Preoperative Planning of Percutaneous Nephrolithotomy Using Three-Dimensional (3D) Printed Models of Complex Kidney Stones

2015 Endourology Society Summer Student Scholarship Summary Report

Student: Kyle Spradling
Department of Urology
University of California, Irvine

Mentor: Jaime Landman, MD
Professor and Chairman, Department of Urology
University of California, Irvine
Orange, California, USA
Background:

Percutaneous nephrolithotomy (PCNL) has emerged as the gold standard for treatment of large kidney stones. However, despite improvements in surgical techniques, stone-free rates in patients with large, complex stones remain unsatisfactory. Patients with highly complex calculi may have stone-free rates ranging from 27% - 64% after PCNL. Using novel technology to educate and train urology residents to optimally plan and perform PCNL procedures in patients with complex kidney stones may lead to improved stone-free outcomes.

Recently, 3D computed tomography (3D-CT) imaging technology has shown promising results when used as a preoperative planning tool for PCNL. Furthermore, Silberstein and colleagues successfully constructed a physical model of a renal tumor using 3D printing technology and utilized their model as an education tool for residents and patients undergoing partial nephrectomy. Using similar methods, high quality models of kidney stones surrounded by renal parenchyma can be generated using standard CT images coupled with 3D printing technology. Three-dimensional printing technology allows these models to be customized to match the anatomy of the patient with high fidelity. These physical models could potentially be used to educate residents on how to characterize and localize kidney stones, develop a preoperative plan, and practice technical skills used during PCNL.

Objectives:

The primary objective of our project was to design and create patient-specific, physical 3D models of complex kidney stones, such as branched or complete staghorn stones, using 3D printing technology in order to reproduce the kidney with its specific collecting system and the indwelling stone in one model.

Our secondary objective involved testing the utility of the 3D printed model as a urology resident educational tool. Specifically, we assessed if the model could improve resident understanding of the stone anatomy and their ability to plan PCNL procedures using specific anatomical findings, including determination of the optimal calyx of entry into the collecting system.
system to provide the broadest range of access to stone-bearing calyces and angles of access from the intrarenal plane of the nephrostomy tract to each of the major and minor stone bearing calyces.

Finally, our third objective was to test the utility of the model in improving resident technical skills by designing a model made from soft rubber that allow residents to introduce the needle through the kidney to simulate the process of gaining access for PCNL procedures. Testing the models for utility as a technical trainer is still ongoing at our institution.

**Design and Methods:**

**Phase 1: 3D Printing of Models of Complex Kidney Stone**

We used specialized medical imaging processing software (Mimics, Materialise Inc., Belgium) to convert 64 serial axial computed tomography images of a complete staghorn kidney stone into patient-specific 3D computer-aided designs (CAD) of renal and stone anatomy (Figure 1). Three 3D printing technologies were used to manufacture three different stone-containing renal models: fused deposition modeling of thermoplastics, polyjet printing of rubber-like TangoPlus elastomers, and polyjet printing of rigid VeroClear thermoplastics (Stratasys Ltd. MN, USA). The VeroClear model was designed as a translucent renal parenchyma with an opaque white stone inside. Following the 3D printing, kidney models were cleaned and all internal and external support structures were manually removed.

**Phase 2: Resident Education Using 3D Printed Models**

To assess the educational utility of the VeroClear kidney and stone model, a cohort of 10 urology residents and fellows were randomized into two groups. The first group of 5 trainees (Group A) used the 3D printed renal model in addition to traditional cross-sectional CT imaging in order to physically examine the renal anatomy, shape, configuration and location of the stone. The second group of 5 trainees (Group B) evaluated traditional cross-sectional CT images but did not have access to the 3D printed models.

After evaluating traditional cross-sectional CT images and 3D printed training model for the patient with a complex renal stone, all participants
completed a Likert scale questionnaire to prospectively assess their understanding of stone shape and location, ability to determine the optimal calyx of entry into the collecting system to provide the broadest range of access to stone-bearing calyces, ability to make an operative plan to access each major and minor stone-bearing calyx, and their overall confidence in performing the PCNL procedure. Additionally, the residents who used the 3D printed model also completed additional survey questions assessing their opinion of how useful the 3D models would be as a preoperative planning tool.

