REVIEW PAPER

UROLOGICAL ONCOLOGY

Simulation-based training in minimally invasive partial nephrectomy

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Citation: Bouchalakis A, Paspalaki E, Somani BK, et al. Simulation-based training in minimally invasive partial nephrectomy. Cent European J Urol. 2025; 78: 116-124.

Article history
Submitted: Aug. 28, 2024
Accepted: Feb. 16, 2025
Published online: Apr. 28, 2025

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Introduction Minimally-invasive partial nephrectomy (MIPN) is the standard treatment for kidney tumors with a diameter smaller than 4 cm. It is also performed in selected cases of tumors reaching 7 cm, but it may lead to potential complications. We investigated the current literature for simulators that could be used to teach urologists alone or within the boundaries of a course or a curriculum.

Material and methods We performed a literature search using PubMed (Ovid Medline Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE [R] Daily, and Ovid MEDLINE [R]). Search terms included: simulation, simulation training, education, curricul*, partial nephrectomy, and nephron-sparing surgery. The primary endpoints were the efficacy of different simulators and the impact of different devices, curricula, or courses in training and trainee learning curves.

Results We identified 16 studies evaluating simulation with 3D reconstruction, *ex vivo*, *in vivo*, synthetic models, and virtual reality simulators. Additionally, we identified one study presenting a training curriculum. The results appeared promising, although currently available studies are scarce. Regardless of the type of simulator, participants stated that, to some degree, their skills were improved and their confidence was elevated.

Conclusions Simulation-based training can help novice surgeons familiarize themselves with complex procedure steps and reduce learning curves. A specific validated curriculum for this operation still needs to be included. Validating simulators or curricula for MIPN could be essential to enable more urologists to treat patients safely and effectively.

Key Words: simulation ‹› simulation training ‹› education ‹› curricula ‹› partial nephrectomy ‹› nephron-sparing surgery

INTRODUCTION

Renal cell carcinoma (RCC) is the 6th most frequently diagnosed cancer in men and the 10th in women, accounting for 5.0% and 3.0% of all oncological diagnoses worldwide in men and women, respectively [1]. The increase in early diagnosis has been attributed mainly to the widespread availability of computed tomography (CT) and magnetic resonance imaging (MRI) [2]. For localized RCC, surgery remains the gold standard treatment.

The European Association of Urology (EAU) guidelines suggest minimally-invasive partial nephrectomy (MIPN) as the first treatment option for localized T1 cancer [3]. This procedure is considered more complex than radical nephrectomy, especially the laparoscopic approach, which has a steep learning curve [4] and relatively high rates of potential complications [4, 5]. The robotic-assisted approach also has a steep learning curve, with up to 150 cases needed for excellence [6]. Training with a simulation modality is one way to face these difficulties and improve the outcomes.

doi: 10.5173/ceju.2024.0189

This work presents a descriptive overview of currently available simulation modalities and curricula in MIPN.

MATERIAL AND METHODS

We searched using the following terms: simulation, simulation training, education, curricul*, partial nephrectomy, nephron-sparing surgery. We carried out a comprehensive electronic search using MEDLINE (Ovid Medline Epub Ahead of Print, In-Process & Other Non-Indexed Citations, Ovid MEDLINE [R] Daily, and Ovid MEDLINE [R]). The study search strategy was conducted without limitation on publication year until December 2023. Additionally, we reviewed cited references from published systematic reviews/meta-analyses and the included studies.

The study is registered on the OSF platform with registration number (https://doi.org/10.17605/OSF.IO/Z7FYU). After excluding duplicate records, citations in abstract form, and non-English citations from the final literature search, the titles and abstracts of full papers were screened for relevance and defined as original research. A narrative synthesis was conducted due to the nonstandardized quality appraisal and the heterogeneity of the studies. Consideration is given to the drawbacks of utilizing a single database for assessment [7].

RESULTS

We included 17 studies suitable for qualitative synthesis. Five studies presented simulation models with 3D reconstruction [8–12], 5 presented simulation *ex vivo* models [13–17], 2 studied virtual reality (VR) simulation modalities [18, 19], 2 studied *in vivo* models [20, 21], and 2 presented synthetic models [22, 23].

