

Creating patient-specific anatomical models from highly elastic materials using 3D-printed molds

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Introduction

- Realistic physical models or 'phantoms' of anatomical structures are useful for simulating surgery and other medical procedures.
- Creating soft-tissue-mimicking patient-specific models allows for practicing rare or difficult procedures for which no generic models are available, such as heart surgery for pediatric patients with congenital heart disease.
- Volumetric images are good for visualization, and direct 3D printing is good for recreating shape, but 3D-printable materials are not flexible enough to simulate certain procedures.



Fig 1. Brain white matter phantom

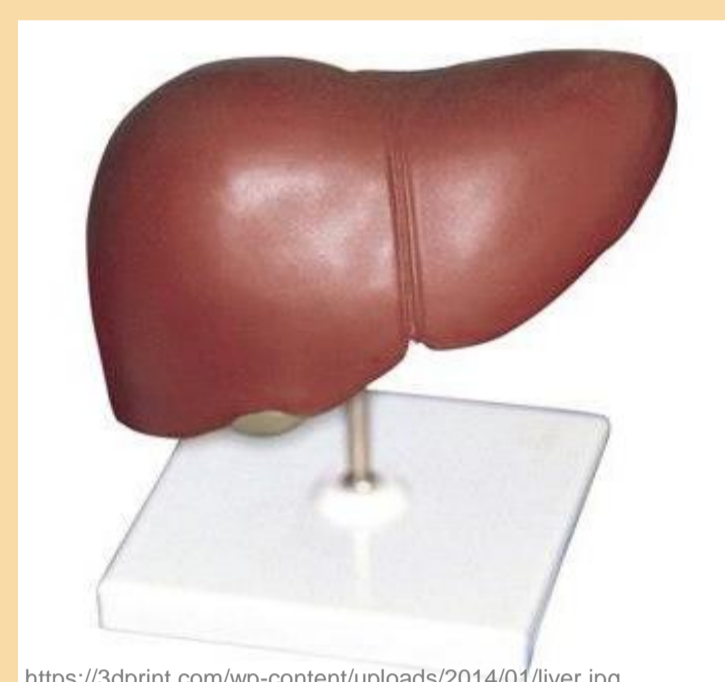


Fig 2. Liver phantom



Fig 3. Heart phantom

Objective

- Workflow to design **3D-printed molds** using **open-source** tools to create **flexible patient-specific models** for teaching, simulating surgery, and other medical procedures.

Methods

- Step 1: Segmentation.** Segment the object of interest from 3D image.
- Step 2: Mold design.** Create a rectangular prism segment surrounding the object. Separate into two mold pieces. Subtract the object of interest. Add tunnels in top mold segment to allow air bubbles to escape. Save the mold parts as STL files.
- Step 3: Mold printing.** 3D print the mold parts using standard hard materials.
- Step 4: Physical model creation.** Fill the molds with a highly elastic material such as silicone or PVC and allow to set. Remove the phantom from mold and trim any excess material.

