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# Impact of a 3D printed model on patients' understanding of renal cryoablation: a prospective pilot study

Collin Schmit,[1] Jane Matsumoto,[1] Kathleen Yost,[2] Amy Alexander,[1] Lori Ness,[1] A. Nicholas Kurup,[1] Thomas Atwell,[1] Bradley Leibovich,[3] and Grant Schmit[1]

[1]Department of Radiology, Mayo Clinic, 200 1st St. SW, Rochester, MN 55905, USA
[2]Department of Health Sciences Research, Mayo Clinic, Rochester, MN, USA
[3]Department of Urology, Mayo Clinic, Rochester, MN, USA

## Abstract

*Purpose:* To determine whether a 3D printed model improves patients' understanding of renal cryoablation and the involved anatomy.
*Methods:* This prospective study included 25 control patients, who received standard of care renal cryoablation education (verbal explanation accompanied by review of relevant 2D imaging) and 25 experimental patients, who received education using a 3D printed renal cryoablation model in addition to standard of care. Subsequent patient surveys included 5 anatomy and 5 procedural knowledge questions. The experimental cohort also subjectively graded the importance of the 3D model for understanding the renal cryoablation procedure and associated anatomy.
*Results:* Mean percent of anatomy questions answered correctly was significantly higher in the experimental cohort than that in the control group (87.2% vs. 72.8%; $p = 0.007$). After adjusting for the physician providing the education, however, the 3D model was no longer significantly associated with patient anatomy knowledge ($p = 0.22$). Mean percent of procedure-related questions answered correctly was higher in the experimental cohort (93.6%) than that in the control group (89.6%) ($p = 0.16$). The experimental cohort graded the importance of the 3D model for understanding their renal tumor anatomy and upcoming procedure to be very high (mean 9.4 and 9.5, respectively, on a 0–10 point scale). Twenty-three (92%) patients "definitely recommended" continued use of the 3D model as a patient educational tool.
*Conclusions:* Although patients' objective anatomy and procedural knowledge was not significantly improved with the 3D renal cryoablation model in this small pilot study, patients' high perceived value of the model supports investigation in a larger study.

**Key words:** 3D Printing—Kidney—Cryoablation—Patient Education

Medical applications for three-dimensional (3D) printing are rapidly expanding. 3D printed anatomic models have been shown to be valuable tools to help physicians understand anatomy, plan procedures, and even practice procedures [1–5]. Additional studies have shown the value of 3D printed models for educating residents and fellows [6–9]. Since patients have significantly less experience looking at cross-sectional imaging than physicians, it is intuitive that 3D models would also be valuable to patients to help understand their medical conditions and potential treatments.

Percutaneous cryoablation has become an increasingly popular treatment option for patients with small renal tumors [10–13]. However, it is still much less common than surgery and probably harder to conceptualize for patients. Despite the best efforts of the clinical team, potential renal cryoablation patients may select alternative treatments if they do not confidently understand how the procedure is performed. The goal of this study was to determine if a 3D printed renal cryoablation educational model would help patients better understand the involved anatomy and procedure.

## Materials and methods

### *Study design*

Institutional Review Board approval for this single institution prospective pilot study was obtained, and the

*Correspondence to:* Grant Schmit; *email:* schmit.grant@mayo.edu

study was compliant with the Health Insurance Portability and Accountability Act (HIPPA). Written informed consent was acquired from all patients included in the study. The control group comprised 25 consecutive renal cryoablation patients, who received the current patient education standard of care between 10/5/2016 and 3/2/2017. This included verbal explanation of the procedure accompanied by review of the patient's relevant 2D imaging (computed tomography or magnetic resonance imaging). The experimental cohort comprised the next 25 consecutive patients, who received renal cryoablation education between 3/3/2017 and 11/15/2017 using the 3D printed model in addition to the standard of care education. The groups were not randomized due to logistic reasons. Given the significant amount of time required to plan, segment, and print the 3D renal cryoablation model, the control arm was assessed first while the model was being created. The experimental cohort was then evaluated when the model became available.

A survey was administered to all patients immediately following the educational session, which included objective questions regarding the patient's specific renal tumor anatomy and scheduled ablation procedure. Patients in the experimental cohort were also asked to subjectively grade how important the 3D model was to their understanding of the relevant anatomy and procedure. Patient variables that could potentially influence patients' comprehension of the presentation or impression of the 3D model were obtained from the medical record including: patient age, sex, level of education, and the physician providing the education. English was the primary language for all patients in both the control and experimental groups.

### *Creation of 3D printed model*

The 3D model for renal cryoablation patient education was created in an institutional 3D printing lab by a college student (author CS) during a summer radiology internship. This student was mentored by the 3D lab director (author JM) and lead biomedical engineer (author AA). The life-sized 3D model was generated using high-resolution images from a CT urogram of a prior renal cryoablation patient. This patient had a 3 cm exophytic tumor in the posterolateral lower pole of the left kidney, which was in an optimal location for renal ablation. Digital Imaging and Computing in Medicine (DICOM) 2D images were imported into dedicated 3D software (Mimics, Materialise; Leuven, Belgium), and segmentation of the relevant anatomy was performed using both automated and hand-tracing techniques (Fig. 1A). The resultant 3D virtual computer model included both kidneys, the renal collecting systems and proximal ureters, the left renal tumor, the renal arteries and veins, and the aorta and inferior vena cava. The spine, lower ribs, psoas muscles, and iliac crests were also included to help patients better understand the location of the kidneys in the body. The model was then converted to Standard Triangle Language (STL) files and further augmented using computer-aided design software (Materialize 3-Matic, Plymouth, MI). A translucent ablation ice ball was created around the renal tumor, pilot holes were formed into the tumor for subsequent cryoprobe placement, and a plane was generated through the left kidney, tumor, and ablation ice ball, so the internal renal anatomy could also be visualized (Fig. 1B). Connecting pegs were added to attach nontouching anatomic structures and hold the model together after printing. The STL files were then imported into the printer software, and the 3D model was printed (Objet350 Connex printer, Stratasys; Eden Prairie, MN). This multicolor 3D printer continuously deposits 30-µm layers of photopolymer, which are immediately hardened by ultraviolet light. The model took approximately 40 h to print, and the printing materials cost approximately $400. The model was cleaned, sanded, and sealed. Magnets were installed to hold the two pieces of the left kidney together. To complete the model, cryoprobes were inserted via the pilot holes present in the left renal tumor and ablation ice ball (Fig. 1C).

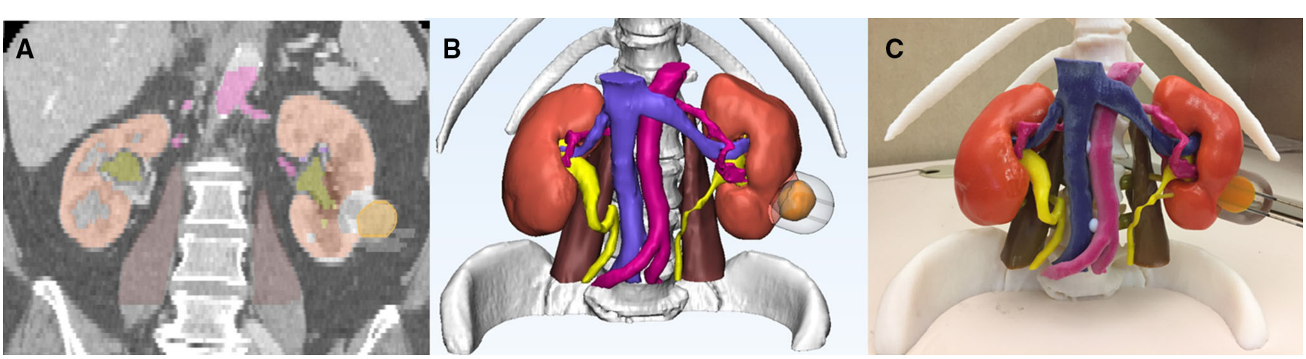


**Fig. 1.** Renal cryoablation model shown in **A** 2D segmented form **B** 3D electronic form, and **C** 3D printed form.

