Three-dimensional printing to facilitate anatomic study, device development, simulation, and planning in thoracic surgery

Sergei N. Kurenov, MS,[a] Ciprian Ionita, PhD,[b] Dan Sammons,[c] and Todd L. Demmy, MD[a]

ABSTRACT

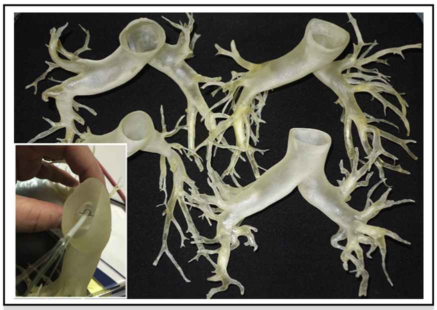
Background: The development and deployment of new technologies in additive 3-dimensional (3D) printing (ie, rapid prototyping and additive manufacturing) in conjunction with medical imaging techniques allow the creation of anatomic models based on patient data.

Objective: To explore this rapidly evolving technology for possible use in care and research for patients undergoing thoracic surgery.

Methods: Because of an active research project at our institution on regional lung chemotherapy, human pulmonary arteries (PAs) were chosen for this rapid prototyping project. Computed tomography (CT) and CT angiography in combination with segmentation techniques from 2 software packages were used for rapid generation and adjustment of the 3D polygon mesh and models reconstruction of the PAs. The reconstructed models were exported as stereolithographic data sets and further processed by trimming, smoothing, and wall extrusion.

Results: Flexible 3D printed replicas of 10 patient PAs were created successfully with no print failures; however, 1 initial test print with a 1 mm mural thickness was too fragile so the whole group was printed with a 1.5 mm wall. The design process took 8 hours for each model (CT image to stereolithographic) and printing required 97 hours in aggregate. Useful differences in anatomy were defined by this method, such as the expected greater number of proximal branches on the left versus right (2.5 ± 1.1 vs 1.0 ± 0.0; $P = .001$).

Conclusions: Reconstructed models of pulmonary arteries using 3D rapid prototyping allow replication of sophisticated anatomical structures that can be used to facilitate anatomic study, surgical planning, and device development. (J Thorac Cardiovasc Surg 2015;149:973-9)



Flexible 3D printed models with inset, showing their use testing a catheter prototype.

Central Message

Additive 3D printing (rapid prototyping) of specially processed medical images allows the creation of sophisticated pulmonary artery replicas that can be used to facilitate anatomic study, surgical planning, device development, and patient education.

Perspective

Three-dimensional printing is moving relatively quickly from the domain of manufacturing to medical disciplines and even into the homes of patients and doctors. This protean technology can interest all surgeons by improving their tools or replicating useful anatomic structures for planning operations. In this report, we detail using various software packages to convert CT images into pulmonary arteries to innovate catheter design. This article provides basic information on how to segment imaging data and also tabulates software and hardware resources for the reader. A downloadable STL file of our work is provided for the reader to view or print.

See Editorial Commentary page 980.

Supplemental material is available online.

Three-dimensional (3D) printing or additive manufacturing refers to any of the various processes for printing a 3D object.[1] Primarily additive processes are used, in which successive layers of material are laid down under computer control.[2,3] These objects can be of almost any shape or geometry, and are produced from a 3D model or other electronic data source. A 3D printer is a type of industrial robot.[1] Additive manufacturing technology requires digitized representation of geometrical data, which comes in stereolithographic (STL) or in additive manufacturing file formats.

This technology enables building accurate patient-specific 3D printed anatomic models that can be used for new surgical instrument development,[4] physical measurements, diagnosis, surgical planning, and presentation to patients.[5-8] Such

From the Department of Thoracic Surgery,[a] Roswell Park Cancer Institute, Buffalo, NY; Department of Biomedical Engineering,[b] Toshiba Stroke and Vascular Research Center, State University of New York at Buffalo, Buffalo, NY; and Engineering and Design,[c] Incodema 3D LLC, East Syracuse, NY.

