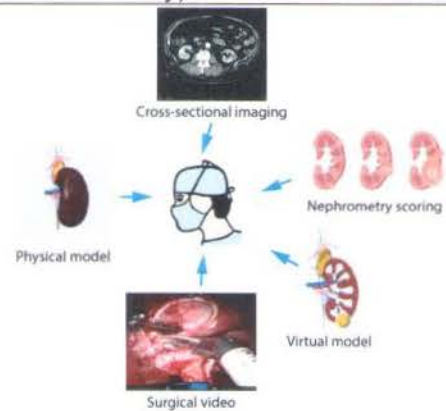


APPLICATION FOR ACADEMY OF DISTINGUISHED EDUCATORS FULBRIGHT & JAWORSKI L.L.P. EDUCATIONAL GRANT		LEAVE BLANK-FOR ADMINISTRATIVE USE ONLY	
		Date received:	Date Reviewed:
TITLE OF PROJECT: Electrons to atoms: using patient-specific digital and physical anatomic models to teach skills critical for robotic renal surgery.			
NAME OF APPLICANT: Richard E. Link		DEGREE(S): M.D., Ph.D.	
POSITION TITLE: Associate Professor of Urology Director, Comprehensive Kidney Program Director, Division of Endourology and Minimally Invasive Surgery		MAILING ADDRESS: c/o Ms. Carol Vacek BCM Faculty Center 1709 Dryden, Suite 16.12 Houston, Texas 77030	
DEPARTMENT, SERVICE, SECTION: Scott Department of Urology, Baylor College of Medicine			
TEL: 713-798-3498	FAX: 713-798-5553	EMAIL: link@bcm.edu	
PROJECT ABSTRACT (maximum of 300 words):			
<p>Over the past decade, the standard of care for treating kidney cancer has dramatically shifted from open to robotic surgery. It is now absolutely essential for urology trainees to achieve competency in robotic renal surgery before completing residency, although the most efficient path remains unclear. Today, robotic partial nephrectomy (RPN) is a common and highly challenging procedure involving tumor excision and kidney reconstruction within a virtual reality environment. It requires a detailed three-dimensional understanding of the relationship between tumor and vital renal structures, which can differ dramatically between cases. For urologic trainees, achieving this sophisticated spatial understanding from standard cross-sectional imaging can be difficult. Failure results in long operative times, higher complication rates, incomplete tumor removal, extended periods of warm ischemia, and unnecessary permanent kidney injury.</p> <p>We hypothesize that a structured curriculum outside the operating room based on multiple teaching modalities can shorten the learning curve. Our primary goal is to develop a case-based library of tumors derived from actual RPN cases. For <u>each</u> case, the learner explores the anatomy interactively by combining (a) cross sectional imaging, (b) digital models created by volumetric reconstruction, (c) nephrometry scoring, (d) intraoperative surgical video showing tumor isolation, resection and reconstruction and (e) a physical scale-model of the kidney and tumor <i>in situ</i> created via 3D printing. Trainees take pre and post training tests to assess their ability to predict surgically relevant tumor/kidney relationships before and after completing the curriculum.</p> <p>A secondary goal is to explore efficient conversion of cross sectional imaging data into volumetric kidney models suitable for 3D printing. We hope to develop a streamlined, cost-effective workflow for generating these models preoperatively for new cases. This would provide groundwork for future studies assessing model value in improving minimally invasive surgical treatment of renal tumors, complex stones and ureteral obstruction.</p>			
<p><i>"The signature below testifies that upon receipt of the grant, I will submit an annual one-page progress report and a one-page final report upon conclusion of all activities to the Academy Educational Grant Review Committee"</i></p>			
SIGNATURE OF APPLICANT:		DATE:	
		May 12, 2013	

Narrative Section (limit to 3 pages)	A) Goals/ Objectives and Specific Aims B) Proposed plan of work C) Significance: role of the proposed activity in a) enhancement of applicant's development as an educator, b) to the department and or the College D) Applicant's background, skills, previous work pertinent to the project E) Clear methods of assessment of work proposed (if applicable) F) Timeline G) Feasibility / Demonstration of time and ability to complete the activity)
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(A) Goals/Objectives:

Goal #1: Develop a structured educational library of illustrative renal tumor cases based on imaging and surgical video from de-identified patients. The goal will be to enhance the surgeon's three-dimensional anatomic understanding of various tumors relative to vital renal structures and potentially shorten the early learning curve for robotic-assisted laparoscopic partial nephrectomy (RPN). The library will combine multiple educational modalities for each case, including cross sectional imaging, nephrometry scoring, virtual models derived from volumetric reconstruction, surgical video as well as physical scale models created by 3D printing technology.



Specific aim #1a: Identify fifteen patients with illustrative tumor morphologies and collect cross-sectional DICOM imaging data and surgical video during robotic-partial nephrectomy cases. Cases will be selected spanning a wide range of visualization difficulty including (a) anterior and posterior, upper and lower pole tumors; (b) anterior and posterior mid-pole tumors involving the renal vascular hilum; (c) completely endophytic tumors involving the renal collecting system; as well as (d) tumors spanning a size range from one to seven cm (T1a, T1b). An illustration will be prepared for each case demonstrating calculation of the R.E.N.A.L. nephrometry score, which has been shown to correlate with difficulty during surgical resection.^{1,2}

Specific aim #1b: Perform volumetric reconstructions of the DICOM data to generate a three-dimensional virtual model. These virtual models will contain, at minimum, anatomic information including the renal cortex and medulla, the collecting system and renal pelvis, the main renal vasculature and the tumor of interest *in situ*. These models will be rotatable and various components can be highlighted or rendered transparent (i.e. to allow visualization of a completely endophytic tumor within the renal cortex).

Specific aim #1c: Convert the virtual models into a format suitable for 3d printing and generate scale physical models for each case. Models will be generated using additive printing technology with different classes of structures color-coded appropriately. In addition, models will be bivalved to allow the relationship of the tumor to internal kidney structures (vessels, collecting system, renal sinus) to be appreciated.

Specific aim #1d: Integrate the virtual and physical models into a structured curriculum that can be implemented within the Scott Department of Urology or nationally. Residents and fellows will be offered the curriculum including both pre and post testing on challenging tumor visualization cases. Feedback will be elicited concerning which of the multiple educational modalities was most and least beneficial for the learning of individual participants.

Goal #2: Develop a streamlined; cost-effective workflow to generate 3D printed physical renal models from standard cross-sectional imaging datasets. The goal is to allow easy production of physical models prior to complex renal surgery on a regular basis. This workflow will provide the necessary groundwork for subsequent trials assessing the value of models in improving minimally invasive surgery for renal tumors, complex nephrolithiasis and ureteral obstruction.

Specific aim #2a: Explore several software and hardware workflows to find the most streamlined and cost-efficient method for producing patient-specific renal models. Time invested and unit cost will be recorded for each workflow using different software pathways including both open source and commercial packages. Likewise, several different 3d printing modalities (additive 3d printing, fused deposition modeling and

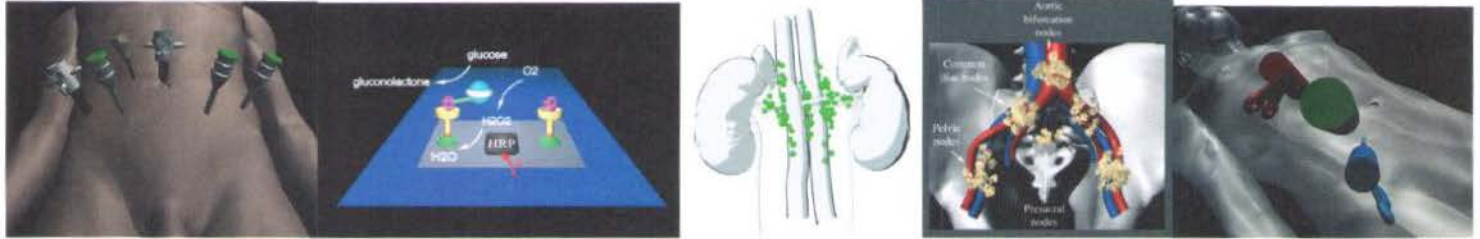
stereolithography) will be explored and assessed for cost and usability of the generated model.

(B) Proposed plan of work: Fifteen cases will be selected for inclusion in the library based on a diversity of tumor morphologies and locations as defined in specific aim #1a. DICOM cross-sectional image files from triphasic abdominal CAT scans will be transferred to a Drobo[®] 5D RAID storage drive with multi-drive redundancy for backup. Figures will be prepared showing standard R.E.N.A.L nephrometry scoring¹ calculation for each case. Uncompressed video will be collected during robotic-partial nephrectomy surgery, transferred to the Drobo and then converted to compressed mp4 format for subsequent editing. Video editing will be performed using *Final Cut Pro X*[®] (Apple). A target video length of 10 min will include edited footage of renal mobilization, tumor exposure and excision and kidney reconstruction. DICOM files for an additional challenging 5 pre and 5 post test cases will be stored for test preparation. For the fifteen library cases, DICOM image files will be visualized using *Osirix*[®] software (©Antoine Rosset, 2013) and 3D volumetric reconstructions will be generated for the kidney and tumor of interest and saved in .stl format (specific aim #1b). Refinement of the renal models will be handled using *Rhino 5*[®] (R. McNeel & Assoc), a powerful 3D free-form modeling software package suitable for organic shapes with complex curved surfaces. Photorealistic rendering of these models as well as design of educational animations will be created by importing them into *Maya*[®] (Autodesk), a versatile software package used in the entertainment industry. To prepare the models for subsequent 3D printing (specific aim #1c), they will be imported into *Solidworks*[®] (Dessault Sys.), a parametric CAD package. Within *Solidworks*, the relevant anatomic components (renal cortex, medulla, tumor, collecting system, arteries and veins) will be isolated as separate components and assigned unique colors for printing. Note that there are already streamlined rapid prototyping workflows for converting *Solidworks* CAD components into full color 3D printed objects. We intend to explore the cost and quality of models printed using three different technologies: additive 3d printing, fused deposition modeling and stereolithography (specific aim #2a). Several companies provide on-demand rapid prototyping of uploaded models using each of these technologies on a per-item basis. Once a primary method is selected, the remaining library case models will be printed using that technology. Once printed, the models will be bivalved and reassembled using small rare earth magnets to allow internal color-coded structures to be seen as needed. The cross-sectional images, rendered and animated virtual models, nephrometry figures, physical models, and pre/post tests will be combined into a curriculum (specific aim #1d), which will then be administered to urology residents and fellows.

(C) Significance: Driven by patient desire for less invasive surgery, the standard of care for treating renal masses less than 7 cm (T1) has rapidly evolved from open to robotic partial nephrectomy (RPN) over the past decade.³ Today, urology trainees must achieve competency in robotic renal surgery before completing residency, although the most efficient path remains unclear. For patients, RPN has great advantages over open surgery: decreased blood loss, accelerated recovery, less scarring and preservation of critical kidney function without compromising cancer control. However, RPN is a complex procedure performed under the time pressure of renal ischemia, during which tumor resection and kidney reconstruction must be completed rapidly and precisely. Success depends on a sophisticated spatial understanding of the relationship between tumor and critical internal kidney structures to avoid incomplete removal and unnecessary complications. Even for highly experienced laparoscopic surgeons, the learning curve for successful transition to RPN can be 25 – 50 cases.^{4,5} Low-fidelity *ex-vivo* anatomic models have been used to teach the generic steps of RPN⁶, although these approaches don't address the broad variation in anatomy between cases. When assessing the suitability of a particular tumor for RPN in the clinic, the surgeon must translate standard cross-sectional imaging into a 3D mental image of tumor location, depth and shape. Better visualization preoperatively equals safer and more effective patient care in the operating room.

Teaching RPN effectively is a critical mission of urology residency and fellowship programs both at BCM and nationally. No specific curriculum exists to aid in mastery of this skill set in 2013. The urology trainee must depend solely on a very inefficient and non-standardized process of accumulating experience from many random surgical cases. By creating a structured, patient-specific curriculum based on visual and tactile representations of particularly educational tumor cases, we hope to accelerate the tumor visualization learning curve for trainees both in our department and nationally. Developing an efficient workflow for generating virtual and physical renal models from CT data would also provide critical groundwork for future work assessing the value of preoperatively generated models in improving the quality of laparoscopic, robotic and percutaneous renal surgery.

(D) Applicant's background, skills, previous work pertinent to the project: I am the Director of the Division of Endourology and Minimally Invasive Surgery and Director of the MIS fellowship in the Scott Department of Urology. I perform more than 50 RPN procedures yearly and have been performing laparoscopic or robotic partial nephrectomy since 2003. I have also taught national courses on RPN through the American Urological Association since 2006 and lecture frequently on this topic. I have fairly extensive experience with the technical media skills required for this project including video editing, 3D volumetric reconstruction, and preparation of rendered medical illustrations and animations from 3D models. I've published several edited videos and received two national awards for video production. My illustrations have been included in several publications (e.g.⁷⁻⁹) A few other examples are included:



(E) Assessment of work proposed: Timed (45 min) "Pre" and "post" tests will be prepared for five challenging cases each (5 questions per case). Based on cross sectional images, the trainees will be asked to answer specific questions about tumor size and location, the relationship between the tumor and the renal vasculature, involvement of the collecting system, planned surgical details and calculation of the nephrometry score. A control group will then be given the post test one week later without additional training. The experimental group will be put through the curriculum of 15 cases over a one-week period and then take the post test. Comparison in improvement will be made between the two groups with the goal to see >20% improvement with training. A questionnaire will also be given to elicit opinions about the curriculum and which modality was most valuable in teaching the visualization concepts. Results from this work will be prepared for presentation at the World Congress of Endourology and the American Urological Association Annual Meeting.

(F) Timeline:

	Months 1 - 3	Months 4 - 6	Months 7-9	Months 10-12
Identify patients, collect cross-sectional imaging and surgical video	[Green bar]			
Volumetric reconstruction and virtual model creation		[Orange bar]		
Create physical models via 3d printing and edit surgical videos		[Blue bar]		
Construct final curriculum including pre and post test cases			[Red bar]	
Implement curriculum and assess performance				[Yellow bar]
Prepare results for presentation and publication				[Purple bar]
	Months 1 - 3	Months 4 - 6	Months 7-9	Months 10-12

Flowsheet showing timeline for anticipated phases of the project.

(G) Feasibility: I am transitioning to 30% protected time for research during the next academic year. My primary project focuses on probing the molecular genetics of renal cell carcinoma using transposon mutagenesis in the mouse. I am also pursuing a project investigating the genetic basis for nephrolithiasis using copy number variation and exome sequencing in a large database of stone patients. The project proposed in this grant is a natural extension of my clinical work and training efforts with residents and fellows. This project is feasible because we have access to a large number of relevant clinical cases and the technical barriers to building patient-specific virtual models for the curriculum are manageable. I am also highly motivated to pursue this project because the workflows developed will be critical for a series of downstream projects that depend on construction of preoperative patient specific models to facilitate complex renal surgery.

BUDGET FOR ENTIRE PROPOSED PROJECT PERIOD (DIRECT COSTS ONLY)

(Indirect costs or overhead expenses cannot be requested, fill-in only requests that are applicable, maximum amount requested should not exceed \$ 5000/ year)

BUDGET CATEGORY TOTALS	INITIAL BUDGET PERIOD	
PERSONNEL	0	
CONSULTANT COSTS	2000	
EQUIPMENT	2684	
SUPPLIES	235	
TRAVEL	0	
TUITION, FEES FOR COURSE WORK	0	
OTHER EXPENSES	0	
TOTAL DIRECT COSTS	4919	
TOTAL DIRECT COSTS FOR ENTIRE PROPOSED PROPROJECT PERIOD		\$ 4919

JUSTIFICATION

Consultant costs

3d printing expenses \$2,000.00 Outsourced 3d printing, 15 models + 5 demos

Equipment and software:

Osirix 64-bit DICOM visualization software \$399.00 For volumetric reconstruction

Rhino 5.0 modeling software - Academic version \$195.00 Primary model refinement

Solidworks - Academic version \$150.00 Conversion to CAD format for printing

Autodesk Maya creation suite - Academic version \$205.00 For rendering and animation

Drobo 5D storage and backup RAID drive \$849.00 Redundantly backed up storage system

2Tb 7200 RPM drives, Seagate black x 3 \$537.00

Wacom Intuos 5 medium graphics tablet \$349.00 Necessary input device for modeling

Supplies

Recordable DVDs for video transfer from OR \$35.00 For transfer of raw video from OR recorder

Publication and poster preparation expenses \$200.00

Total \$4,919.00

PLAN OF DEMONSTRATION OF INFORMATION GAINED FROM PROPOSED WORK (IF APPLICABLE)

Curriculum and results will be submitted for presentation at the World Congress of Endourology and the American Urological Association Annual Meeting. Depending on the results, I also intend to submit for publication in the Journal of Endourology. If the curriculum is deemed valuable, we may consider integrating it into the next iteration of the American Urological Association's yearly Mentored Laparoscopy Course¹⁰, which I have taught as faculty since 2006, or distributing it through the AUA to all urology residency programs.