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Ex Vivo Porcine Model for Robot-Assisted Partial Nephrectomy Simulation at a High-Volume Tertiary Center: Resident Perception and Validation Assessment Using the Global Evaluative Assessment of Robotic Skills Tool

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Abstract

Introduction: With increased demands on surgeon productivity and outcomes, residency robotics training increasingly relies on simulations. The objective of this study is to assess the validity and effectiveness of an ex vivo porcine training model as a useful tool to improve surgical skill and confidence with robot-assisted partial nephrectomy (RAPN) among urology residents.

Methods: A 2.5 cm circular area of ex vivo porcine kidneys was marked as the area of the tumor. Tumor excision and renorrhaphy was performed by trainees using a da Vinci Si robot. All residents ranging from postgraduate year (PGY) 2 to 5 participated in four training sessions during the 2017 to 2018 academic year. Each session was videorecorded and scored using the global evaluative assessment of robotic skills (GEARS) by faculty members.

Results: Twelve residents completed the program. Initial mean GEARS score was 16.7 and improved by +1.4 with each subsequent session (p = 0.008). Initial mean excision, renorrhaphy, and total times were 8.2, 13.9, and 22.1 minutes, which improved by 1.6, 2.0, and 3.6 minutes, respectively (all p < 0.001). Residents’ confidence at performing RAPN and robotic surgery increased after completing the courses (p = 0.012 and p < 0.001, respectively). Overall, residents rated that this program has greatly contributed to their skill (4/5) and confidence (4.1/5) in robotic surgery.

Conclusions: An ex vivo porcine simulation model for RAPN and robotic surgery provides measurable improvement in GEARS score and reduction in procedural time, although significant differences for all PGY levels need to be confirmed with larger study participation. Adoption of this simulation in a urology residency curriculum may improve residents’ skill and confidence in robotic surgery.

Keywords: surgical simulation, robot-assisted partial nephrectomy, robotic training, residency education

Introduction

With the introduction of the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA), minimally invasive partial nephrectomies can now be widely replicated effectively and safely. The combination of these features allows for ease of renal hilar dissection, tumor excision, and renorrhaphy suturing. Warm ischemia time, renorrhaphy time, and postoperative renal function have all significantly improved when comparing the robotic to laparoscopic approach.1

Robot-assisted partial nephrectomy (RAPN) has demonstrated a more manageable learning curve (~25 cases) compared with its technically demanding counterpart, the laparoscopic partial nephrectomy, which demands a learning curve of >200 cases.2–4 Urologists in practice and in training

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Currently, how confident are you with surgical autonomy.6

As a solution, training programs have adopted surgical simulation models to complement surgical training of the RAPN. The utilization of three-dimensional (3D) printed silicone models have demonstrated improved surgical outcomes, such as renal artery clamp time, preserved renal parenchyma, and negative surgical margins, across trials.7 The use of virtual reality has also shown a benefit with shorter operative time, clamp time, and lower estimated blood loss.8 A disadvantage of both models is the lack of face validity in replicating natural tissue texture and plane for resection and suturing, thus reducing their value in adoption of advanced technical skills.7,9

In this study, we present our ex vivo porcine surgical simulation model in teaching RAPN to urologic surgery residents. Our objective is to evaluate improvement of robotic surgical skills as scored by a validated robotic skills assessment tool, global evaluative assessment of robotic skills (GEARS)10 and to present residents’ perspective of this workshop on their ability and confidence to perform a RAPN in practice.

Materials and Methods

The appropriate IRB was approved prior to conduct of this study.

Porcine model surgical simulation

Four surgical simulation sessions were held and spaced out every 3 months throughout the 2017 to 2018 academic year. There was no formal didactics for teaching the RAPN procedure, and knowledge of procedure thus varied based on clinical exposure with increasing experience with rising postgraduate level. Please refer to Table 1 (Items 1 and 2) for a summary of robotic console exposure before and after the simulation sessions.

A 2.5 cm circular area of porcine kidneys was marked with a surgical marker as the area of the tumor. All marked tumors were located on the anterior surface of the kidney. Each RAPN setup consisted of a porcine kidney and an Intuitive da Vinci SI surgical system with a three-arm setup. No electrocautery was used. Tumor excision was performed with instructions to maintain a circumferential surgical margin at the border of the premarked area and to achieve a depth of excision to expose the underlying collecting system. Renorrhaphy was performed in two layers, with a deep layer closing the exposed collecting system using a running 3-0 Vicryl suture on small half needle, and a capsular layer using interrupted 0 Vicryl suture on CT needle using the sliding-clip technique (Fig. 1).11

Participants

Each urology resident ranging from postgraduate year (PGY 2–5) participated in four training sessions in random pairs of seniors (PGY 4–5) and juniors (PGY 2–3) to perform the model tasks. Residents were randomly paired for each of the four sessions depending on availability from clinical duties and rotation sites. Each resident completed a nonvalidated questionnaire before and after completion of the training program evaluating the content validity of the simulation model and the resident’s confidence with performing a RAPN and robotic surgery in general. Response to each question ranges from 1 (not at all helpful/confident) to 5 (extremely helpful/confident) (Fig. 2).

