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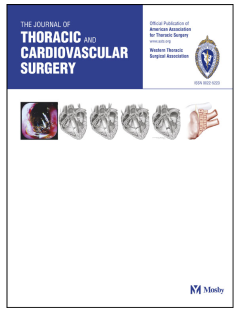

Unlocking vendor-specific tags: Three-dimensional printing of echocardiography data sets

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Figure 1 legend Graphic representation of process of converting DICOM data-sets into 3d prints.

Figure 2 legend Side-by-side comparison of original clinical TEE images (top), computer-generated renderings of the 3-D STL mesh file as produced by the described workflow (middle), and photos of 3-D prints produced by a desktop 3-D printer (bottom) for four valves in three routinely acquired views: A) a normal aortic valve in mid-systole, B) a normal left atrial appendage, C) a normal mitral valve, D) a mitral valve with a posterior leaflet segment flail.

Video legend https://youtu.be/LQLC31QJaWI

Video walk-through illustrating the workflow from extracting the DICOM files from the Philips IE33 echo machine to generating the .stl file in 3D Slicer.

Interest in 3-D printing of anatomical structures continues to grow for a range of applications within the medical field. Proprietary software limits the accessibility of information stored within echocardiography datasets. This study aims to unlock vendor-specific tags and establish an open-source workflow for generating three-dimensional (3-D) anatomical models of cardiac structures from routine clinical echocardiography datasets.

Challenges in 3-D printing of echocardiographic datasets

The use of 3-D prints has been reported in many areas of health care, including planning of percutaneous cardiovascular procedures, congenital heart surgery, and medical education(1). Projects currently underway at our institution utilize the prints for sizing of neochords used in mitral valve repair as well as sizing and placement of left atrial appendage occlusion devices.

Previous work using echocardiography datasets has relied on proprietary software and 3-D transesophageal echocardiographic (TEE) datasets to 3-D print the mitral valve annulus and leaflets(2). The software requires user interpretation of the echocardiographic images with manual overlay and assignment of data points to create the 3-D model that is then printed. This technique can lead to loss of anatomic detail and preclude the ability to accurately print the leaflet and annular thicknesses from actual echocardiographic data. Current 3-D transesophageal echocardiography modeling is often limited to restrictive proprietary software packages that focus on the mitral valve alone. Due to these limitations, datasets are difficult to process.

Open-source workflow

Existing 3-D TEE datasets acquired on Philips IE33 with xMatrix Ultrasound system (Philips Healthcare, Andover, MA) were exported from Philips QLab® (Philips Healthcare, Andover, MA) to a 4-D ultrasound DICOM format. The frame of interest is first identified on QLab. For the purposes of our prints, we chose mid-systole. The frame was then converted into a NRRD file (the n-dimensional Nearly Raw Raster Data format) using custom software developed within this study. NRRD is a widely used imaging file format in scientific visualization and image processing. This NRRD file is then viewed using the free, open source software, 3-D Slicer (http://www.slicer.org) (3). Thresholding of the gray scale dataset was performed in 3-D Slicer to generate the desired surface, which was then exported to standard STL stereolithography file format. The STL file was further cropped to the region of interest using Meshmixer - another free software (http://www.meshmixer.com).

No change to volumetric data occurs during the process of converting ultrasound images to NRRD files. Thresholding introduces a source of potential deviation from the original image, however, this deviation is generally negligible. The aortic and mitral valve prints were manually measured and compared to the Qlab measurements with good correlation. To demonstrate general interoperability, the STL files were used to create 3-D physical models on a commercially available Form 2 Desktop SLA 3-D printer® (Formlabs, Inc, Somerville, MA). Figure 1 illustrates the entire workflow.

The custom software developed runs entirely within the browser and requires no downloads. It is accompanied by a step-by-step instructional video of the entire process (see supplemental material). We successfully generated multiple prints from 3-D echo datasets of various cardiac structures (Figure 2). Time for data processing was less than five minutes. The time required by the 3-D printer was the predominant limiting factor and varies by specific printer settings.