Simulation with 3D reconstruction

In a prospective feasibility study, one surgeon had rehearsals using the daVinci™ Sirobotic surgical system (Intuitive Surgical, Sunnyvale, CA, USA) on 10 kidney models with complex renal masses (R.E.N.A.L. nephrometry score ≥7). The models were based on pre-operative CT or MRI and made of silicone and thinner. The rehearsals took place in a laparoscopic box trainer. The results were promising in surgical planning, pre-surgical rehearsal, and robotic-assisted laparoscopic MIPN training, showing successful construct validity. No differences were detected in volume, shape, negative margins, or time to resection between the model and the tumor [12].

Another prospective study for laparoscopic MIPN on 3 patients used 3 silicone models for pre-operative rehearsals. Resection and renorrhaphy were performed on the model before the actual operation. The average training and operation time of removal was similar in all cases. The study failed to present face, content, or construct validity [9].

Soft tissue physical individual models from selectively deposited photopolymer material filled with agarose were used in another prospective study for robotic-assisted MIPN, including 6 patients with 7 tumors. Investigators prospectively resected tumors on the models using the da Vinci Si surgical robot platform (Intuitive Surgical, Sunnyvale, CA, USA), followed by renorrhaphy the week before the surgery. The average R.E.N.A.L. nephrometry score was 8. The results of the operations were compared to the prospectively maintained robotic-assisted MIPN database. No significant differences were detected except the overall blood loss in favor of the study group. Although a larger cohort is needed to evaluate face and content validity, the authors considered this novel modality a potentially helpful training tool [10].

Another prospective study included 24 individuals: 4 medical students, 14 residents, 3 fellows, and 3 attending surgeons. A representative kidney with a single tumor was selected from the hospital's database. R.E.N.A.L. nephrometry score was 8. Models with and without tumors were printed and filled with 9 : 4 silicone to deadener, initially in the tumor mold. Then, in the tumor mold, the cavity was filled with silicone. Four trials, 2 on two different days, were executed from each participant. All had the same script, and the process was performed on a da Vinci robot system. One blinded researcher evaluated the 3 operation-specific metrics (renal artery clamp time, preserved renal parenchyma, and surgical margins). Metrics were significantly improved from trials 1 to 4. Face and content validity were assessed at the end of the trial (questionnaire 0–100/realistic–unrealistic, useful–useless for training) with mean responses of 79.2 and 90.7 for realism and usefulness, respectively. The trainee self-assessed operative demand was surveyed using the NASA Task Load Index (NASA TLX), significantly improving specific metrics from trials 1 to 4. The standardized and validated Global Evaluative Assessment of Robotic Surgeons (GEARS) was used for surgical performance by blinded experts, and significant improvement was observed in several metrics from trials 1 to 4. The results suggested that training could benefit from such a model, especially for naïve trainees to robotic-assisted MIPN, but can also help experienced trainees improve their skills [11].

Lastly, a prospective multi-institutional study validated a perfused robot-assisted MIPN simulation 3D platform. Face, content, and construct validity were assessed. A CT of a tumor with a nephrometry score of 7 and polyvinyl alcohol (PVA) as material were used for the model. Water-tight hilar structures were 3D-printed with an inner lumen to mimic bleeding and urine leakage functionality. Finally, other anatomical structures to replicate the anatomy were assembled. Artificial blood was perfused to simulate bleeding, and a pad allowed diathermy. From the 5 participating institutes, a total of 43 patients were recruited. Twenty-seven surgeons, novices (1–30 upper tract robotic cases), and 16 experts (>150 cases) participated in the study. Si or Xi da Vinci robotic platforms were used. Experts completed non-validated surveys assessing educational impact, realism, and comparison with other platforms. The validated GEARS was used for third-party validation of 30 participants (10 experts, 20 novices). Clinically Relevant Objective Metrics of Simulators (CROMS) were used for validation. Experts had significantly better results in all aspects of CROMS than novices. The same applied to GEARS.
Finally, experts rated the model higher than porcine or cadaveric models in terms of replication of the steps of the procedure. The experts believed the model's perfused nature benefited trainees [8].
The different simulations with 3D reconstruction are presented in Table 1.

