Medical Devices: Evidence and Research
Dovepress
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ORIGINAL RESEARCH

Creation of a multidisciplinary and multicenter study group for the use of 3D printing in general thoracic surgery: lessons learned in our first year experience

This article was published in the following Dove Press journal:
Medical Devices: Evidence and Research

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Introduction: In recent years, the use of 3D printing in medicine has grown exponentially, but the use of 3D technology has not been equally adopted by the different medical specialties. Published 3D printing activity in general thoracic surgery is scarce and has been mostly limited to case reports. The aim of this report was to reflect on the results and lessons learned from a newly created multidisciplinary and multicenter 3D unit of the Spanish Society of Thoracic Surgery (SECT).

Methods: This is a pilot study to determine the feasibility and usefulness of printing 3D models for patients with thoracic malignancy or airway complications, based on real data. We designed a point-of-care 3D printing workflow involving thoracic surgeons, radiologists with experience in intrathoracic pathology, and engineers with experience in additive manufacturing.

Results: In the first year of operation we generated 26 three-dimensional models out of 27 cases received (96.3%). In 9 cases a virtual model was sufficient for optimal patient handling, while in 17 cases a 3D model was printed. Per pathology, cases were classified as airway stenosis after lung transplantation (7 cases, 25.9%), tracheal pathology (7 cases, 25.9%), chest tumors (6 cases, 22.2%) carcinoid tumors (4 cases, 14.8%), mediastinal tumors (2 cases, 7.4%) and Pancoast tumors (one case, 3.7%).

Conclusion: A multidisciplinary 3D laboratory is feasible in a hospital setting, and working as a multicenter group increases the number of cases and diversity of pathologies thus providing further opportunity to study the benefits of the 3D printing technology in general thoracic surgery.

Keywords: 3d printing, thoracic surgery, multidisciplinary group, preoperative study

Introduction

In recent years, the use of 3D printing in medicine has grown exponentially,[1] its most frequent uses being (i) the creation of anatomical models, (ii) helping in surgical instrumentation and (iii) the manufacturing of prostheses and custom implants.

However, the use of 3D technology has not been adopted by all medical specialties equally, nor by all countries. If we analyze the use of 3D printing by geographical distribution, several articles coincide in placing the USA, Germany and China as the countries with the highest scientific production in this field.[1,2]

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If we analyze the systematic reviews concerning use of 3D printing by specialties, the main medical specialties in using 3D printing technology are traumatology and maxillofacial (or otorhinolaryngology) surgery. These are closely followed by vascular, neurosurgery and cardiac surgery.[1–4] It is not surprising that much of the current work in the area revolves around the applications related to bone, as trauma and maxillofacial surgeons use a wide range of prostheses and implants in their daily practice. Therefore, including 3D printed materials is only a natural step.[3] In addition, it should be noted that solid 3D printing models adapt very well to these applications and that in the segmentation process, when selecting regions of interest, the simplest part is the bone.

General thoracic surgery represents a small percentage of all publications related to 3D printing, and almost always the published papers present isolated clinical cases.[5–8] We analyzed in depth our specialty and we realized that this happened for two main reasons: (i) in numerous occasions the region of interest was included or was surrounded by soft tissue, so the process of segmentation and creation of 3D models was complex (especially when compared to cases where only bone had to be segmented); (ii) on the other hand, being a very specific specialty, there are few cases in each center where this technology can be used, so the learning curve required a lot of time.

Therefore, we decided to create a working group in which these two weaknesses became the strength of the research. On the one hand, we created a multidisciplinary working group in which both medical doctors (surgeons and radiologists) and biomedical engineers collaborated. In addition, we decided to create in the Spanish Society of Thoracic Surgery (SECT) a multicenter working group dedicated to 3D printing technology, with the participation of 24 hospitals of Spain.

We worked on two main hypotheses: (i) The creation of 3D printed biomodels is useful in the surgical planning of patients in general Thoracic Surgery, and (ii) the creation of a multidisciplinary team (doctors and engineers) improves the workflow and generates the opportunity to create more complex 3D printed models.

The aim of this study is to show the results and what we have learned in the first year of operation of the multidisciplinary and multicenter 3D unit of the SECT.

Methods

Design

This is a pilot project to determine the feasibility and usefulness of 3D models for patients with thoracic malignancy or airway complications, based on real data obtained by CT or MRI. In addition, the satisfaction with the 3D model of each responsible surgeon was analyzed.