Institutional funds were used for onsite printing of 1 prototype and for the procurement of software packages. Printing services for 9 of the described models were funded by an unrestricted grant from Incodema3D, which employs D.S.

S.K. conducted image translation and 3D process engineering yielding final STL files, image creation, and manuscript preparation. C.I. conducted prototype printing using a university printer and provided manuscript preparation. D.S. conducted oversight of industry prototype printing and made contributions to the manuscript limited to Table 2 and details of the industry manufacturing process. T.D. is the corresponding author, provided postprinting model analysis and data collection, study conceptualization and design, and manuscript preparation.

Received for publication Aug 31, 2014; revisions received Nov 29, 2014; accepted for publication Dec 31, 2014; available ahead of print Feb 7, 2015.

Address for reprints: Todd L. Demmy, MD, Department of Thoracic Surgery, Roswell Park Cancer Institute, Buffalo, NY 14263 (E-mail: Todd.Demmy@roswellpark.org).

0022-5223/$36.00

Copyright © 2015 by The American Association for Thoracic Surgery

http://dx.doi.org/10.1016/j.jtcvs.2014.12.059

EDU

Abbreviations and Acronyms

3D	=	three-dimensional
DICOM	=	Digital Imaging and Communications in Medicine
PA	=	pulmonary artery
STL	=	stereolithographic

models are useful for educational purposes and physiologic simulations in resident physician training because they increase 3D perception and add tactile feedback to the trainee. In addition, these printers can be used for custom implantable prostheses and are useful for test and validation of newly developed surgical instruments without risk to patients. Disadvantages of this technology are its high relative cost, limited availability of medical-grade biomaterials, and the complexity of translating patient anatomic data to the computer for rendering.

We explored and documented our experience with what we found as the available tools for this rapidly evolving technology with the aim of describing its possible use in thoracic surgical patient care and research. Because of an active research project on regional lung chemotherapy at our institution, human pulmonary arteries (PAs) were chosen for this rapid prototyping project.

MATERIALS AND METHODS

Software and Hardware

Our method of processing computed tomography (CT) scans used 2 commercial software packages: Amira 5.5 (FEI Visualization Sciences Group, Burlington, Mass) and the evaluation version of Vitrea 3D version 6.5.1 (Vital Images, Inc, Toshiba Medical Systems, Minnetonka, Minn). At the time of this project's fulfillment, the combination of these 2 software platforms allowed accurate and efficient PA reconstruction and sufficient preparation of reconstructed models for 3D rapid prototyping. A number of other packages are available (Table 1) and we trialed some of them but we found the above to be the most useful. It should be noted that a variety of radiologic software packages will allow viewing and manipulation of 3D reconstructions, but most do not allow for generation of a file for 3D printing.

The first model was printed on PolyJet Eden 260 V 3D printer (Stratasys, Inc, Eden Prairie, Minn). The printer was chosen because of its fine details, complex geometries, and very thin walls due to ultrafine 16-μm layers printing capability. For rigid materials, the accuracy in each printed plane is between 20 and 85 μm for features smaller than 50 mm; and up to 200 μm for full model size. The net printing area is 255 $\times$ 252 $\times$ 200 mm. For soft materials, the layer resolution is about 32 μm and up to 200 μm in-plane accuracy. It should be noted that there are now a multitude of 3D printers at a variety of price points (Table 2). In general, these printers are much more expensive if they are capable of using a variety of printing resins or other materials. For this application, the ability to print a soft material with high tolerances required a relatively expensive device. The models printed at Incodema3D were produced on the Objet500 Connex printer (Stratasys, Inc). The Connex offers the ability to print with dual materials to provide a wide range of soft, rubber-like models.