Simulation *ex vivo* models

One study used a fresh porcine kidney in a metallic box for the laparoscopic MIPN training [16]. Red-dyed water was used to simulate the blood of renal vessels. Key steps used in *in vivo*.
MIPN were reproduced. Five experienced residents participated in the study. Two experts mindlessly evaluated them after completing 1 simulation every 2 days for a total of 10 in 20 days regarding the improvement of the quality of the operation. The evaluation was done through a video of the operations. Significant progress was found in all review aspects from the first to the last trial, with the mean quality score steadily increasing from 2.02 to 4.50 on a scale from 1 to 5.
Finally, the participants completed a questionnaire and characterized the model as valuable and helpful regarding their skills in laparoscopic MIPN, intracorporeal suturing and knotting techniques, and instrument manipulation of the renal parenchyma. However, no face, content, or construct validity was assessed.
Another prospective validation study for robotic MIPN used a porcine kidney, in which a Styrofoam ball was built to replicate a tumor [14]. Forty-six participants were categorized as novices (24 completed no robotic console cases), intermediate (9, at least one robotic console case but <100 console cases), or experts (13, ≥100 robotic cases).

Table 1. *Simulation with 3D reconstruction*

3D reconstruction								
Author, year of publication	Participants	Design and structures	Evaluation	Face validity	Content validity	Construct validity	Important findings	MERSQI score
Ghazi et al. 2021 [8]	n = 43 (27 novices,16 experts)	Multi-institutional prospective	1. CROMS 2. GEARS	✓	✓	✓	Experts significantly outperformed novices Model useful as a training tool (93.8%) and assessment simulation platform (87.5%)	14.5
Golab et al. 2017 [9]	Expert/s 3 patients	Prospective	–	–	–	–	No complications No positive margins	7
Maddox et al. 2018 [10]	Expert/s 6 patients	Prospective	–	–	–	–	Simulation: significantly lower blood loss	9.5
Monda et al. 2018 [11]	n = 24 (4 medical students, 14 residents, 3 fellows, 3 experts)	Prospective	1. GEARS 2. NASA TLX	✓	✓	✓	Mean responses: 79.2 on realism, 90.2 for usefulness as a training tool GEARS scores: significantly better in experts Scores: improved across trials	13.5
von Rundstedt et al. 2017 [12]	Expert/s 10 patients	Feasibility prospective study	–	–	–	✓	Resection time, resected tumor volume, and margins: similar between rehearsals and operations	9.5

CROMS – Clinically Relevant Objective Metrics of Simulators; GEARS – Global Evaluative Assessment of Robotic Surgeons; MERSQI – The Medical Education Research Study Quality Instrument score; NASA TLX – the NASA Task Load Index

The first task was to remove the Styrofoam ball with clear margins without damaging the parenchyma.

After completion, the experts completed a questionnaire concerning realism and its utility as a training tool on a scale of 1–10 (face and content validity). The model was characterized as very realistic (7/10) and valuable as a training tool (9/10) for residents and fellows but not for experts (5/10). Furthermore, 3 experts (>300 robotic cases) blindly validated objective parameters from video recordings prospectively of all the participants (construct validity), such as time to task completion, number of robotic instrument collisions, tumor margin status, and closest tumor margin if the margin was negative. Performance scoring was based on the Global Operative Assessment of Laparoscopic Skills (GOALS). Overall, the experts outperformed the intermediates and the novices. Lastly, 2 novel metrics, "precision, instrument, and camera awareness", were correlated with the GOALS results.

The results showed that such a model could be an essential tool for training, especially for residents and fellows.

In another *ex vivo* porcine model for robot-assisted MIPN simulation, 12 participants (residents, postgraduate years 2 to 6) participated [13]. Four surgical simulations were conducted in a year. Each surgery was performed with a da Vinci SI surgical system with a three-arm setup, and each tumor area was marked on the anterior side of the porcine kidney. Excision of the tumor with clear borders and depth to the collecting system plus renorrhaphy were performed. The participants completed a questionnaire from 1 to 5 before and after the sessions to evaluate content validity, concluding that the model improved skills and confidence. Furthermore, 5 fellowship-trained robotic surgery faculty members blindly assessed the participants using GEARS. Mean excision, renorrhaphy, and total times decreased significantly throughout the simulations. Significant improvement to the overall GEARS scores was also found for each subsequent session from 1 to 4 for residents in postgraduate year 4.

In another study, testing a hemorrhaging laparoscopic MIPN simulation scenario, 7 residents participated in testing the non-technical skills with the Non-Technical Skills for Surgeons (NOTSS) framework [15]. They completed a self-assessment NOTSS after the scenario, and it was compared with NOTSS recorded videos from the staff.

Each simulation used a porcine kidney with a Styrofoam ball in the renal parenchyma as the renal tumor. A foley catheter connected to a bag with dyed water was punctured into the renal hilum to simulate the bleeding. The four-step scenario started with the excision of the tumor, continued with minor bleeding after half unclamping the tube to cause minor bleeding, and then major bleeding with a whole opening of the tube. The scenario finished with at least one round of chest compressions and the alleged success in converting to open surgery to stop the bleeding.

The residents stated that the simulation's usefulness lay in decision-making and communication with anesthesia. This feasibility study found that urology residents needed more experience practicing non-technical surgical skills in simulation and cited interdisciplinary communication as the most critical aspect of the study. The study failed to present face content or construct validity.

Finally, an randomized controlled trial (RCT) evaluated a continuously perfused laparoscopic MIPN model using porcine kidneys [17]. A plastic bag containing 1,000 ml of red gelatin and glycerol was placed above the porcine kidney to simulate blood perfusion with a specially designed glass syringe and rubber catheter connected to the plastic bag and renal artery. Six experts (more than 100 cases), 5 intermediate (some experience), and 18 novices (little exposure) were recruited. Before the training, novices were asked to attend lectures, pre-training sessions, and examinations. Finally, they were examined on picking up beans, suturing silicone models, and having basic knowledge of laparoscopic MIPN. Those who passed the test were eligible to participate. They were then randomly assigned to 2 groups completing 15 rounds of training, a single-model training group (SMTG) training only on a continuously perfused model (CPTM) or a mixed-model training group (MMTG) training first half on a low-fidelity dry-box training models (DBTMs) and the second half on (CPTM). The experts completed a laparoscopic MIPN on a CPTM. The validity was based on the Messick frame, which has 3 parts: content, relationships with other variables, and consequences elements.

Experts assessed content validity and intermediates on a 5-point scale regarding the realism, anatomy, surgical feedback, and sensation during the model's cutting, stitching, and bleeding. All experts and intermediates gave positive questionnaire scores. Significant differences were detected among experts and intermediates compared to the novices. Significant intergroup differences were detected regarding tear length and postoperative bleeding volume within 5 minutes between the SMTG and MMTG in the 8th round in favor of SMTG, with the same results plus fixation rate in the 15th round. The learning curve in the SMTG also showed significant progression of skills, with a plateau in the

11th round. The study showed positive results and suggested that CTPM is a valuable tool for laparoscopic training for novices.
The simulation *ex vivo* models are presented in Table 2.

Virtual reality simulation modalities

The application of virtual reality (VR) in everyday practice is becoming increasingly imminent (Table 3). Although some verified VR simulations exist for robotic surgeries, none are specific to MIPN. A novel platform based on the dV-Trainer (Mimic, Seattle, WA, USA) that features augmented reality (AR) and VR content was validated in a prospective study with 42 participants (15 experts with at least 100 procedures,13 intermediate with less than 100 procedures, and 15 novices without experience) [18].
A recorded operation was shown, and questions and tasks regarding the anatomy and steps of the operation were given. In the end, a full VR renorrhaphy exercise was embedded. Experts found the platform very realistic and helpful as a training tool for residents and fellows, with a median of 9/10 and 8/10 on a scale from 1 to 10, respectively (face and content validity). However, the platform seemed inferior compared to an *in vivo* porcine model. Experts outperformed novices in all tasks of the AR platform. Finally, for the renorrhaphy task, GEARS was as-