Study population

All patients from participating hospitals with:

- central endobronchial tumors (both benign and malignant) in which the pulmonary tumor committee in a multidisciplinary session decides: surgical resection or improve preoperative study before decision.
- Airway complications after lung transplantation
- Airway stenosis
- Thoracic wall tumors
- Pancoast tumors

Workflow

We designed an in-house 3D printing workflow, creating a multidisciplinary team composed by two thoracic surgeons, two radiologists (experts in intrathoracic pathology) and two engineers (experts in additive manufacturing).

The flow chart goes as follows: clinicians detect the need of a 3D model, and DICOM data are obtained. The segmentation of the region of interest (using Mimics inPrint 2.0 software, from Materialise) begins and the STL file is created. Depuration and preparation for printing of the file (using Autodesk Meshmixer or Mimics inPrint 2.0 software) is done. Depending on the case, the final model is printed (by using Stratasys Fortus 450, Stratasys J750 or Formlabs Form 2 printers; Figure 1) or a virtual model is sent. In all cases, the time elapsed between the application and delivery of the model was less than 7 days.

This is a purely descriptive study; it shows the initial cases that have been worked on and the difficulties that we found. The study was approved by the local ethical committee (the clinical research ethics committee of the Gipuzkoa health region). No informed consent was requested from patients because we used anonymized DICOM data to create the models and only the surgeon knew which patients corresponded to each case.

Results

During this period of time we received 27 cases, of which we were able to create a 3D model in 26. In 9 cases we only created a virtual model, and in the rest the printed ones. The decision to print or not to print, was based on the time available and the perceived use of the 3D printed model. In 4 cases, surgery was scheduled 48 hrs after the application was received, so we could not create the model

Figure 1 Printers used in the study (**A**) Formlabs Form 2; (**B**) Stratassys Fortus 450; (**C**) Stratassys J750.

and print it. In terms of use, in 5 cases the objective was to establish the anatomical relationship of the thoracic wall tumor (3 cases) or mediastinum tumor (2 cases) and the surrounding vessels to determine the best surgical approach. In these cases, the information provided by the virtual models was sufficient for the surgeons to make the decision and it was decided not to print these models.

Types of cases

The most repeated pathology found in our study was airway stenosis after lung transplantation (7 cases, 25.9%) and tracheal pathology (7 cases, 25.9%), followed by chest tumors (6 cases, 22.2%). Less frequent 4 carcinoid tumors (14.8%), 2 mediastinal tumors (7.4%) and one Pancoast tumor (3.7%).

Lessons learned

Airway stenosis after lung transplantation (ASALT)

The most efficient way we found to create this kind of models was by following three steps: to select ROI using airway threshold, then edit using Separate (Split) tool and then create parts using Solid part or Hollow part. We asked to the surgeons what they preferred, to have the airway itself printed (Solid part) or the airway-wall (Hollow part, outward direction with 1,5 mm thickness). Both strategies have advantages and disavantages (for example, printing the inner part we can exactly measure the length of the stenosis and the exact diameter of the airway; on the other hand, printing the wall we can perform a bronchoscopy and try different kinds of prothesis). When printing the airway wall, we used different printers: in the Formlabs form2, we obtained models with very realistic shape and transparent wall. On the other hand, with Stratasys J750 we could add some flexibility to the models (but added flexibility also implied loss of transparency). In our opinion, we achieved most realistic airway-wall softness adding 30% of Tango to the 1,5 mm wall.

If the quality of the CT scan is important to create an accurate 3D printed model, for airway stenosis this is primordial: many times the cross section of the airway is around 1 mm, and if we don´t have enough images, it can look like there is no continuity (the only model that we didn´t create was a case of airway stenosis after lung transplantation with loss of continuity in the CT scan, because it had slices every 1,5 mm instead of slices of 0,6 mm).

Tracheal pathology

The method for creating the models was the same as for tracheal stenosis and ASALT, but the most challenging part was creating the cartilaginous tissue surrounding the trachea. This was the most time-consuming step, and it was specially complicated in young people, because they had less calcification in cartilaginous tissue. To perform this part, we used the Interpolate tool and added parts by hand (Figure 2).

Chest tumors

To perform 3D models of chest tumors, there were different challenges: ribs and sternum were very easily segmented using the Bone threshold tool. Here it was important to know if the anterior cartilaginous part of the ribs were important for the reaction of the model or not, because it is very time-consuming. For the segmentation of the tumor, Interpolate tool was the most useful, and special care was needed, with engineers and doctors working together, for the delimitation of the healthy soft-tissue and tumor limits (Figure 3).

Figure 2 Two models of tracheal stenosis. (**A**) Lateral view, printed using resin. (**B**) and (**C**), anterior and posterior views, respectively, of tracheal stenosis created using FDM technology.

Carcinoid tumors

As in the cases of airway stenosis, we segmented the air, and created a 1 mm wall around it. To select the tumors, we used the Interpolate tool. Here the challenge was at the printing step, since it was especially interesting printing the airway wall with transparent material, and inside the tumor in color. These models have been especially useful in the choice of surgical approach, since we were able to measure the distance between the bifurcations and the tumor, to see if there was enough space to introduce a stapler, which is necessary to operate through video surgery.

Segmentation times

The median segmentation time was 70 mins, although the time we needed for segmentation decreased in the last cases of the most repeated types (Figure 4).

Questionnaire for surgeons

After each surgery, the following questionnaire was circulated to all surgeons, where a score of 0 points means to be in total disagreement with the affirmation and 10 completely agree.

1. The protocol to get the 3D model has been comfortable.
2. The time elapsed between the model request and the receipt of the model has been satisfactory.
3. The 3D model accurately reflected what was found in the surgical field.
4. Having the 3D model helped presurgical planning.
5. The material used for the 3D model is adequate.
6. Being able to visualize the tumor in the model helps explain the surgical procedure to patients in consultation.

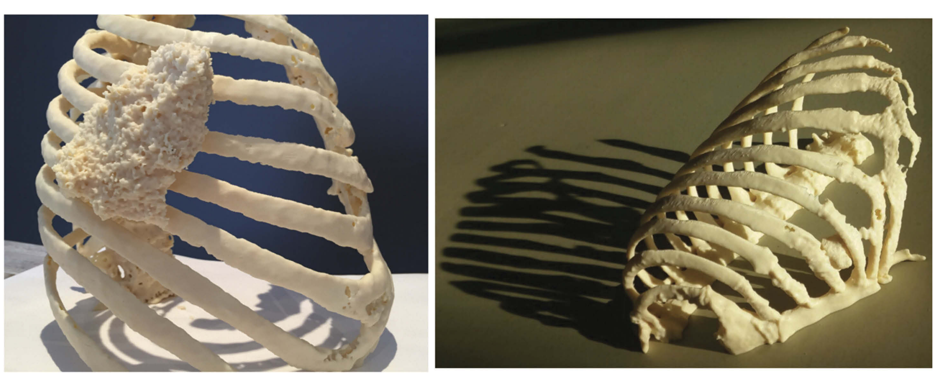

Figure 3 Two chest tumor models printed using FDM technology.

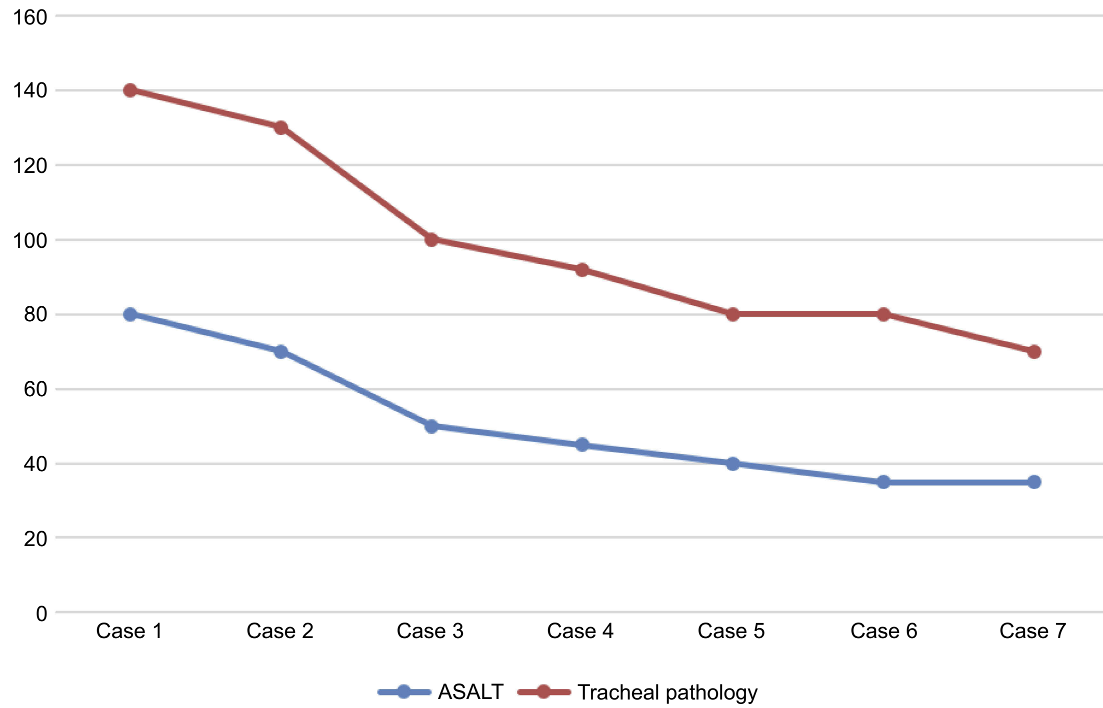

Figure 4 Evolution of time for segmentation

7. The model allows to improve training to the rest of the team (residents, nursing, anesthesia, etc.)
8. Suggestions/comments for model enhancement.

The answers to questionnaires are collected in Table 1. In no case a score less than 5 was obtained. The lowest scores were obtained in the first case of thoracic wall tumor and in the first case of stenosis airway.

Discussion

The manufacture of anatomical models represents the most common use of 3D printing in medicine. In fact, it accounts for more than 70% of scientific production linked to 3D printing in surgery.[1,2] It is already demonstrated that the creation of anatomical models offers several advantages in some medical specialties such as traumatology or maxillofacial surgery.[2–4,9] But there is a lack of information about 3D printing technology in general thoracic surgery.

There are some case reports about personalized dynamic prosthesis,[5] but there are no long series with suggestions or tips. After our first year working, our main conclusion is that a multidisciplinary approach is necessary: there is still a long way until any software is able to differentiate automatically soft tissue from tumor, and the eye of the experienced radiologist and the anatomical knowledge of the surgeon, together with the engineer knowledge are indispensable to achieve accuracy of the created models.

Table 1 Survey results

	5 points	6 points	7 points	8 points	9 points	10 points
Question 1	0	1 (3.8%)	0	0	2 (7.7%)	23 (88.5%)
Question 2	0	0	0	0	4 (15.4%)	22 (84.6%)
Question 3	2 (7.7%)	0	1 (3.8%)	1 (3.8%)	2 (7.7%)	20 (76.9%)
Question 4	0	0	2 (7.7%)	2 (7.7%)	3 (11.5%)	19 (73.1%)
Question 5*	3 (17.6%)	0	3 (17.6%)	0	1 (5.9%)	10 (58.8%)
Question 6	0	0	1 (3.8%)	1 (3.8%)	1 (3.8%)	23 (88.5%)
Question 7	0	0	1 (3.8%)	1 (3.8%)	3 (11.5%)	21 (80.8%)

Note: In question 5 there are only 17 answers, because in 9 cases there were only virtual models.

Figure 5 Team work is essential.

The quality of the CT scan used for the diagnosis is fundamental: being the first step of the entire chain, if the CT scan is of poor quality, we will obtain a coarser and less precise model. Even in cases such as ASALT, in which the caliber of the airway can be minimal, using a CT scan with slices every 1.5 mm instead of 0.6 mm can prevent generation of a model.

The creation of 3D models in the point-of-care setting opens the door to innovation and it poses new challenges: what is the best material to print ribs or airway, possibility of creating models of augmented reality… mixing engineers and doctors brings new solutions to old problems (Figure 5).

With this work we wanted to demonstrate that 3D models can be generated for general thoracic surgery, and that the increase in number of cases makes the final quality of the models better. Future work will determine the benefits obtained from the creation of models prior to surgery, measuring surgical times, complications, blood loss etc., in the same way that they have already shown improvements in specialties like maxillofacial surgery or orthopedic surgery.[10,11]

If we evaluate the surgeons response to surveys by pathology, we have observed that the best scores were obtained in the cases of ASALT and carcinoid tumors. Since in carcinoid tumors valuing the diameter of the airway on both sides of the tumor can be of vital importance to planning the surgery, and getting this with conventional diagnostic techniques is not easy, we posit that it could be the pathology that most benefits from 3D printing.

We would not like to close the article without mentioning the importance of the multicenter group. The fact that 24 hospitals in Spain have joined the project, in addition to demonstrating the interest that this technology arouses, allows new ideas or applications to appear: in the beginning of the study we didn´t consider ASALT patients (because we do not perform lung transplantation in our center), until a surgeon who works with transplants joined the group and suggested us to start working with this kind of patients. Right now, ASALT is one of the most demanded pathologies for modelling.

Conclusions

Creating a 3D laboratory with a multidisciplinary group is feasible, having biomedical engineers working side by side with the medical team (thoracic surgeons and radiologists) and allows creating better and more specific models. In the thoracic surgery field, a multicenter group increases the opportunity to study the benefits of the 3D printing technology, by increasing the number of cases to work on and establishing the possibilities to work on different types of pathologies.

Acknowledgments

This study was supported by a Bottom-Up innovation grant from the Department of Health of the Basque Government (17BU218; 5.715€) and an Emerging group grant from the Spanish Society of Thoracic Surgery (SECT; 3.000€).

Disclosure

The authors report no conflicts of interest in this work.

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