Outcome measurement

Five fellowship trained robotic surgery faculty members, blinded to participant identification, each independently reviewed all the video recordings using a validated standardized tool for assessment of robotic skills, GEARS. The GEARS assessment tool consists of six measures of robotic skills: depth perception, bimanual dexterity, efficiency of movement, force sensitivity, autonomy, and robotic control. Each of the six domains was scored on a 1 to 5-point system with 30 being the highest possible cumulative score. In addition, performance was also graded with a nonvalidated RAPN Specific Scoring System on the quality of tumor excision, renorrhaphy, and overall performance on a 5-point scale, with 1 correlating to novice level to 5 correlating to

<table>
<thead>
<tr>
<th>Table 1. Resident Experience Before and After Four Sessions of Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PGY 2 (n = 3)</strong></td>
</tr>
<tr>
<td>Before training</td>
</tr>
<tr>
<td>How many robotic surgeries have you performed as a surgeon (performed 50% or more of the case)?</td>
</tr>
<tr>
<td>How many robotic surgeries have you assisted with (performed &lt;50% of the case)?</td>
</tr>
<tr>
<td>Currently, how confident are you with performing robotic surgery as the primary surgeon? 1 = Not comfortable at all, 5 = Very comfortable</td>
</tr>
<tr>
<td>Currently, how confident are you with performing robotic partial nephrectomy as the primary surgeon? 1 = Not comfortable at all, 5 = Very comfortable</td>
</tr>
</tbody>
</table>

PGY = postgraduate year.
expert level. Independent scores from faculty members were averaged for a final score. Total time and times of tumor excision and renorrhaphy were recorded and analyzed.

Statistical analyses

One-sample t-tests were used to test the change in confidence level for the residents. Pearson correlation coefficient was used to examine the correlation between the GEARS score and time variables of interest. To compare the different PGY levels (2–5) and the change in GEARS score and time variables from session 1 to session 4, multiple comparison testing was used on univariate linear models. Multilevel random intercept linear models were used for GEARS score and the time variables of interest to estimate the change in those variables over the four sessions. Statistical significance was set to $p < 0.05$. All analyses were performed using R version 3.5.2. Each resident was allowed a random intercept representing their natural skill or experience which reduces the variability of the model to better determine the significance of change over sessions without changing the actual estimates from a standard linear model.

Resident Survey

1. Currently, how confident are you with performing robotic surgery as the primary surgeon? 1 star = Not comfortable at all, 5 stars = Very comfortable

2. How much did the robotic porcine lab contribute to your robotic skills in general? 1 star = Not at all, 5 stars = Critical to my robotic skills training

3. How much did the robotic porcine lab contribute to your confidence when performing a robotic surgery in general? 1 star = Not at all, 5 stars = Significantly improved my confidence

4. Currently, how confident are you with performing robotic partial nephrectomy as the primary surgeon? 1 star = Not comfortable at all, 5 stars = Very comfortable

5. How much did the robotic porcine lab contribute to your robotic partial nephrectomy skills? 1 star = Not at all, 5 stars = Critical to my robotic partial nephrectomy skills training

6. How much did the robotic porcine lab contribute to your confidence when performing a robotic partial nephrectomy? 1 star = Not at all, 5 stars = Significantly improved my confidence
Results

A total of 12 urologic surgery residents participated in 4 training sessions. See Table 1 for resident’s self-reported clinical experience with RAPN before and after the four sessions of ex vivo porcine RAPN simulation.

Performance

For session 1, the mean excision, renorrhaphy, and total times for the entire cohort were 8.2, 13.9, and 22.1 minutes, respectively. Mean GEARS score for the entire cohort was 16.7. Pearson correlation coefficients between GEARS score and excision, renorrhaphy, and total times were −0.68, −0.50, and −0.70, respectively (all \( p < 0.001 \)), indicating an inverse correlation between GEARS score and time variables.

Over the course of the four sessions, mean excision, renorrhaphy, and total times decreased by 1.6, 2.0, and 3.6 minutes, respectively (all \( p < 0.001 \)), whereas mean GEARS, excision, and overall scores improved by +1.4, +0.2, and +0.3, respectively (all \( p < 0.05 \)), with each subsequent session. Comparing the fourth and first sessions, while all PGY levels improved GEARS, statistically significant improvement was identified solely for the PGY 4 surgical residents. Conversely, when comparing the fourth and first sessions, while all PGY levels improved in total time, statistical significance was found for all but PGY 4 surgical residents (Table 2). Over the course of the four sessions, the average nonvalidated RAPN Specific Scoring System improved by +0.2 for excision \( (p = 0.04) \), +0.2 for renorrhaphy \( (p = 0.18) \), and +0.3 for overall performance \( (p = 0.02) \) (Fig. 3).

Resident ratings

Average residents’ confidence at performing RAPN and robotic surgery increased over the course of the program (1.7–2.3, \( p = 0.012 \); 1.6–2.6, \( p < 0.001 \), respectively). However, there was no observed difference in change in confidence between junior and senior residents \( (p = 0.213 \) for RAPN; \( p = 0.140 \) for robotic surgery). On average, residents rated that this porcine model RAPN program has greatly contributed to their skill (4 out of 5) and confidence (4.1 out of 5) in robotic surgery (Table 3).

Table 2. Change in Global Evaluative Assessment of Robotic Skills Score and Total Procedure Time

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean change in GEARS score (attempt 4–attempt 1)</th>
<th>Mean change in total time (attempt 4–attempt 1)</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total average ( (N=12) )</td>
<td>+1.4</td>
<td>−3.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>PGY 2</td>
<td>+3.0 (3.6)</td>
<td>−12.6 (2.9)</td>
<td>0.017</td>
</tr>
<tr>
<td>PGY 3</td>
<td>+1.7 (3.5)</td>
<td>−8 (2.0)</td>
<td>0.021</td>
</tr>
<tr>
<td>PGY 4</td>
<td>+9 (1.0)</td>
<td>−12.9 (8.1)</td>
<td>0.110</td>
</tr>
<tr>
<td>PGY 5</td>
<td>+2.0 (2.6)</td>
<td>−7.5 (1.5)</td>
<td>0.013</td>
</tr>
</tbody>
</table>

GEARS = global evaluative assessment of robotic skills.

Discussion

In our analysis of an ex vivo porcine model for RAPN simulation, we found an overall improvement in acquisition and refinement of robotic surgical skills for our urologic surgery residents regardless of PGY status. While previous studies have been done using other evaluation assessment tools to analyze training methods for RAPN, our study is the first to our knowledge to apply the GEARS assessment to the ex vivo porcine model for RAPN-simulated training. GEARS is a validated and useful tool that assesses the skills of surgeons in robotic surgery in a way that differentiates varying degrees of robotic surgical competence, demonstrating excellent construct validity. Furthermore, efficiency also improved with a reduction of total operative time by 7.5 to 12.9 minutes, which can have dramatic implications in the clinical setting in lowering warm ischemia time during on-clamp RAPN.
GEARS score and the mean difference in total procedure time improved for every PGY level but interestingly, this improvement was statistically significant in the PGY-4 cohort. Our residents are not exposed to console time of RAPN until the PGY-4 year, and the concurrence of the simulation with clinical handling of the console allows for more improvement. One study showed that only 52% of programs expose junior residents (PGY 2–3) to robotic surgery with only ~33% of residents serving as console surgeon by the start of PGY-4. This relatively small number of residents who experience hands-on exposure as a console surgeon before the fourth PGY may also suggest that junior level will not show overall differences in GEARS score after only four sessions and with porcine model training alone. Nonetheless, we still see improvement in scores and efficiency across all resident levels. In fact, junior residents (PGY 2–3) experienced improvements in procedural time and GEARS score although not statistically significant. We are interested in comparing the junior resident’s performance as they progress to senior residents and objectively compare them with our initial cohort represented in this study.

Training models for RAPN using virtual reality or silicone models have been commended for effective learning, yet the downfall is lacking realness of tissue planes for excision and suturing. Porcine models are unique in that they also provide an understanding of true anatomical structures (normal parenchyma, sinus fat, vessels, and collecting system), which are critical for identification during tumor excision and re-norrhaphy. Another limitation for alternative models is cost. The material cost for silicone models is insignificant ($3.90 USD per 125 g of silicone) but can be driven up with initial production cost ($260 per model) as well as the cost of the high-resolution 3D printer and associated maintenance fees. On the other hand, ex vivo porcine models are economical and widely available—our models cost <$1 per model and were purchased at a local butcher’s shop. Hung and colleagues also reported a financial advantage with the ex vivo kidney model, with each porcine kidney costing $15.00 USD. This allows for economic reproduction of the models for our residents throughout the year.

The face and content validity of our RAPN simulation model was assessed by high ratings of usefulness (4/5) by participating residents. All residents across PGY’s report high ratings that the ex vivo porcine simulation model was beneficial in acquisition of skills and improved confidence levels not only for RAPN but for all robotic surgery. Furthermore, a comparison of confidence levels in both RAPN and robotic surgery increased significantly at the conclusion of the training. The most common resident feedback was better understanding of natural tissue movement with dissection and suturing, which cannot be appreciated with virtual reality.

In the current state of surgical training, we perceive several challenges met by the urological surgery resident to achieve comfort and proficiency with the RAPN. The first is the case volume of RAPN. Omitting high-volume training centers, it may be difficult to substantially reach beyond the 30 cases to achieve mastery of the RAPN at the completion of residency training. From an accreditation perspective, the Accreditation Council for Graduate Medical Education (ACGME) Review Committee for urology requires that a resident complete a total of 30 kidney cases with no specification on the minimum for partial nephrectomies, let alone RAPN. Satisfying the case numbers for ACGME, graduate requirements may not accurately reflect true surgical competence due to the variable degree of resident participation depending on case complexities. Lastly, restrictions on house officer’s work hour restraints and decreased resident autonomy may curtail the time needed to master the procedure.

A recent 2019 survey of U.S. residency programs reported that 59% of urology chief residents and recent graduates admit doubt and incompetency in performing a RAPN in practice. Reflected in the poor proficiency and confidence in specialized robotic surgery, 61% of residents who pursue fellowship do so for further technical training rather than pursuing academics or expertise. The general acceptance of surgical simulation in residency training has been previously supported with most residents believing that surgical simulation should be incorporated in residency training. Implementing recurring robotic simulation and utilizing porcine model, similar to our model, demonstrates an increasing confidence in procedural specific steps as well as overall confidence with robotic platform. Furthermore, robotic simulation models provide a low-pressure environment to learn and enhance surgical skills, compared with the operating arena where time constraint, patient safety, and case complexity may all limit resident participation.

We acknowledge potential limitations with the design of our ex vivo porcine simulation model. Our experience included a small sample size of residents with short-term
analysis of training benefit. While statistically significant improvement in GEARS scores was found only in the PGY-4 cohort, this finding may be reflective on our small number of analysis and will need to be supported by confirmatory studies. Furthermore, this experience stems from a single institution with large robotic volume (~200 RAPN/year). We understand that the training experience, including aspects of console participation, case volume, and didactics, vary across residencies and our resident’s response may not be generalizable across all trainees. We also recognize that the improvement in GEARS scores and confidence level may be confounded by clinical robotic console experience as the study was performed throughout an academic year. Nonetheless, the use of this quarterly surgical simulation throughout the academic year can also serve as a surrogate to measure competence of robotic surgical skills acquired throughout the year.

Another limitation is the required personnel and resources needed to run a successful simulation laboratory. Blinded assessment requires dedicated time by expert faculty members to evaluate and provide feedback. Our faculty members are all fellowship trained in robotic surgery and had volunteered their time to participate in the study. Although each of our ex vivo porcine models is relatively cheap, we also require the availability of a surgical system dedicated to surgical simulation, which may not be present in some academic centers. In comparison, virtual trainer (Mimic dv-Trainer or Mimic backpack) is accessible at about 65% of academic centers.22

One may find limitation in construct validation as minimally invasive fellows and attendings did not participate in the model tasks for assessment to serve as “expert performers.” Yet, our study was able to differentiate levels of surgical experience by training level as gauged by an expert robotic surgeon. We found that the performances of our residents by training year was on par with average scores of a prior external validation GEARS study, which showed an average scores of 19 for novice, 20.75 for intermediate, and a full score of 30 for expert faculties.15 Despite high approval ratings by participants, our model lacks the presence of an actual tumor mass, which may question its face validity. This can be modified by embedding a styrofoam ball on the porcine kidney to emulate renal tumors.17 Yet even without this modification, the mechanics of tissue manipulation and renorrhaphy should be similar.

Finally, our ex vivo porcine model lacks certain aspects of the operation that would on the other hand be present in an in vivo model, such as hilar dissection, hemostasis management, and hilar clamping. There is increasing cost in the utility of in vivo porcine model, but we may consider this in the future selectively for senior residents who require more advanced surgical simulation.

Conclusion

An ex vivo porcine simulation model for RAPN and robotic surgery provides measurable improvement in GEARS score and reduction in procedural time, although significant differences for all PGY levels need to be confirmed with larger study participation. Adoption of this simulation in a urology residency curriculum may improve residents’ skill and confidence in robotic surgery.

Author Disclosure Statement

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References


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Abbreviations Used
3D ¼ three-dimensional
ACGME ¼ Accreditation Council for Graduate Medical Education
CT ¼ computed tomography
GEARS ¼ global evaluative assessment of robotic skills
PGY ¼ postgraduate year
RAPN ¼ robot-assisted partial nephrectomy