

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

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**Introduction.** Realistic physical models of anatomical structures are useful for surgical simulations and other medical procedures. These physical models or 'phantoms' should mimic the functional, mechanical and acoustical properties of the structure being modeled. The shape of structures can be accurately modeled using direct 3D printing, but currently available soft printing materials may still be too rigid to imitate human tissue. We propose a method for designing 3D-printable molds, which can be filled with a highly elastic material to create flexible and tear-resistant phantoms. We demonstrated this method by creating heart valve phantoms.

**Methods.** 3D Slicer software is used for designing the 3D-printable mold<sup>1</sup>. **Step 1: Segmentation.** Segment the object of interest from a 3D image using Segment Editor module. **Step 2: Mold design.** Create a rectangular prism segment surrounding the object using Scissors effect. Separate the rectangular prism into two segments to create the top and bottom mold pieces, following the shape of the structure being modeled. Add air tunnels in the top mold segment to allow air bubbles to escape when filling the mold. Export the top and bottom mold segments as models and save as STL files. **Step 3: Mold printing.** 3D print the mold models using standard ABS printing plastic. **Step 4: Physical model creation.** Fill the mold with a highly elastic material such as silicone or PVC and allow to set. Remove the phantom from the mold and trim any excess material.

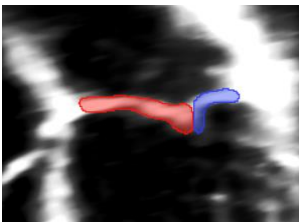


Figure 1. Segmentation of a mitral heart valve based on ultrasound image (step 1).

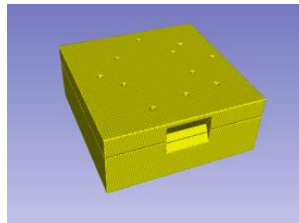


Figure 2. 3D mold box model for a mitral valve (step 2).

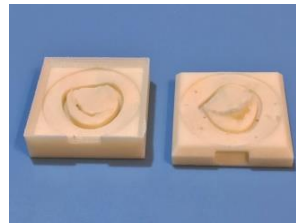


Figure 3. 3D-printed bottom mold (left) and top mold (right) for a mitral valve (step 3).



Figure 4. Silicone mitral valve created from mold (step 4).

**Results.** For simulating heart valve tissue, we created a silicone mixture of 2 parts Dragon Skin® Part A, 2 parts Dragon Skin® Part B, 1 part Slacker® tactile mutator and 1 drop Silc Pig® flesh tone silicone pigment (Smooth On, Inc., Macungie, PA, USA). This silicone is suitable for creating ultrasound phantoms<sup>2</sup> and its flexibility can be manipulated by altering the levels of tactile mutator added. Six cardiac surgeons evaluated the heart valve models and practiced suturing on them. They found the silicone material has a good flexibility, and cuts and holds sutures well without tearing<sup>3</sup>. 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. This method can be used to create phantoms of various structures such as heart valves, livers, and brain tumours, and can be automated for a specific structure.

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

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