Results:
As seen in Figure 2, we successfully manufactured 3 patient-specific 3D kidney models containing anatomically-accurate staghorn stones using three different 3D printing technologies. First, using fused deposition modeling of white thermoplastics, we were able to print kidney parenchyma and staghorn stone separately with anatomically-correct size and shape (2A, 2D). Second, using polyjet printing of TangoPlus elastomers we were able to construct a rubber-like kidney which contained a solid plastic staghorn stone (2B). The soft, rubber-like material allowed our team to introduce needles into the model and reach the stone inside. While this model combined both stone and kidney, the TangoPlus material was not translucent enough to easily visualize the anatomy of the stone within the kidney model. Therefore, we also used polyjet printing of rigid VeroClear thermoplastics to create a translucent renal parenchyma with an opaque white stone inside (2C). This model successfully combined both kidney and stone in their anatomically correct orientation while also allowing easy visualization of the stone through the translucent kidney.

Results of the urology resident and fellow questionnaires are shown in Figure 3 and trended in favor of the model as a useful educational tool for urology trainees learning to perform PCNL. Average total questionnaire scores were 38/50 and 30.4/50 for Group A and Group B, respectively (p=0.23). Group A trended toward higher familiarity with the shape and orientation of the stone (8.2/10 vs. 6.4/10, p=0.22) and trended toward greater overall confidence in performing PCNL (6.4/10 vs. 5/10, p=0.26); however, these differences did not achieve statistical significance. All trainees (5/5) using the renal model reported that a 3D printed model could be a useful tool in planning PCNL.
Figure 2: Patient-specific 3D printed models of renal and stone anatomy using (A) fused deposition modelling of thermoplastics, (B) semi-translucent, rubber-like TangoPlus polyjet printing, and (C) polyjet printing of VeroClear thermoplastics. (D) Additionally, the complete staghorn stone was 3D printed separately to show detail.
**Figure 1:** 3D CAD reconstruction of complete staghorn renal calculus was generated from standard cross-sectional computed tomography images.

**Figure 3:** Average trainee scores for Group A and Group B for each question in the Likert scale questionnaire.
Comments:

Our results of this pilot study suggest that 3D printing of patient-specific complex renal calculi is feasible. Furthermore, our technique of using VeroClear thermoplastics to print kidney parenchyma allows easy visualization of the kidney stone inside the model. While limited to only 10 urology trainees at our institution, our early data was compatible with a trend favoring these 3D printed models as a useful education and training tool for urology residents and fellows. Further study is in progress with a larger cohort of residents to better evaluate the role of 3D printed kidney stone models in trainees’ understanding of renal anatomy and the percutaneous approach to large renal calculi.

Additionally, our team is currently developing other designs of the 3D printed model with hollow spaces within the calyces in order to enable urology trainees to practice endoscopic skills by introducing endoscopic devices into the hollow spaces and simulate PCNL procedures. Our future objectives will be to use 3D printed kidney models to perform exercises such as establishing access sites, dilating the nephrostomy track and, and navigating the collecting system using nephroscopes and ureteroscopes to determine track suitability for accessing various areas of the renal collecting system.

Finally, our ultimate goal is to prospectively evaluate the impact of our 3D models on outcomes of PCNL procedures. We expect that the use of preoperative 3D models will improve the surgeon’s understanding of the stone location, influence operative decision-making, and improve overall rates of stone-free status in patients undergoing PCNL for large, complex stones. Our team is currently recruiting patients for this prospective study.

Acknowledgements:

I would like to thank the Endourology Society for supporting this research through the 2015 Summer Medical Student Scholarship Program, and for the opportunity to present this work at the 2015 World Congress of Endourology in London. I would also like to thank my mentor, Dr. Jaime Landman, for his guidance and support throughout this project. Finally, I would like to thank Statasys for providing their 3D printing services.
References:

