Special Review

Logistics of Three-dimensional Printing: Primer for Radiologists

Taryn Hodgdon, MD, Raman Danrad, MD, Midhir J. Patel, MD, Stacy E. Smith, MD, Michael L. Richardson, MD, David H. Ballard, MD, Sayed Ali, MD, Anthony Paul Trace, MD, PhD, Carolynn M. DeBenedectis, MD, Matthew E. Zygmont, MD, Leon Lenchik, MD, Summer J. Decker, PhD

The Association of University Radiologists Radiology Research Alliance Task Force on three-dimensional (3D) printing presents a review of the logistic considerations for establishing a clinical service using this new technology, specifically focused on implications for radiology. Specific topics include printer selection for 3D printing, software selection, creating a 3D model for printing, providing a 3D printing service, research directions, and opportunities for radiologists to be involved in 3D printing. A thorough understanding of the technology and its capabilities is necessary as the field of 3D printing continues to grow. Radiologists are in the unique position to guide this emerging technology and its use in the clinical arena.

Key Words: 3D printing; three-dimensional printing; 3D modeling; logistics; radiology.

INTRODUCTION

Producing three-dimensional (3D) physical prototypes from digital models became popular in the late 1990s (1). Over the past decade, the heath-care sector has shown increased interest in this technology for clinical use. Radiology has a long-standing history of acquiring and maintaining volumetric anatomic data. This precedent leaves our specialty at an advantage to unlock the true potential of medical 3D printing for mainstream use.

The process of creating 3D models from digital data can be categorized into four major steps: image acquisition, image segmentation, creation of a 3D model, and transfer of model data to a 3D printer (1,2). Image acquisition is most commonly in the form of computed tomography (CT), due to rapid acquisition and relative ease of image post-processing for 3D printing (1). The volumetric data are analyzed to ensure that there are no gaps in anatomy during acquisition (3,4). Volumetric data from CT, magnetic resonance imaging (MRI), or ultrasound images are rendered in digital imaging and communication in medicine (DICOM) format. DICOM data cannot be 3D printed, and thus image data require conversion using specialized software into one of several output file types amenable for 3D printing. The most common of these is Standard Tessellation Language or STereoLithography (STL) format, which helps 3D printers to define objects by surfaces that enclose a region of space (1). These surfaces are defined as collections of triangles called facets.

Segmentation is the process of extracting region of interest (ROI)-specific data and refining the STL representation of the selected anatomy (2). This step requires specialized software to ensure model integrity, preferably with software programs that are approved by the Food and Drug Administration (FDA) (5,6). Parts of segmentation can be automated or manual, which can serve as a challenge for radiologists who may be unfamiliar with the application software.

After segmentation, acquired STL data are sent to another program for creation of a 3D model (1,3). Open-source and commercially available computer-aided design or computer-aided manufacturing software packages include many post-processing techniques, such as smoothing and wrapping, that must be used to ensure printability of a 3D model (Table 1). Lastly, the completed STL file is transferred to a 3D printer for production. The various steps of creating a 3D model are illustrated in Figure 1.

Acad Radiol 2017; ■:■■–■■

From the Department of Radiology, The Ottawa Hospital, University of Ottawa, 501 Smyth Road, Ottawa, Ontario K1H 8L6, Canada (T.H.); Department of Radiology, LSU Health Sciences Center-New Orleans, New Orleans, Los Angeles (R.D.); Department of Radiology, University of South Florida Morsani College of Medicine, Tampa, Florida (M.J.P., S.J.D.); Department of Radiology, Brigham and Women's Hospital, Harvard Medical School, Boston, Massachusetts (S.E.S.); Department of Radiology, University of Washington School of Medicine, Seattle, Washington (M.L.R.); Mallinckrodt Institute of Radiology, Washington University School of Medicine, St. Louis, Missouri (D.H.B.); Department of Radiology, Temple University Hospital, Philadelphia, Pennsylvania (S.A.); Department of Radiology, Eastern Virginia Medical School, Norfolk, Virginia (A.P.T.); Department of Radiology, University of Massachusetts Medical School, Worcester, Massachusetts (C.M.DB.); Department of Radiology and Imaging Sciences, Emory University Hospital Midtown, Atlanta, Georgia (M.E.Z.); Department of Radiology, Wake Forest School of Medicine, Winston-Salem, North Carolina (L.L.). Received June 1, 2017; revised August 31, 2017; accepted August 31, 2017. **Address correspondence to:** T.H. e-mail: tahodgdon@toh.ca

https://doi.org/10.1016/j.acra.2017.08.003

TABLE 1. Examples of Various Free Software Platforms Available for the Creation of 3D-printed Models