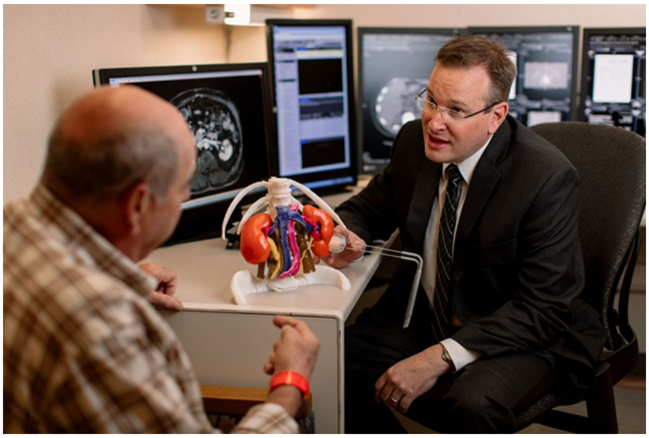

Fig. 2. Radiologist educating one of the experimental group patients using the 3D printed renal cryoablation model.

**Table 1.** Objective questions for the control and experimental groups

Anatomy questions
1. You have two kidneys?
2. Your tumor is in the lower half of the kidney?
3. Your tumor is in the right kidney?
4. Your tumor is at least partially outside the kidney?
5. Your tumor is close (< 2 cm) to the ureter?

Cryoablation procedure questions
1. For cryoablation to be successful, the ice ball needs to completely encase the tumor?
2. An advantage of cryoablation is that it kills the tumor while saving most of your kidney?
3. During the cryoablation, the tumor is removed from your body?
4. Bleeding is the main complication risk with renal cryoablation?
5. You need a ureteral stent placed prior to cryoablation?

Available answers for the above questions included: True, False, and Don't Know

### *Renal cryoablation educational session and study questionnaire*

Patient educational sessions (Fig. 2) were performed by one of three interventional radiologists (authors ANK, GS, and TA) with 9, 12, and 14 years of renal cryoablation experience respectively. The approximately 20 min patient consultations were standardized to the extent possible, and the three radiologists addressed the patients' specific renal tumor anatomy and procedure using 2D imaging only in the control group and using the 3D printed model in addition to the patients' 2D imaging in the experimental cohort.

At the conclusion of the educational session and after the radiologist had left the room, a paper survey was administered to each patient by a dedicated renal ablation nurse (author LN). The control group questionnaire included 5 renal tumor anatomy questions and 5 procedure-related questions, which we believed should have been answerable following the educational session (Table 1). The goal of these 10 questions was to assess patients' objective understanding of the relevant anatomy and renal cryoablation procedure. Patients were also asked to grade their overall impression of the quality of the educational session on a 0–10 point scale, with 0 being worst possible and 10 being best possible. The experimental group questionnaire included all of the questions in the control group survey, as well as additional subjective questions regarding the patients' perceived importance of the 3D printed model on their understanding of the relevant anatomy and ablation procedure (Table 2). These subjective questions were also graded on a 0–10 point scale. Finally, the experimental group was asked whether they felt the 3D printed model should continue to be used as a tool for educating future renal cryoablation patients. Available answers to this question included: definitely yes, probably yes, probably not, and definitely not.

**Table 2.** Subjective questions for the experimental group

1. How important do you think the physician's use of the 3D model was in helping you understand the size and location of your kidneys?
2. How important do you think the physician's use of the 3D model was in helping you understand the size and location of your renal tumor?
3. How important do you think the physician's use of the 3D model was in helping you understand how the renal cryoablation procedure will be performed?

