

Automated Design and Low Cost Production of Patient-Specific MRI-Based Prostate Molds for the Correlation of MRI with Histopathology

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INTRODUCTION: There is mounting evidence in the literature that multi-parametric MRI performs better at detecting prostate cancer than single parametric maps or contrast based images. It is clear that with the added complexity of interpreting multiple images and quantitative maps, decision support systems can play a crucial role in the widespread use of multi-parametric MRI in clinical practice. In order to develop these systems, a gold standard correlating prostate MRI to whole-mount sections would be valuable. Unfortunately, the prostate gland is deformable and it is distorted by the use of endorectal coils leading to a deformed image. Furthermore, it is difficult to process the prostatectomy specimen such that the tissue blocks match the MRI. Individualized patient-specific molds designed from in-vivo MRI of each patients prior to surgery has been used to hold the specimen in the same shape as the MRI such that tissue blocks with the correct location and orientation can be obtained by cutting the deformable prostate (1). This method has been shown to be accurate (2), facilitating improved correlation of multi-parametric MRI with histopathology (3). The procedure of designing the mold using commercially available 3D CAD software, however, is labor intensive as it involves manual adjustments of the dimensions to fit each case. The procurement, operation and maintenance of the 3D printer required to create the molds is also expensive. In this work, we describe and demonstrate an automated method for designing these molds and creating them using open source software and a low cost 3-D printer.

METHODS: The prostate margin was segmented manually using MIPAV (<http://mipav.cit.nih.gov/>) in 3 mm multi-slice T₂-weighted Turbo Spin-Echo images in the axial (perpendicular to the rectum), coronal and sagittal orientation obtained from a 3 T MRI scanner with an endorectal coil and the anterior half of a 32-channel cardiac coil (Philips Medical Systems). The volume of interest in the three-views were combined into cloud of points and imported into Meshlab (<http://meshlab.sourceforge.net/>) where they were filtered to obtain a 3D model of the prostate and exported as an stereolithography (STL) file. A similar procedure was used to generate 3D models of the urethra in the apex and base of the specimen.

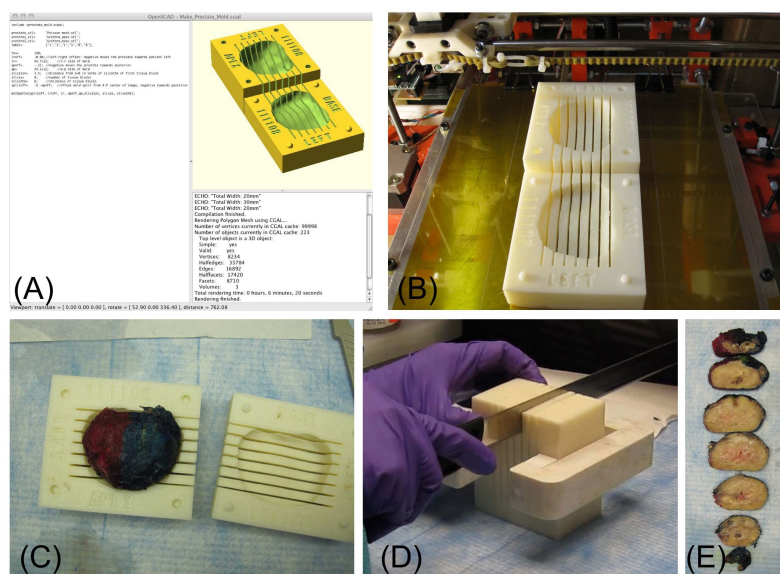
The customizable mold was designed in an open-source software, OpenSCAD (<http://www.openscad.org>). This software functions like a programming language where designs are modular and parametric. Variables were used to define the dimensions of the mold, the number and location of the slots for the cutting blade, the position of the prostate in the mold, and the where the mold is split in half. These parameters were determined from the STL file of the prostate using a MATLAB code. The spacing between blade slots was fixed at 6 mm. The dimensions of the mold in the three directions and the offset of the prostate model were determined from the minimum and maximum x, y and z vertices in the prostate STL file. The location of the split between the halves were determined from the average y location of the minimum and maximum y but sometimes needed to be manually adjusted. Thus, for the most part, the mold STL files were generated automatically after obtaining the STL model of the prostate (Figure A).

A Mendel RepRap 3D Printer (<http://reprap.org/wiki/Mendel>) with a 0.5 mm nozzle and a heated bed at 120C was constructed, contained in a box to maintain a temperature of around 40C, and used to produce the molds using 3 mm diameter ABS plastic feed (Figure B). The method was used in four prostatectomy cases.

RESULTS AND DISCUSSION

The use of the mold in one of the cases is shown in Figure C-E. Figure C shows the painted specimen (left posterior in red and right posterior in blue) contained in one half of the mold. Figure C shows the specimen contained in the mold while being cut through the slots. And, Figure C shows the resulting tissue blocks. The mold generated using the automated method functioned identically to those designed manually while requiring almost no human intervention. The use of OpenSCAD not only saves on the cost of the commercial software, but it also saves on the labor required to design the molds. The open source 3D printer is more than 10x cheaper to procure and operate that the commercial alternative and produce molds that are adequate for processing specimens.

CONCLUSION: The automated method of designing patient-specific molds would be practical in large population studies necessary to compile a training set for developing a decision support system for detecting and localizing prostate cancer. With the addition of automated prostate margin segmentation, the whole process can be automated starting from the MRI images.



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