Table 2. *Simulation ex vivo models*

Ex vivo models								
Author, year of publication	Participants	Design and structures	Evaluation	Face validity	Content validity	Construct validity	Study result	MERSQI score
Chow et al. 2021 [13]	n = 12 (resident PGY 2–5)	Prospective	Questionnaire GEARS	✓	✓	–	GEARS improves in all residents, statistically significant only in PG4 Confidence and skills improved in all participants	12.5
Hung 2012 [14]	n = 46 (24 novices, nine intermediates, 13 experts)	Prospective	Questionnaire GOALS	✓	✓	✓	Model: cited as realistic (9/10) and helpful (9/10) Experts outperformed novices	14
Lusty 2022 [15]	n = 7 (resident PGY 3–5)	Prospective	Questionnaire NOTSS	–	–	–	Interdisciplinary communication: the most important component of simulation	7.5
Yang et al. 2009 [16]	n = 5 (trainees)	Prospective	Questionnaire and quality evaluation from 2 supervisors	–	–	–	Model: helpful in increasing confidence Quality scores: increased through trials	12.5
Zhang et al. 2023 [17]	n = 29 (6 experts, 6 intermediates,18 novices)	RCT	Questionnaire	✓	✓	✓	Model: better results than the dry-box training	14.5

GEARS – Global Evaluative Assessment of Robotic Surgeons; GOALS – Global Operative Assessment of Laparoscopic Skills; MERSQI score – The Medical Education Research Study Quality Instrument score; NOTSS – Non-Technical Skills for Surgeons; PGY – postgraduate year; RCT – randomized controlled trial

Table 3. *Virtual reality simulation modalities*

VR simulations								
Author, year of publication	Participants	Design and structures	Evaluation	Face validity	Content validity	Construct validity	Study result	MERSQI score
Hung et al. 2015 [18]	n = 42 (14 experts, 13 intermediates, 15 novices)	Prospective	Questionnaire GEARS	✓	✓	✓	Experts found the model very realistic (8/10) and a good training tool (8/10) Experts outperformed novices	13.5
Rasheed 2023 [19]	n = 12 (7 final year residents, 5 interns)	Prospective	Questionnaires	✓	✓	–	Precision and interactivity: Metrics with the highest scores (6/9) Model: helpful for novices to improve cutting skills (7/9)	7.5

MERSQI score – The Medical Education Research Study Quality Instrument score; VR – virtual reality signed as a validation score by computer metrics and blinded expert video review. Experts outperformed intermediates, and the correlation between porcine and VR models was high. This study showed that specific VR simulations are possible and that further understanding tissue deformity will elevate the whole process.

Another prospective study with 12 participants (7 final-year residents and 5 interns) validated a novel VR laparoscopic MIPN modality [19]. The modality has an interactive interface with a physical and a 3D visualizing aspect. The trainees needed a CT scan to identify the mass and then identify the mass on the kidney being displayed. Trainees could mark and cut with precision along the malignant structure with the aid of 2 laser-emitting controllers while minimizing harm to the nearby tissues. After completing the task, participants answered questionnaires with a scale of 0–9 for face and content validity. The platform was found easy to use with precision and interactivity as the metrics with the highest scores (6/9). The simulation could have been more helpful for advanced surgeons but was useful for novices to enhance their cutting tissue skills (7/9).

In vivo models

Porcine models are standard *in vivo* models for laparoscopic training. Specific models for laparoscopic MIPN are scarce (Table 4).

In one study, investigators used liquid plastic and placed it in the kidneys of 5 pigs under anesthesia to simulate exophytic tumors [21]. The study assessed content validity. The model was evaluated in 2 phases. The first 5 experienced surgeons performed unilateral laparoscopic MIPN. The tumors were easily detected with ultrasound; visually, the margins were negative, and the mean operational time was 32 minutes. In the second phase of evaluation, 28 urologists attended the course, and one week after, a questionnaire with a scale of 1 to 10 was completed. The response rate was 86.0%, 96.0% considered the tumor model to have enhanced their learning experience, 63.0% thought the tumors to be easily resectable. Seventeen participants used ultrasound to locate the tumor, and 4 had difficulties with hemostasis. This novel model with liquid plastic resembles features of actual tumors and can be used as a training model for laparoscopic MIPN.

Another study using *in vivo* swine models evaluated the time required to complete different steps in laparoscopic radical nephrectomy and MIPN, with 12 residents participating [20]. The curriculum lasted 2 weeks, including didactic instruction, inanimate simulation, and live-tissue models. After the didactic instructions and laparoscopic training box skills, on the 14^{th} day, participants participated in live tissue surgery. Senior residents were randomly assigned to junior residents for the live tissue operations. Ten laparoscopic MIPNs were performed, 6 of which were from seniors and 4 of which were junior residents. The mean times were 152 and 173 minutes, respectively. The senior residents required half the time to achieve hilar control, taking 23 minutes vs 42 minutes for junior residents. Additionally, seniors outperformed junior residents during the excision of the simulated lesion.