CURA	Beginner	Slicer software to prepare STL files for 3D printing	Free	PC, Mac, Linux
CRAFTWARE	Beginner	Slicer software to prepare STL files for 3D printing	Free	PC, Mac
OSIRIX	Intermediate	To create 3D model and prepare STL file	Osirix lite (32 bit) is free. Osirix MD (64 bit) costs about $600 USD	Mac only
HOROS	Intermediate	To create 3D model and prepare STL file	64-bit Free, donation to user group requested	Mac only
NETFABB	Intermediate	Slicer to prepare STL files for 3D printing	Basic free, professional edition paid	PC, Mac, Linux
REPETIER	Intermediate-advanced	Slicer software to prepare STL files for 3D printing	Free	PC, Mac, Linux
3-D TOOL	Intermediate	To view and check STL files	Free	PC
MESHFIX	Intermediate	Check STL files	Free	PC
SLIC3R	Professional	Slicer software to prepare STL files for 3D printing	Free	PC, Mac, Linux
BLENDER	Professional	Edit STL files for 3D printing	Free	PC, Mac

PC, personal computer; STL, Standard Tessellation Language or STereoLithography; 3D, three-dimensional.

3D Print production relies on fusing successive two-dimensional (2D) layers of material as guided by the STL data set. Selection of the 3D printer and materials depends on the clinical task at hand, as well as other factors such as cost, time of production, and familiarity with the corresponding hardware and software of a printer (1,7). Preparing the 3D print for clinical use typically requires cleaning, curing, polishing, or sterilization (1).

This article by the 3D Printing Task Force of the Radiology Research Alliance reviews the logistics of 3D printing and their implications for radiologists. Specific topics include printer selection for 3D printing, software selection, creating

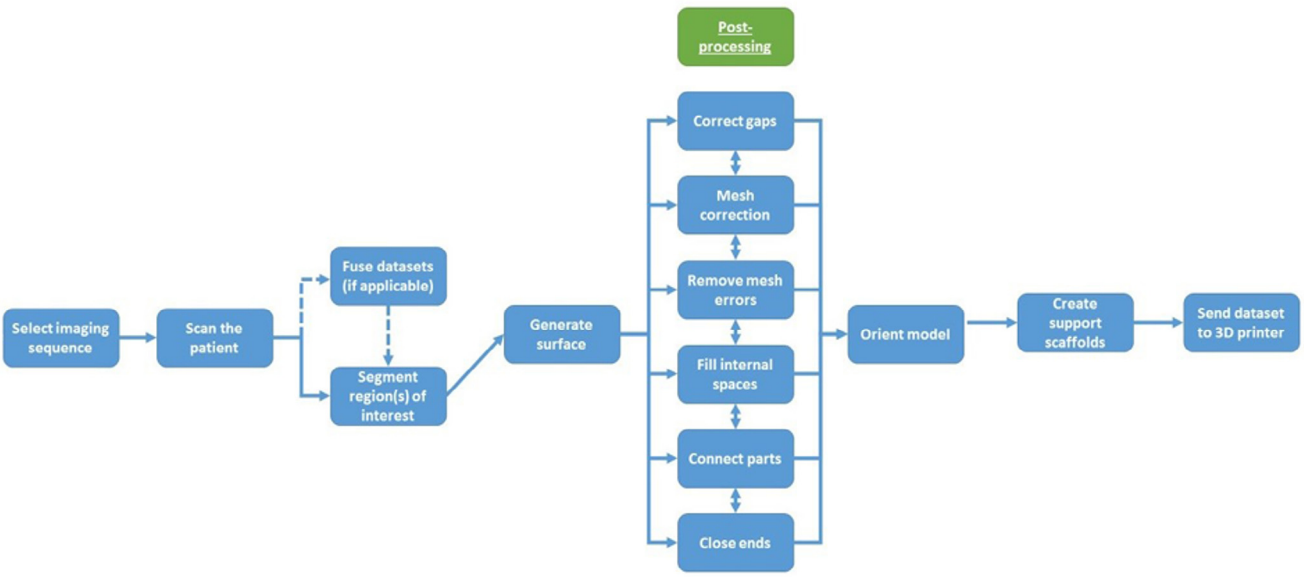

Figure 1. Flowchart demonstrating the workflow for printing of a 3D model. After acquiring the images, DICOM files are initially segmented to extract the anatomy of interest. An STL file is created and post-processed with CAD software. Support scaffolds can also be created to hold the model parts in place. The completed STL file is then sent to the 3D printer for printing. CAD, computer-aided software; DICOM, digital imaging and communication in medicine; STL, Standard Tessellation Language or STereoLithography; 3D, three-dimensional.