The above questions were graded on a 0–10 point scale, with 0 being not at all important and 10 being extremely important

### *Statistical analysis*

The patient surveys were graded by author GS after review of each patient's preprocedural cross-sectional imaging and the ablation consultation clinical note in the medical record. Nominal and ordinal participant characteristics (patient sex, education, and physician performing the education) were compared across groups using Chi square or Fisher's exact test. Age was compared using t-tests. General linear models were used to evaluate the association between knowledge scores and group (control vs. experimental) unadjusted and adjusted for the effect of the specific physician performing the education. $p$ values $< 0.05$ were considered statistically significant. Statistical analyses were performed using SAS software (SAS Institute Inc., Cary, NC, USA).

## Results

### *Patient characteristics*

Mean age of the 25 control group patients was 67.2 years (SD 10.7) and 14 (56%) patients were male; mean age in the 25 experimental group patients, who underwent renal cryoablation education with the 3D printed model, was 67.5 years (SD 11.7) and 19 (76%) patients were male.

Patient characteristics in the control and experimental groups were similar with respect to age, sex and education, but differed significantly across physician performing the education ($p = 0.001$) (Table 3).

### *Study outcomes*

Unadjusted patient anatomy knowledge scores were significantly higher in the experimental cohort compared to the control group (87.2% vs. 72.8%; $p = 0.007$). Unadjusted patient procedural knowledge scores were also higher in the experimental cohort compared to the control group (93.6% vs. 89.6%), although this difference was not statistically significant ($p = 0.16$). Unadjusted anatomy knowledge scores were significantly different depending on the physician performing the education, with a range of 69.4% correct for patients educated by Radiologist 2 to 89.2% correct for patients educated by Radiologist 3 ($p = 0.002$). Unadjusted procedural knowledge scores did not differ significantly by physician ($p = 0.31$) (Table 4).

Because anatomy knowledge scores differed significantly by the physician performing the education and because patients were not evenly distributed across physicians in the control and experimental groups, the association between anatomy knowledge scores and group was further assessed after adjusting for the potential confounding effect of physician. Table 5 shows that after adjusting for the effect of the physician performing the education, the improvement in anatomy knowledge scores for the experimental cohort compared to the control group was no longer statistically significant ($p = 0.22$). Patient anatomy knowledge scores improved most with the use of the 3D model for Radiologist 2 (control group mean 69.4% correct vs. experimental group mean 88.4% correct), and use of the 3D model therefore significantly raised the minimum threshold level of anatomy knowledge for patients regardless of physician.

Patients' perceived quality of the consultation was extremely high in both the control and experimental groups. Mean score in the control group was 9.7 (SD 0.5), and mean score in the experimental group with the 3D model was 9.7 (SD 0.6) on a 0–10 point scale ($p = 0.91$). There was also no significant difference in patients' scoring of the quality of the consultation depending on which of the three physicians provided the educational session ($p = 0.74$). Patients in the experimental group graded the 3D model to be extremely important for understanding their specific renal tumor anatomy (mean 9.4 (SD 1.3)) and upcoming procedure (mean 9.5 (SD 1.3)) on a 0–10 point scale. Twenty-three (92%) of patients reported that they would "definitely recommend" continued use of the 3D printed renal ablation model for patient education, while one patient would "probably recommend" and one patient would "probably not recommend" its continued use.