The results showed that the only significant difference in time to complete a step was found in hilar control, and thus, focusing on this area in the training process should be necessary. No face, content, or construct validity was assessed.

Synthetic models

In this category, the simulation training is done on a kidney made of an artificial material (Table 5). In one study, a kidney model made of polyvinyl alcohol with two threaded tumors was used. Five residents participated, completing 10 identifications, each with laparoscopic ultrasound and 10 laparoscopic MIPN. From the 50 identification processes, the tumor was not visible in only one case, and the same applied in the MIPN with 49 successful procedures. Thirteen cases had positive margins. In the questionnaire (scale 1 to 5), residents found that the tumor was eas-

Table 4. *In vivo models stimulations*

In vivo models								
Author, year of publication	Participants	Design and structures	Evaluation	Face validity	Content validity	Construct validity	Study result	MERSQI score
Eber et al. 2022 [20]	n = 12 (residents PGY 3–6)	Prospective	NA	–	–	–	Junior residents: longer time for hilar control	14
Hidalgo et al. 2005 [21]	n = 28 (experts)	Prospective	Questionnaire	–	✓	–	Model: enhanced laparoscopic skills (96.0%)	8.5

MERSQI score – The Medical Education Research Study Quality Instrument score; PGY – postgraduate year

ily identified in the model with good realism. The texture was found realistic except for one student who considered it moderate (face validity).
Residents found conducting laparoscopic MIPN on the model strenuous and moderate, respectively. All residents found the model helpful for training and would recommend it for teaching. However, because of the small sample of participants, content validity was not evaluated. Polyvinyl alcohol, a material resembling actual tissue in US CT and MRI, showed promising results as a simulation modality for partial nephrectomy [23].
Another study for laparoscopic MIPN simulation also used a polyvinyl alcohol kidney model with a 3-cm exophytic tumor affixed to a silicone slab. Anesthesia urology residents and the nursing staff participated in the study. The number of urology residents was 9. The NOTSS assessment tool was used to evaluate non-technical skills, which was the study's primary goal. Technical skills involved in MIPN were also assessed as the second goal.
The study involved a scenario with phases, control of the right tools, the patient's anaphylaxis during the tumor's excision, and wrong reports from the pathologist during the renorrhaphy. After the scenario, a debriefing session followed. Residents in postgraduate years 4–5 were considered seniors, and those in postgraduate years 2–3 were considered juniors. As far as the results of the technical skills, seniors outperformed the juniors. Non-technical skills were assessed blindly by 2 raters based on recorded videos. The overall Network Time Protocol (NTP) score was significantly higher for the seniors. Residents thought the debriefing was essential and gave them insight into what is necessary for communication. The residents agreed that simulation-based training improves technical and communication skills [22].

Curricula

There are no validated curricula for laparoscopic or robotic MIPN. EAU's Robotic Urology Section (ERUS) developed a curriculum for robot-assisted MIPN and made a pilot clinical validation [24]. Using the Delphi modified method and through surveys based on robotic-assisted MIPN and robotic-assisted training programs literature, opinions from 30 experts were collected. The clinical validation was done with one trainee in an ERUS operational center under mentorship for 18 months.
Robot-assisted MIPN was divided into 10 steps, each with a 1 to 5 degree of difficulty. In the first phase, the trainee observed cases and received theoretical material. In the second phase, the trainee practiced robotic skills using various types of simulators, from VR to *in vivo* porcine models. The third phase was clinical training with a console, and the fourth consisted of a blind evaluation of recorded video of robotic-assisted MIPN. During the curriculum, 40 patients were treated while the trainee took part in the operation and 160 by an expert. No significant differences were found regarding outcome or complications except the duration of the operation (longer for the patients treated involving the trainee).
The curriculum from ERUS seemed very effective; it successfully transitioned a beginner surgeon to be able to complete an entire case and ensured patients were treated safely during the learning curve period of a surgeon. The most significant cohort of trainees and patients is needed to establish the program.
The results of this review of MIPN simulation models and curricula are promising, although currently available studies are scarce. Each study was assessed for quality using the MERSQI score as a tool [25]. The mean score for all the studies was 11.2. The *ex vivo* studies achieved the highest score, with 12.2, while the lowest score was shared between phantom models and VR simulators, with 10.5. The average score of studies that are published is above 10.7. Those getting rejected have a score below 9 [26].
This assessment shows that the quality of the published studies trying to create a model for partial nephrectomy needs significant improvement. Even though the mean was above 10.7, some studies had