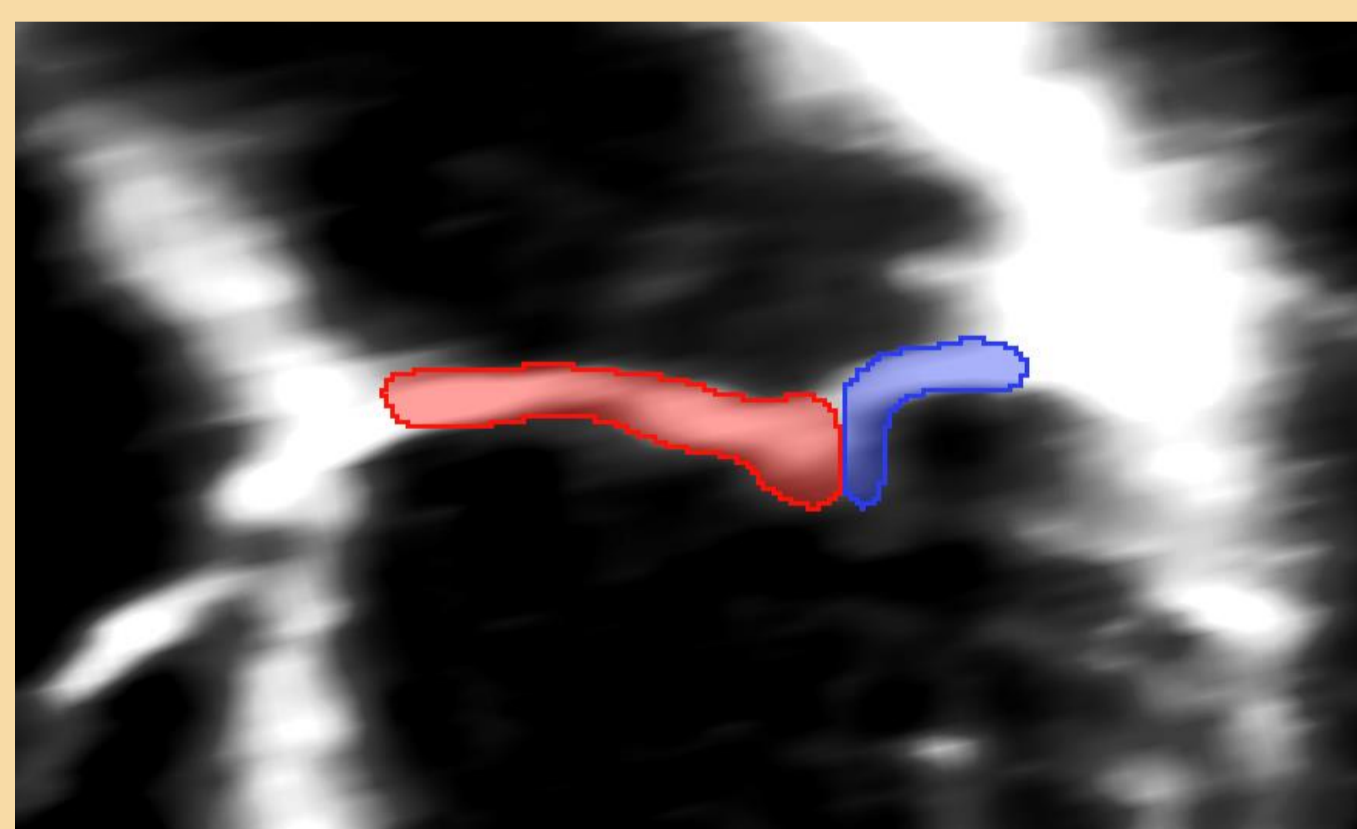


Fig 4. Segmentation of a mitral valve based on ultrasound image (step 1)