Unlocking vendor-specific tags

One of the main challenges facing the utilization of 3-D echocardiographic data in research is the lack of a standardized format for 3-D ultrasound data storage. There is almost no interoperability between vendors and standalone software packages. Many essential parameters are stored in vendor-specific "private tags" (see supplemental material). While the community attempts to exert significant pressure on vendors to cooperate in developing a DICOM standard for 3-D ultrasound imaging data, the export of such data remains a problem(4). Our method bypasses interoperability issues until standards are set, with certain limitations (see supplemental material). We also utilize the free open-source 3-D Slicer, which unlike a typical radiology workstation, is not tied to specific hardware whilst providing versatile visualizations and advanced functionality.

The quality of prints of a specific structure will depend upon the choice of modality best suited for that structure. Studies using 3-D prints from CT and MRI scans have been abundantly reported in the literature as there is better standardization of data from the DICOM data-sets obtained from these scanners, compared to ultrasound. Although 3-D echo is not the best imaging choice for every cardiac structure, echo data-sets are very commonly obtained for cardiac surgical patients. Our technique provides the ability to create near exact prints of 3-D images generated by the ultrasound machine. However, if the image does not accurately represent particular elements of a structure, the print will not either. Utilization of the free tool that we have developed to unlock the ultrasound data-sets will allow for the same ease in processing as CT and MRI data-sets. Our method is free, open, and efficient. It is our hope that this technique will further enable clinicians and researchers to generate 3-D prints from 3-D ultrasound data sets.

Supplemental material

Open-source tool and tutorial: A web-based tool has been developed to extract ultrasound slices at timeframe of interest from 3-D ultrasound DICOM files. The tool is developed to run in the browser as a client-side-only application and is thus developed in javascript. This ensures confidentiality as patient data is not processed on remote servers. The code is made available as an open-source code repository at https://github.com/ahmedhosny/ultrasound-converter and the web application can be found at https://ahmedhosny.github.io/ultrasound-converter/ (Chrome browser supported only). Additionally, we have included on the website a video walk-through illustrating the workflow from extracting the DICOM files from the Philips IE33 echo machine to generating the .stl file in 3D Slicer. The video is available directly at https://youtu.be/LQLC31QJaWI. Current work is underway to expand supported files beyond those exported by Philips QLab software, expand export file types such as DICOM, as well as expand supported browsers.

An example of vendor-specific tag: a 3-D volume in a single DICOM file exported from a Philips QLab® workstation shows slice spacing (or pixel Z height - essential for the 3-D reconstruction of the dataset) in a tag labeled "(3001, 1003) PrivateTagData." The DICOM standards specifies that slice spacing should live in the "(0018, 0050) SliceThickness" tag. This 3-D ultrasound multiframe DICOM file is hence only correctly parsed by the software that exported it, and any attempt to parse it using other software is bound to return inaccurate results or be incompletely unsuccessful.

Limitations: Although our method currently only deals with files generated from Philips QLab®, it is fully extensible to other workstation models. One limitation arises with this proposed method:

the loss of patient identifiers and information when converting DICOMs into other file formats. This can be remedied by dumping the extracted information from vendor DICOMs into entirely standard DICOMs.