Table 5. *Synthetic models stimulations*

Phantoms/Materials models								
Author, year of publication	Participants	Design and structures	Evaluation	Face validity	Content validity	Construct validity	Study result	MERSQI score
Abdelshehid et al. 2013 [22]	n = 9 (residents)	Prospective	Questionnaire NOTSS	–	✓	–	Model: helpful in developing communication skills (100.0%), and developing technical skills (88.0%)	12.5
Fernandez et al. 2012 [23]	n = 5 (residents)	Prospective	Questionnaire	✓	–	–	Model: realistic and helpful for training	8.5

MERSQI – The Medical Education Research Study Quality Instrument score; NOTSS – Non-Technical Skills for Surgeons a mean below 9, and the mean score of the 2 categories in this review was below 10.7. Regardless of the different types of modalities used as a simulation model, participants stated that, to some degree, their skills were improved, and their confidence was elevated. Simulations can help novice surgeons familiarize themselves with complex procedures and reduce learning curves. These aspects are essential in clinical practice, considering that robotic and laparoscopic operations tend to replace open surgeries completely. Nevertheless, the laparoscopic and robotic MIPN approach is highly demanding, and a validated simulator/curriculum, especially for this operation, is absent.

That leads to a wide heterogeneity between the studies and renders it impossible to compare the different models and their efficiency. One critical heterogeneity factor is the non-uniformly defined surgeon experience through the studies. External validation is also lacking in most studies, and the results are based on participants' opinions or non-validated questionnaires. Another limitation is the non-randomized design of most of the included studies and the lack of comparison between the model and a control group. Furthermore, some studies did not have MIPN training as the main objective, and the sample of participants was too small to make conclusions about the model's usefulness safely. Finally, only a few studies included face, content, and constructed validity, while 5 studies did not conduct any validation.

CONCLUSIONS

Through simulation-based training, inexperienced surgeons can shorten their learning curves and become more comfortable with intricate procedural processes like MIPN. However, a specialized, verified curriculum for this procedure remains necessary. Validating MIPN simulators or curricula might empower more urologists to provide safe and efficient patient care.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

FUNDING

This research received no external funding.

ETHICS APPROVAL STATEMENT

The ethical approval was not required.

