org/wiki/CT_scan)
- [20] <https://www.mayoclinic.org/tests-procedures/ct-scan/about/pac-20393675#dialogId7648275>
- [21] [https://pl.wikipedia.org/wiki/Tomografia\\_komputerowa](https://pl.wikipedia.org/wiki/Tomografia_komputerowa)
- [22] [https://www.researchgate.net/publication/319247119\\_Metastatic\\_spread\\_of\\_solid\\_subtype\\_lung\\_adenocarcinoma\\_to\\_the\\_small\\_intestine\\_with\\_anemia\\_and\\_melena\\_A\\_case\\_report/figures?lo=1](https://www.researchgate.net/publication/319247119_Metastatic_spread_of_solid_subtype_lung_adenocarcinoma_to_the_small_intestine_with_anemia_and_melena_A_case_report/figures?lo=1)
- [23] [https://en.wikipedia.org/wiki/Magnetic\\_resonance\\_imaging](https://en.wikipedia.org/wiki/Magnetic_resonance_imaging)
- [24] [https://www.researchgate.net/publication/323147635\\_Brain\\_MRICT\\_Images\\_Feature\\_Extraction\\_to\\_Enhance\\_Abnormalities\\_Quantification](https://www.researchgate.net/publication/323147635_Brain_MRICT_Images_Feature_Extraction_to_Enhance_Abnormalities_Quantification)
- [25] [https://www.researchgate.net/publication/224822138\\_Iron\\_Accumulation\\_in\\_Deep\\_Cortical\\_Layers\\_Accounts\\_for\\_MRI\\_Signal\\_Abnormalities\\_in\\_ALS\\_Correlating\\_7\\_Tesla\\_MRI\\_and\\_Pathology](https://www.researchgate.net/publication/224822138_Iron_Accumulation_in_Deep_Cortical_Layers_Accounts_for_MRI_Signal_Abnormalities_in_ALS_Correlating_7_Tesla_MRI_and_Pathology)
- [26] <https://ohfoundation.ca/be-inspired/3d-printing-helps-complex-surgery-to-remove-50-tumours-saves-uterus/>
- [27] <https://ohfoundation.ca/be-inspired/3d-printing-helps-complex-surgery-to-remove-50-tumours-saves-uterus/>
- [28] <https://3dprintingindustry.com/news/tongue-cancer-patient-receives-best-treatment-thanks-3d-printing-tech-94699/>
- [29] <https://3dprintingindustry.com/news/tongue-cancer-patient-receives-best-treatment-thanks-3d-printing-tech-94699/>
- [30] [http://www.ptzp.org.pl/files/konferencje/kzz/artyk\\_pdf\\_2018/T1/2018\\_t1\\_634.pdf](http://www.ptzp.org.pl/files/konferencje/kzz/artyk_pdf_2018/T1/2018_t1_634.pdf)
- [31] <https://pulsmedycyny.pl/polscy-lekarze-stworzyli-modele-serca-plodu-3d-892323>



- [32] [http://dydaktyka.fizyka.umk.pl/Wystawy\\_archiwum/z\\_omegi/serce%203D.htm](http://dydaktyka.fizyka.umk.pl/Wystawy_archiwum/z_omegi/serce%203D.htm)
- [33] <https://www.materialise.com/en/medical/mimics-innovation-suite/mimics>
- [34] <https://www.slicer.org/>
- [35] <https://www.3d-doctor.com/>
- [36] <https://en.wikipedia.org/wiki/InVesalius>
- [37] [https://en.wikipedia.org/wiki/Blender\\_\(software\)](https://en.wikipedia.org/wiki/Blender_(software))
- [38] <https://www.prusa3d.com/prusaslicer/>
- [39] <https://www.kaupo.de/shop/en/SILICONE-RUBBER-Platinum-Cure/SORTA-CLEAR-SERIES/SORTA-Clear-12/SORTA-Clear-12-1-Silicone-Rubber.html>

This project has been funded with support from the European Commission. This publication [communication] reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