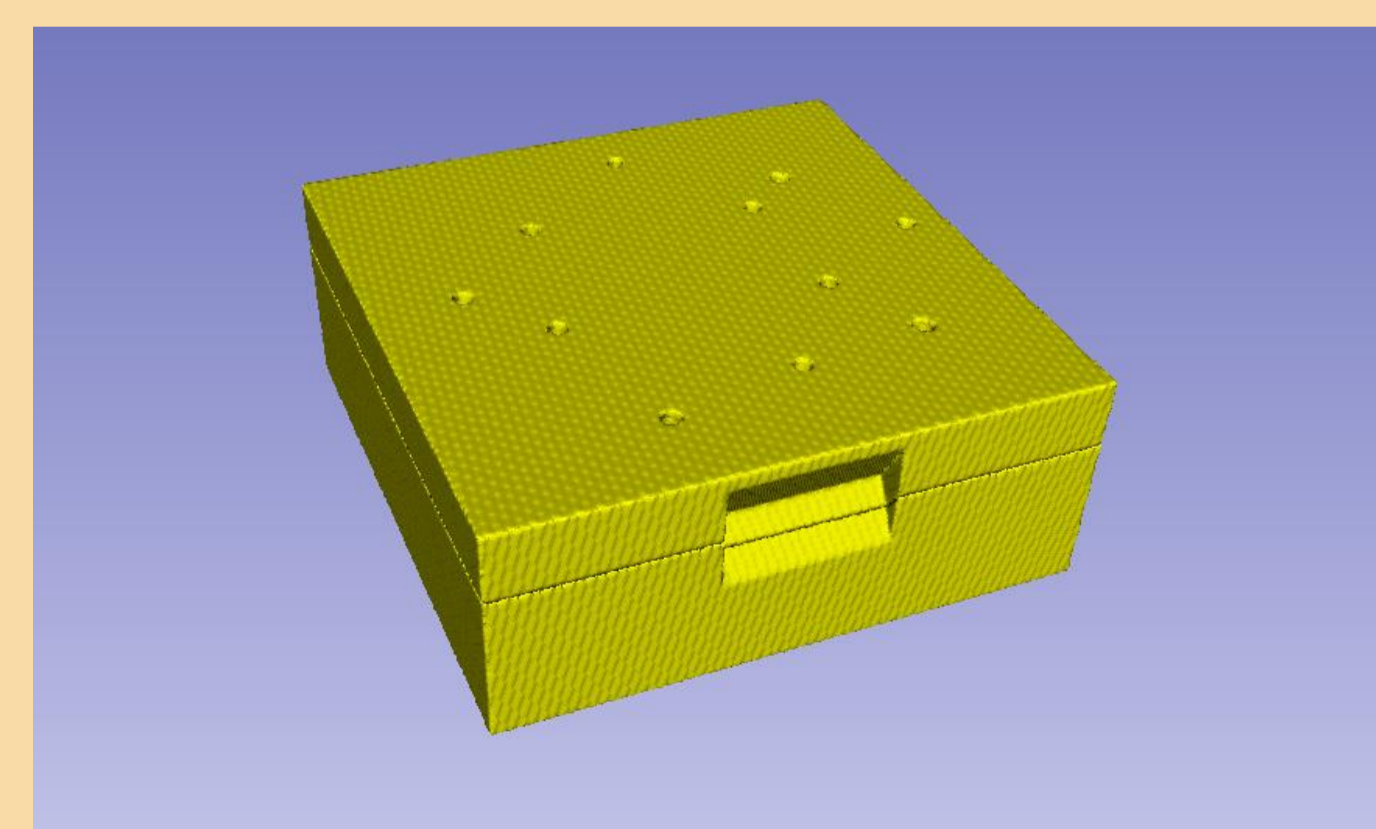


Fig 5. 3D mold box model for a mitral valve (step 2)



Fig 6. 3D-printed bottom mold and top mold for a mitral valve (step 3)



Fig 7. Silicone mitral valve created from mold (step 4)

Results

- Workflow demonstrated on heart valve phantoms for three rare pediatric cases¹.
- Heart valve tissue: Dragon Skin® silicone - good elasticity, cuts and holds sutures well.
- This silicone is also suitable for creating ultrasound phantoms².
- Six pediatric cardiac surgeons practiced suturing on the silicone valve models.
- All six surgeons considered the models to be useful for training for cardiac surgery and practicing difficult cases.
- 3D Slicer software was used to design the 3D-printable mold.³ [Segment editor, scissors effect] (www.slicer.org)
- For very thin or detailed structures such as heart valve leaflets, manually separating the mold into two pieces took 2-5 hours. To speed up the process, we wrote a module in 3D Slicer to automate mold creation for heart valves.
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Fig 8. A surgeon practices suturing on a valve model, with similar view to open heart surgery



Fig 9. Silicone valve models left to right: tricuspid, complete atrioventricular canal defect, mitral