**Table 3.** Patient characteristics

| | Control ($N = 25$) (%) | Experimental ($N = 25$) (%) | *p* value |
|---|---|---|---|
| Age (years); mean (SD) | 67.2 (10.7) | 67.5 (11.7) | 0.91 |
| Sex (*n*, %) | | | 0.14 |
| Male | 14 (56) | 19 (76) | |
| Female | 11 (44) | 6 (24) | |
| Education | | | 0.92 |
| High school or less | 8 (32) | 8 (32) | |
| Some college | 6 (24) | 5 (20) | |
| College graduate | 5 (20) | 7 (28) | |
| Post-college degree | 6 (24) | 5 (20) | |
| Physician providing consultation (*n*, %) | | | 0.001 |
| Radiologist 1 | 4 (16) | 3 (12) | |
| Radiologist 2 | 15 (60) | 4 (16) | |
| Radiologist 3 | 6 (24) | 18 (72) | |

## Discussion

While patients who underwent renal cryoablation consultation with the addition of a 3D printed model demonstrated improved objective knowledge of their renal tumor anatomy and upcoming renal cryoablation procedure, the improvement was not statistically significant in this relatively small pilot study. Patients did perceive the model to markedly improve their understanding, and 92% "definitely recommended" the continued use of the 3D printed renal cryoablation model as a patient educational tool.

**Table 4.** Unadjusted association between group or physician and knowledge

| | Percent correct-anatomy knowledge | | Percent correct-procedure knowledge | |
|---|---|---|---|---|
| | Mean (SD) | *p*-value | Mean (SD) | *p*-value |
| Group | | 0.007 | | 0.16 |
| Control | 72.8% (19.9%) | | 89.6% (11.7%) | |
| Experimental | 87.2% (16.2%) | | 93.6% (11.1%) | |
| Physician providing consultation | | 0.002 | | 0.31 |
| Radiologist 1 | 77.1% (13.8%) | | 94.3% (15.1%) | |
| Radiologist 2 | 69.4% (21.5%) | | 88.4% (12.1%) | |
| Radiologist 3 | 89.2% (14.4%) | | 93.3% (9.6%) | |

**Table 5.** Adjusted association between group or physician and knowledge

| Variable | Percent correct-anatomy knowledge | | Percent correct-procedure knowledge | |
|---|---|---|---|---|
| | Mean (%) | *p*-value | Mean (%) | *p*-value |
| Group | | 0.22 | | 0.51 |
| Control | 75.3 | | 90.9 | |
| Experimental | 82.4 | | 93.4 | |
| Physician providing consultation | | 0.04 | | 0.31 |
| Radiologist 1 | 77.6 | | 94.5 | |
| Radiologist 2 | 71.5 | | 89.1 | |
| Radiologist 3 | 87.4 | | 92.7 | |

Prior studies have shown 3D printed models to be useful for medical education [6–9]. Since patients have less experience with looking at cross-sectional imaging than physicians, 3D printed models may be even more valuable to help patients understand their medical conditions and potential treatments. Two small recent studies, including 5 and 7 patients, assessed the value of patient-specific 3D printed models for patient education prior to renal surgery and percutaneous nephrolithotripsy [14, 15]. Both studies showed a significant improvement in patients' objective understanding of the relevant anatomy and procedure. However, in both studies, patients answered the same survey questions following patient education without the 3D printed model immediately followed by patient education with the 3D model. This study design has significant in-built bias due to repetition of information in the 3D model presentation and the fact that the patients already knew the questions that would be asked while receiving education with the 3D model.

Patients in the current study perceived the 3D cryoablation model to be extremely important (mean grade > 9 on a 0–10 point scale) for understanding their renal tumor anatomy and upcoming procedure. This parallels findings from other 3D printed model studies. For example, Giovanni et al. demonstrated that 73% of parents of children with congenital heart disease rated 3D printed models as "very useful" for understanding their child's cardiac condition [16], and a small study by Silberstein et al. evaluating 3D printed models of renal masses reported that patients and their families verbally expressed improved comprehension of the size and location of their tumors and upcoming surgery [17].