References

1. Capitanio U, Bensalah K, Bex A, et al. Epidemiology of Renal Cell Carcinoma. Eur Urol. 2019; 75: 74-84.
2. Cohen HT, McGovern FJ. Renal-cell carcinoma. N Engl J Med. 2005; 353: 2477-2490.
3. Ljungberg B, Albiges L, Abu-Ghanem Y, et al. European Association of Urology Guidelines on Renal Cell Carcinoma: The 2022 Update. Eur Urol. 2022; 82: 399-410.
4. Porpiglia F, Bertolo R, Amparore D, Fiori C. Margins, ischaemia and complications rate after laparoscopic partial nephrectomy: impact of learning curve and tumour anatomical characteristics. BJU Int. 2013; 112: 1125-1132.
5. Ramani AP, Desai MM, Steinberg AP, et al. Complications of laparoscopic partial nephrectomy in 200 cases. J Urol. 2005; 173: 42-47.
6. Larcher A, Muttin F, Peyronnet B, et al. The Learning Curve for Robot-assisted Partial Nephrectomy: Impact of Surgical Experience on Perioperative Outcomes. Eur Urol. 2019; 75: 253-256.
7. Falagas ME, Pitsouni EI, Malietzis GA, Pappas G. Comparison of PubMed, Scopus, Web of Science, and Google Scholar: strengths and weaknesses. FASEB J. 2008; 22: 338-342.
8. Ghazi A, Melnyk R, Hung AJ, et al. Multi-institutional validation of a perfused robot-assisted partial nephrectomy procedural simulation platform utilizing clinically relevant objective metrics of simulators (CROMS). BJU Int. 2021; 127: 645-653.
9. Golab A, Smektala T, Kaczmarek K, Stamirowski R, Hrab M, Slojewski M. Laparoscopic Partial Nephrectomy Supported by Training Involving Personalized Silicone Replica Poured in Three-Dimensional Printed Casting Mold. J Laparoendosc Adv Surg Tech A. 2017; 27: 420-422.
10. Maddox MM, Feibus A, Liu J, Wang J, Thomas R, Silberstein JL. 3D-printed soft-tissue physical models of renal malignancies for individualized surgical simulation: a feasibility study. J Robot Surg. 2018; 12: 27-33.
11. Monda SM, Weese JR, Anderson BG, et al. Development and Validity of a Silicone Renal Tumor Model for Robotic Partial Nephrectomy Training. Urology. 2018; 114: 114-120.
12. von Rundstedt FC, Scovell JM, Agrawal S, Zaneveld J, Link RE. Utility of patient-specific silicone renal models for planning and rehearsal of complex tumour resections prior to robot-assisted laparoscopic partial nephrectomy. BJU Int. 2017; 119: 598-604.
13. Chow AK, Wong R, Monda S, et al. 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. J Endourol. 2021; 35: 878-884.
14. Hung AJ, Ng CK, Patil MB, et al. Validation of a novel robotic-assisted partial nephrectomy surgical training model. BJU Int. 2012; 110: 870-874.
15. Lusty AJ, Bleackley J, Roberts M, Watterson J, Raîche I. Hemorrhaging laparoscopic partial nephrectomy –

feasibility of a novel simulation model. Can Urol Assoc J. 2022; 16: 119-124.

16. Yang B, Zeng Q, Yinghao S, et al. A novel training model for laparoscopic partial nephrectomy using porcine kidney. J Endourol. 2009; 23: 2029-2033.

17. Zhang H, Wang J, Liu C, et al. Development of a continuously perfused ex vivo kidney training model for laparoscopic partial nephrectomy: validity and efficiency. Int J Surg. 2023; 109: 3919-3928.

18. Hung AJ, Shah SH, Dalag L, Shin D, Gill IS. Development and Validation of a Novel Robotic Procedure Specific Simulation Platform: Partial Nephrectomy. J Urol. 2015; 194: 520-526.

19. Rasheed F, Bukhari F, Iqbal W, Asif M, Chaudhry HAH. A low-cost unity-based virtual training simulator for laparoscopic partial nephrectomy using HTC Vive. PeerJ Comput Sci. 2023; 9: e1627.

20. Eber J, Peterson AC. Specific steps in the operation determine resident speed: Experience with a live tissue simulation model of laparoscopic nephrectomy. Front Surg. 2022; 9: 997324.

21. Hidalgo J, Belani J, Maxwell K, et al. Development of exophytic tumor model for laparoscopic partial nephrectomy: technique and initial experience. Urology. 2005; 65: 872-876.

22. Abdelshehid CS, Quach S, Nelson C, et al. High-fidelity simulation-based team training in urology: evaluation of technical and nontechnical skills of urology residents during laparoscopic partial nephrectomy. J Surg Educ. 2013; 70: 588-595.

23. Fernandez A, Chen E, Moore J, et al. A phantom model as a teaching modality for laparoscopic partial nephrectomy. J Endourol. 2012; 26: 1-5.

24. Larcher A, De Naeyer G, Turri F, et al. The ERUS Curriculum for Robot-assisted Partial Nephrectomy: Structure Definition and Pilot Clinical Validation. Eur Urol. 2019; 75: 1023-1031.

25. Reed DA, Cook DA, Beckman TJ, Levine RB, Kern DE, Wright SM. Association between funding and quality of published medical education research. JAMA. 2007; 298: 1002-1009.

26. Reed DA, Beckman TJ, Wright SM, Levine RB, Kern DE, Cook DA. Predictive validity evidence for medical education research study quality instrument scores: quality of submissions to JGIM's Medical Education Special Issue. J Gen Intern Med. 2008; 23: 903-907.