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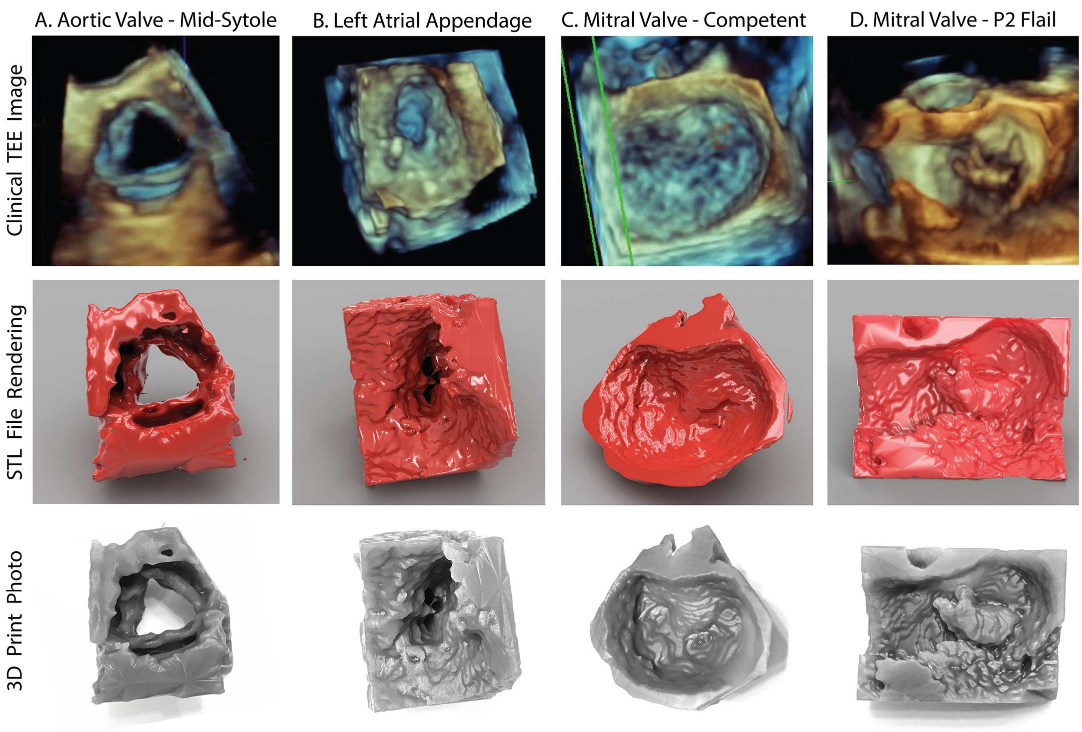
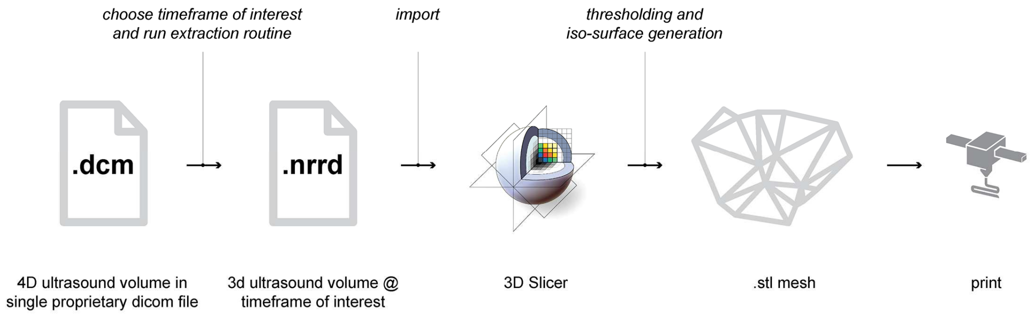
3D
3D 47%
3D 40dB
F# 13
PAT T: 37.0C
TEE T: 37.2C
Patient Directory
Send to...
Exports selected images to external DICOM devices
Beats 1
Send selected images to one or more of the following destinations:
Media
USB
DVD
Archive Servers
QLAB/XCELERA
SYNGO DYNAMICS
SYNGO/QLAB
OK
Cancel
JPG/AVI
Page


A. Aortic Valve - Mid-Sytole
B. Left Atrial Appendage
C. Mitral Valve - Competent
D. Mitral Valve - P2 Flail
Clinical TEE Image
STL File Rendering
3D Print Photo


choose timeframe of interest
and run extraction routine
import
thresholding and
iso-surface generation
.dcm
.nrrd
4D ultrasound volume in
single proprietary dicom file
3d ultrasound volume @
timeframe of interest
3D Slicer
.stl mesh
print