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Simulation and Training in Kidney Cancer Surgery

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Abstract

The rise of robotic surgery coupled with the increased detection of small renal masses has led to a marked increase in renal cancer surgery and, in particular, robotic partial nephrectomy. Given the associated learning curves of these procedures and added external pressures such as work-time directives, training programmes have had to adapt and move away from the traditional apprenticeship model. Simulation in surgery has greatly expanded over the past 20 years to fill this divide and is now commonplace for surgical training and fellowship programmes. This chapter explores the different modalities of simulation available in renal cancer surgery including the latest procedural-specific simulation platforms for both radical and partial nephrectomy. Exciting new developments such as 3D printing and patient-specific modelling are addressed as well as the emerging role of artificial intelligence. Finally, the integration of simulation into a comprehensive surgical training programme is explored.

Keywords: renal cancer, simulation, partial nephrectomy, radical nephrectomy, surgical training, robotic surgery, surgical curriculum

1. Introduction

The traditional apprenticeship style of surgical training is evolving due to a multitude of challenges. The old Halstedian mantra of 'do one, see one, teach one' [1] has become less acceptable as societal and professional expectations change. Current trainees are now expected to achieve a similar level of competency to their mentors despite mounting restrictions on available training opportunities [2]. Initiatives such as the European Work Time Directive (EWTD) [3] have resulted in reduced working hours, and financial restrictions on healthcare budgets have led to increased focus on operating room efficiency. The concurrent emergence

of minimally invasive surgical techniques, such as laparoscopy and robotic-assisted surgery, and their associated learning curves has further compounded the issue. As a result, the development of quality surgical training opportunities in the non-clinical setting has long been on the agenda of the profession, and today, surgical simulation has ascended to occupy a central role in the modern surgical curriculum [4, 5]. For *trainees*, simulation allows the opportunity to develop surgical skills in an environment free of risk to the patient. It overcomes the limitations of operating room exposure and affords flexibility in an often chaotic work schedule. For *trainers*, the controlled nature of simulation allows objective appraisal of performance and progression, as well as a tailored approach to meet individual learning needs.

2. Development and validation of simulators

The ideal simulator should have a significant educational impact, improve subsequent performance in the operating room, shorten the procedural learning curve and subsequently increase patient safety. For novices, it should offer a realistic introduction to basic technical skills, allowing part-task training, while becoming increasingly procedure-specific and patient-specific for the more experienced operator [6].

Simulators must be rigorously evaluated across a number of parameters before they can be used for training and assessment. Validity is a measure of the extent a simulator succeeds in teaching the skill for which it was designed [7]. An ideal simulator would perform well in all of the following aspects of validity [8];

- Face validity: the extent to which the simulator is realistic.
- Content validity: the extent to which the simulator's content is representative of the skill required to be learnt.
- Construct validity: the extent to which experienced and novice operators can be differentiated.
- Concurrent validity: the extent to which the simulation correlates with the current gold standard test used to measure the skill.
- Predictive validity: the extent to which future performance can be predicted by simulator performance.

With the increased pressure on healthcare expenditure and efficiency, the importance of independent and robust validation is critical to ensure that resources are invested in simulator platforms that provide the highest levels of educational impact [9].

3. Different modalities of simulation

Simulators can broadly be divided into two categories: physical and 'virtual reality' simulators. Physical (or mechanical) simulators use physical objects as substitutes for patients and

include bench-top models, animal tissue, live animals and human cadavers. Virtual reality simulators use a computer-based platform with artificially generated virtual environments to interact [9]. This group includes the recent introduction of ‘augmented reality’ platforms, which integrate real-life patient data into a virtual reality environment. The range of different modalities, as well as their perceived advantages and disadvantages is summarised in **Table 1**.

Simulation modality	Description/ examples	Advantages	Disadvantages	Use in kidney cancer surgery
Bench-top model	Synthetic, dry-lab models; e.g. box trainers	Re-usable, portable, use of real instruments	Low fidelity: unrealistic Unable to teach entire procedure High fidelity: Cost	Basic laparoscopic skills Partial Nephrectomy dry-lab models [11, 12] 3D printing allows tumours to be incorporated into models [13, 14]
Animal tissue	Ex-vivo animal tissue; e.g. porcine urinary tract	Tissue handling Cost-effective	Single-use Storage facilities No blood flow Anatomical differences	Partial nephrectomy with porcine kidney and various tumour-mimics (e.g. polystyrene ball, injection of liquid plastic) [15, 16]
Live animals	Live, anaesthetised animals; e.g. pigs, sheep, rabbits	Tissue handling Ability to perform entire procedures Realistic Blood flow	Ethical concerns Need for storage facilities and trained veterinary personnel Single-use Cost Anatomical differences	Live rabbits for laparoscopic nephrectomy [17] Anaesthetised pigs for nephrectomy and partial nephrectomy [18]
Cadaveric material	Fresh frozen or thiel-embalmed cadaveric material	Ability to perform entire procedures Highest face validity	Cost Availability Single use No blood flow	Full procedure training (Nephrectomy and partial nephrectomy) [19]
Virtual-reality	Interaction with computer-generated environment (e.g. RoSS, SEP, dvSS)	Objective evaluation Data capture Repetitive use	Cost/maintenance No availability when robot in use Poor 3D vision	Familiarisation with robotic equipment and basic technical skills [20] Procedure-specific simulation allows for procedures to be performed in their entirety [21, 22]
Augmented reality	Integration of real patient data into virtual reality simulation (e.g. HoST, Maestro AR)	Patient-specific information Data capture Repetitive use	Cost	Patient-specific tumours incorporated into simulation [23] Patient imaging or 3D surgical video incorporated [22, 24]

dvSS, da Vinci skills simulator; RoSS, robotic surgical simulator; HoST, Hands-On Surgical Simulator; SEP, SimSurgery Educational Platform; 3D, three-dimensional.

Table 1. Available simulation modalities (adapted from Aydin et al. [10]).

3.1. Physical simulators (mechanical)

3.1.1. Bench-top/'dry-lab' models

Bench-top models are synthetic models that can vary from simple (i.e. peg-transfer) to more complex tasks (i.e. suturing and knot-tying) in order to acquire surgical skills. These are often incorporated into different surgical platforms via a box-trainer allowing the utilisation of actual surgical instruments and giving the trainee an opportunity to familiarise with the controls and limitations of that platform [12]. Higher-fidelity synthetic models can be utilised for more advanced skills and part-procedural simulation. With the advent of 3D printing, several authors have described high-fidelity partial-nephrectomy models whereby tumour excision and renorrhaphy can be rehearsed [13, 14, 25]. Patient-specific models have even been utilised by expert surgeons to pre-operatively rehearse RAPN in order to determine feasibility of PN and predict warm-ischaemia times [26].

3.1.2. Ex-vivo animal tissue/'wet-lab' models

Inanimate animal tissue has been used to simulate a range of endourological, laparoscopic and robotic-assisted procedures ex-vivo [10]. These models utilise the actual surgical instruments or console similar to dry-lab models and subsequently have similar advantages with regard to developing familiarity with the surgical platform. Porcine kidneys in particular have been utilised successfully for procedural simulation in renal cancer surgery and offer advantages in terms of higher-fidelity tissue handling and even the ability to be artificially perfused, allowing simulation of vascular control and haemostasis [16, 27]. These advantages need to be weighed against the special facilities required for storage and subsequent increased costs, which can be a limiting factor in some institutions.

3.1.3. Live animal tissue

Live animal models facilitate the closest simulation to live surgical cases and also provide an opportunity for whole procedural simulation. Whole-procedural simulation has the significant advantage, allowing development in dissection technique, energy control, vascular control and haemostasis techniques. Several groups have even described the creation of artificial tumours in live porcine models, subsequently allowing specific procedural simulation for robotic-assisted partial nephrectomy (RAPN) [15, 16]. Despite these benefits, however, the higher costs, ethical issues and local legislative restrictions can significantly impact the availability. Subsequently, access to live animal simulation is often limited to a few programmes.

3.1.4. Cadaveric tissue

Human cadaveric material has long been used in surgical training, and it is generally accepted that cadaveric simulation has the highest face validity of all simulation modalities [19, 28]. Simulation using fresh frozen cadavers (FFCs) or thiel-embalmed cadavers (TECs) has shown face, content and construct validity in a range of endourological and laparoscopic procedures [10]. Despite utilisation in various training programmes, validation of the effectiveness of cadaveric training in robotic-assisted procedures remains limited [28], and further research in this area is needed.

3.1.5. Virtual reality (VR) and augmented reality (AR) simulators

Robotic surgery in particular lends itself to VR simulation, and as such, there has been a significant development in this modality in recent times. At present, there exist a number of commercially available products as outlined in **Table 2**.

In recent years, the introduction of augmented reality (AR) simulators has provided increasingly realistic and procedure-specific platforms for simulation. The two AR systems in common use are the Hands-On Surgical Training (HoST) and the Maestro AR system. HoST

Simulation model	Manufacturer	Focus	Advantages	Disadvantages
dV-Trainer	Mimic Technologies, USA	Basic skills	Standalone Availability Extensively validated [20, 29–31]	Mechanically different hand controls
dvSS	Intuitive Surgical, USA	Basic skills	Fixed to console Uses actual console Extensively validated [32–34]	Can only be used when da Vinci robot not in use
RoSS/HoST	Simulated Surgical Systems, USA	Basic skills, procedural specific simulation (RARP, cystectomy, lymph node dissection)	Standalone Availability Extensively validated [35–37] Augmented reality procedural tasks (HoST)	Mechanically different hand controls Cost Limited availability outside USA
RobotiX mentor	Simbionix, USA	Basic skills Procedural simulation	Standalone Availability Laparoscopic assistant module [38]	Mechanically different hand controls No urological procedural tasks
SEP robot	SimSurgery, Norway	Basic skills	Standalone Availability	2D vision Mechanically different hand controls Less robust validity [39]
Pro-MIS	CAE Healthcare, Canada	Basic skills	Standalone VR and use with box trainers	2D vision Originally designed for laparoscopy Limited robotic validation [40] Mechanically different hand controls
Maestro AR	Mimic Technologies, USA	Augmented Reality Procedural simulation (RAPN, RARP) [22]	Standalone Availability Procedural simulation	Unable to manipulate surgical field