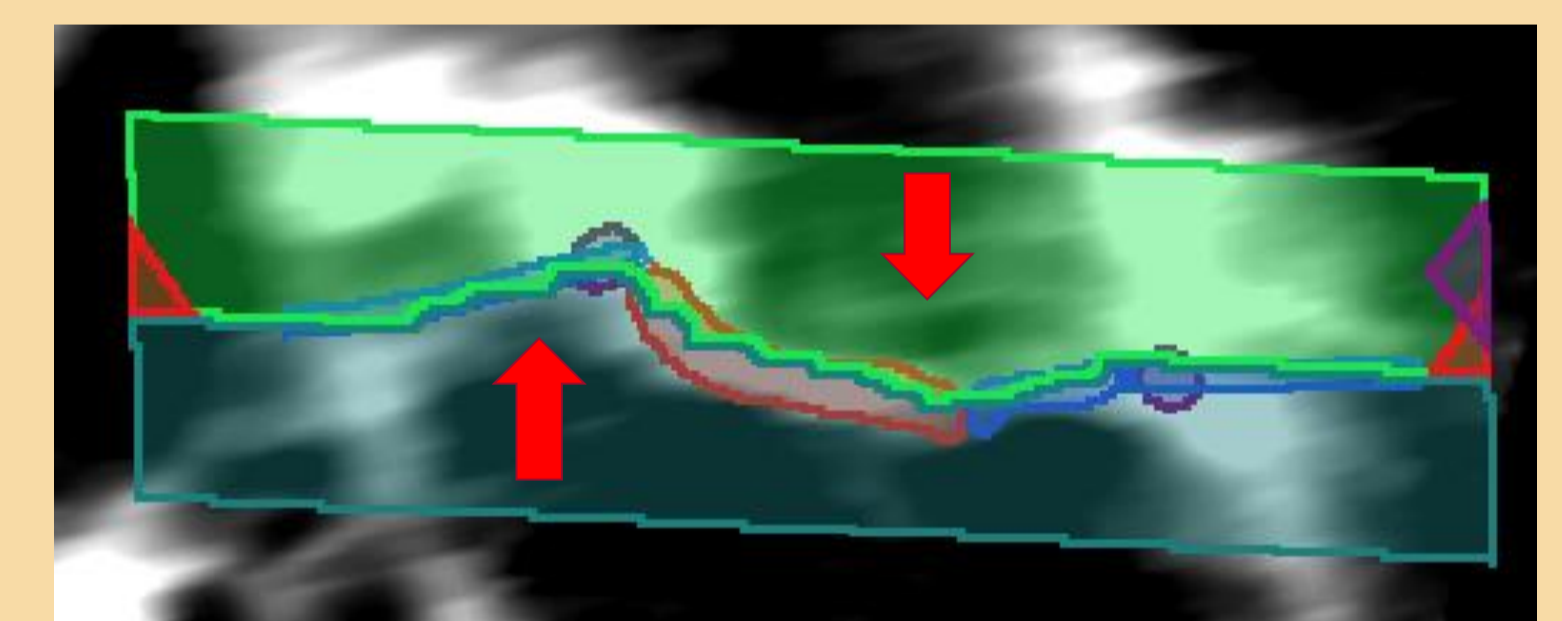
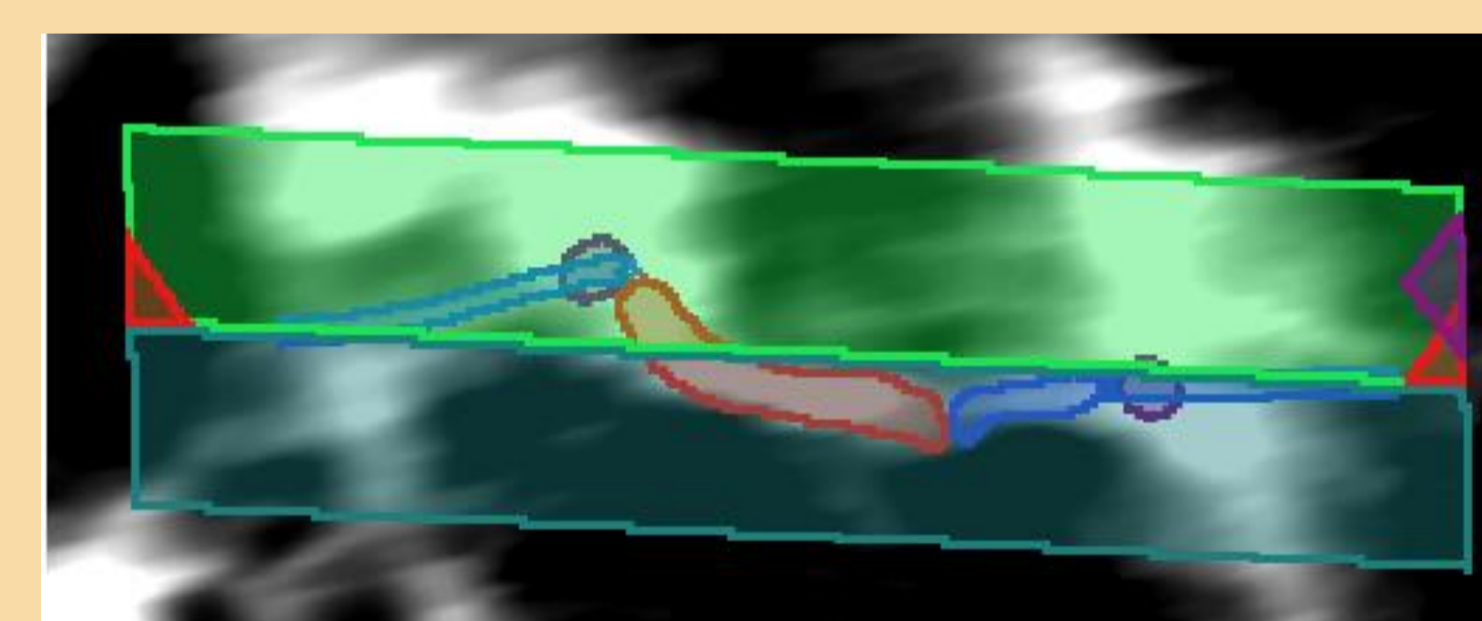


Fig 10. Top and bottom mold models before (left) and after (right) manual editing to fit the shape of the valve model; automating mold separation reduces mold design time

Conclusion

- Custom molds can be designed in the open source 3D Slicer software to create patient-specific models of various anatomical structures. We illustrated this method by creating heart valves for surgical simulation.
- Different materials can be used with the printed mold to create phantoms. Dragon Skin® silicone is well suited to mimicking tissue due to its flexibility and resistance to tearing.

Reference

- [1] Ilina et al., "Patient-specific pediatric silicone heart valve models based on 3D ultrasound," SPIE Medical Imaging 2017.
- [2] Pacioni et al., "Patient-specific ultrasound liver phantom: materials and fabrication method," Int J Cars 10(7), 1065-75 (2015).
- [3] Fedorov et al., "3D slicer as an image computing platform for the quantitative imaging network," Magnetic Resonance Imaging 30(9), 1323-41 (2012).