Physician communication is critical to patient satisfaction. In fact, in a study of 456 surgical patients by Schomocker et al., effective preoperative communication by the surgeon was the most important factor for determining patient satisfaction [18]. The current study and other studies would suggest that 3D printed models can improve patient-physician communication during the preprocedural consultation compared to review of the 2D imaging alone. In addition, patient satisfaction has been shown to improve medical outcomes. In a study of 757 surgical patients, Prabhu et al. showed an association between patient satisfaction and both 30-day readmission and occurrence of surgical complications [19]. As we move to a pay-for-performance healthcare system, patient satisfaction and quality care will become increasingly important. Using 3D printed models, such as the one used in this study for patient education, may be a relatively inexpensive and a time-efficient way to enhance quality care.

Percutaneous ablation has proven to be a safe and effective treatment for patients with small renal masses [10–13], and current American Urologic Association (AUA) guidelines include renal ablation as a viable treatment option for patients with T1a (≤ 4 cm) renal tumors [20]. Urologists at our institution now present all patients with T1a renal tumors with three potential treatment options: surgery, percutaneous ablation, or active surveillance. Risks and benefits of each approach are discussed with the patient, and a specific treatment may be recommended based on patient‘s age and other medical comorbidities. Although renal ablation has become more common, it is likely more difficult for patients to conceptualize than surgery or active surveillance, and a lack of understanding about the procedure may influence patients away from ablation. Other catheter- and needle-based interventional oncology procedures are also likely more difficult for patients to comprehend than alternative treatments such as surgery and radiation therapy, and 3D printed models may be helpful to explain these procedures as well.

This study used a single generic 3D printed renal cryoablation model for patient education. Patient-specific anatomic models would have likely been even more valuable to patients. However, there are significant barriers currently for producing large numbers of 3D printed models. First, at present, there is no reimbursement for medical 3D printing, and the high-end 3D printer used in this study cost approximately $400,000, and the materials for printing the renal cryoablation model cost approximately $400. In addition, the amount of time required to segment a patient's cross-sectional imaging and print a model currently is even more prohibitive than the cost. As more automated segmentation software becomes available and the cost of producing 3D printed anatomic models decreases, we hope to be able to create patient-specific models for patient education.

As a result of this pilot study, an identical printed copy of the 3D renal cryoablation model has been produced for use in the Urology clinic during the initial consultation process. Plans are underway to perform a collaborative, larger-scale, prospective, randomized study of the 3D printed renal cryoablation model, which would include any patient presenting to the Urology clinic with a small renal mass, who is a candidate for surgery, ablation, or active surveillance. In addition to endpoints explored in this pilot study, the primary outcome of interest for the larger study will be to determine if the 3D model increases the number of patients who select percutaneous cryoablation as a treatment option.

There are several limitations to this study. First, the study included a relatively small number of patients, and each patient was asked only 5 anatomy- and 5 procedure-related questions, which limited the power of the study to determine an objective knowledge difference between the control and experimental groups. Second, the study was not randomized to allow patient's accrual into the control arm, while the 3D model was being created. Third, although the renal cryoablation consults were standardized as much as possible, information relevant to the survey questions may not have been completely covered in all patients. Fourth, results were confounded by the significant variability in the number of consults performed by each physician in the control and experimental groups. Fifth, patients likely received variable renal tumor anatomy and renal cryoablation information from Urologists, other physicians, the internet, etc. prior to the ablation consult, and this may have influenced their ability to answer the survey questions correctly. Sixth, the 3D printed model was not patient specific, and this may have limited patients' understanding of their specific renal tumor anatomy. Finally, not all of the anatomy and procedural questions included in the survey could be displayed/answered using the 3D model alone.

In conclusion, patients did not demonstrate a statistically significant improvement in objective knowledge of their renal tumor anatomy and renal cryoablation procedure with the addition of a 3D printed model to the standard patient education in this small pilot study. However, patients' very high perceived value of the 3D model as an educational tool supports further investigation in a larger study.

#### Compliance with ethical standards

**Disclosures** None for any authors.

**Ethical approval** IRB approval was obtained for the study.

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