Process of Preparation

Ten normal, motion-free (ie, no blurring and streaking) de-identified CT angiograms performed that excluded the diagnosis of pulmonary embolism were supplied by a radiologist at a comprehensive cancer center with no affiliation with this research endeavor. No clinical information about the patients was available to the investigators; however, it was assumed that there probably was little bias selecting the cases from a general pool of patients at a cancer center. Based on institutional policy, biologic or imaging data obtained in this way are exempt from special institutional review board oversight or review. Ten anonymized Digital Imaging and Communications in Medicine (DICOM) formatted files were numbered Ptn_01 to Ptn_10 before data manipulation began.

The process of anatomic model preparation, specifically of the PA, for 3D printing requires a few substantial steps: data acquisition from the patient's CT digital data; 3D visualization and segmentation; surface rendering and creating a 3D polygon mesh; geometrical surface preparation, including simplification, refinement, and geometry fixing; and hollowing of an existing volume to ''thicken'' the walls.

Data acquisition. Three sets of data for each patient were selected for visualization and reconstruction—1 contrast CT set at 0.625 mm (512 $\times$ 512) resolution, 1 CT set at 1 mm (512 $\times$ 512) and 1 CT set at 2 mm slice thickness on a GE Optima CT 660 (GE Medical Systems, GE Healthcare, Milwaukee, Wis).

3D visualization and segmentation. The commercial software platforms Amira 5.5 and Vitrea 6.5 were used in conjunction for 3D visualization and data processing. In our findings, the most efficient way for the PA segmentation in Amira 5.5 is connecting the threshold segmentation module with a set of tools such as Blow Tool, Magic Wand, and Threshold Tool. Within the algorithm provided by this module, all gray-value voxels with a defined range of Hounsfield units within the region of interest are selected and directly connected to a predefined voxel.

Because of the high variability of curvature and embedding in complex anatomic scenes with other vessels interference, PA segmentation with Amira tools requires a clear understanding of a patient's anatomy, which takes 4 to 8 hours of time for an experienced operator.

Vitrea 6.5 was then used for additional refinement of the model, especially its most important key feature: the embedded predefined presets for certain types of data and diagnostic questions. Presets were chosen based on the DICOM tags that describe the data sets.[9] This enabled quick access to the specific anatomic structures such as vessels and automatically segmented, tracked, and labeled them. The model was then exported as STL, also known as a standard tessellation language file. However, at the time of this research, Vitrea 6.5 could not provide surface editing and fixing abilities for the STL files it generated. Therefore, Vitrea 6.5 scaffold models were imported back to Amira 5.5 as STL files.

Surface rendering. Once both the scaffold model and the same DICOM dataset used to create it were loaded in Amira, the noise reduction nonlocal means filter was applied on the data set. Using the ImageCrop editor tool, the region of interest was selected and processed as the isosurface, a closed surface that separates ''outside'' from ''inside.'' The boundary between ''outside'' and ''inside'' is the isosurface.

Next, the Amira ExtractSurface module was attached to the reconstructed isosurface. For easy recognition and volume editing, we selected a dark blue on the Vitrea model, and on Amira's isosurface we used a yellow color. We found that all 10 reconstructed by Vitrea and imported into Amira environment models did not require an additional transformation, reposition, and alignment in Amira, because Vitrea's model exactly overlaps the PA isosurface reconstructed in Amira (Figure 1).

Amira's VolumeEdit module removes noise and/or undesired objects in a 3D image before applying isosurfaces, volume rendering, or other image segmentation. We used this module for removing undesired objects around the PA such as bones, heart, aortic arch, trachea, and pulmonary veins.

The threshold value for isosurface computation was 80 to 120, depending on the ratio between noises to the level of details for every particular DICOM data set. Because the VolumeEdit module does not display any geometry in the viewer by default, we attached VolumeEdit module via the IsoSurface module to the ExtractSurface module. The ExtractSurface

Download English Version:

https://daneshyari.com/en/article/2979917

Download Persian Version:

https://daneshyari.com/article/2979917

Daneshyari.com