dV-Trainer, da Vinci trainer; dvSS, da Vinci skills simulator; RoSS, robotic surgical simulator; HoST, Hands-On Surgical Simulator; SEP, SimSurgery Educational Platform; 3D, three-dimensional; 2D, two-dimensional; RARP, robotic-assisted radical prostatectomy; RAPN, robotic-assisted partial nephrectomy.

Table 2. Available VR simulation platforms.

(Simulated Surgical Systems, USA) incorporates a real surgical procedure into the virtual reality framework and guides the user through an enhanced version of the operation, with audio-visual illustration, haptic cues and guided movements [24]. The HoST system currently does not offer procedural simulation for nephrectomy or partial nephrectomy. Maestro AR (Mimic Technologies, USA) provides procedure-specific 3D video and interaction via virtual reality robotic instruments. This includes a module on partial nephrectomy that demonstrates face, content, construct and concurrent validity [22].

4. Procedural simulation for renal cancer

Competently performing a whole procedure requires knowledge of surgical anatomy, procedural steps and the ability to perform each surgical component. Whole procedure simulation is challenging and at present time in renal surgery, it is largely limited to cadaveric and animal models. As a result of these limitations part-procedural simulation, where a particular procedural step is simulated (i.e. tumour excision or renorrhaphy), has advanced significantly over the last decade. The majority of these models are bench-top, either wet or dry, and have the advantage of being able to be utilised for open, laparoscopic and robotic platforms. The following section aims to explore the models available for radical and partial nephrectomy.

4.1. Radical nephrectomy

Radical nephrectomy remains the most utilised treatment approach for renal malignancy [41, 42]. Traditionally performed as an open procedure, laparoscopic radical nephrectomy has become widespread due to the benefits of shorter convalescence and less procedural morbidity [42]. The initial experience with laparoscopy was technically challenging, and the learning curve and associated complication rates for novice surgeons were a significant barrier to uptake [43]. Developments in training and simulation subsequently followed in an attempt to provide an adjunct for skill development outside of the operating theatre [44, 45]. At present there are a vast array of simulators available for acquiring laparoscopic skills with extensive validation ranging from box trainers to develop basic skills, to whole procedural simulation on live animals and VR platforms.

4.1.1. Physical simulation

The first clinical laparoscopic radical nephrectomy (LRN) was performed in 1990 by Clayman and colleagues [46] after extensive experimentation on porcine models. The benefits of animal models for teaching dissection, tissue handling, haemostasis and vascular control are significant, and subsequently this simulation modality remains central to the development and dissemination of minimally invasive surgical techniques [47].

Molinas and colleagues [17] demonstrated the validity of live simulation in LRN using a rabbit model. Ten gynaecologists and 10 medical students each performed 20 laparoscopic nephrectomies over a 20-day training course. The overall time required to perform the LRN decreased from 44 ± 18 to 11 ± 2 minutes for the first and the last procedure, respectively, and

complication rates similarly decreased. Despite the rabbit's smaller size compared to pigs for example, pneumoperitoneum was able to be established, and conventional instruments were used for all procedures. Reduction in acquisition and handling costs associated with the rabbits allowed the authors to provide a more prolonged period of training demonstrating the impact of repetition on learning curves and complication rates.

Cruz and colleagues [48] assessed the impact of repeated LRN in the porcine model on overall surgical performance among established surgeons. Six urologists with limited laparoscopic experience were recruited to perform a live porcine LRN weekly for 10 weeks. Surgical performance was judged quantitatively including total operative time and estimated blood loss. Qualitative measures were also assessed using the Global Operative Assessment of Laparoscopic Skills (GOALS) including depth perception, dexterity, efficiency, tissue handling and autonomy. Over the course of the study, blood loss, depth perception and dexterity showed statistically significant improvements. The remaining domains including operative time showed no statistical improvement.

4.1.2. Virtual reality

Despite the obvious benefits of high-fidelity animal models, the costs and associated ethical issues restrict access which is often limited to several day courses. A high-fidelity virtual reality LRN simulation platform has obvious advantages in overcoming some of these barriers. The LAP Mentor (Simbionix, USA) and LapSim (Surgical Sciences, Sweden) are two commercially available laparoscopic simulators, which provide VR laparoscopic training including a full nephrectomy module. While both simulators have been validated in terms of basic laparoscopic skills [49, 50], the nephrectomy modules remain to be formally scientifically assessed. Despite this, these simulators provide full procedure simulation that is reproducible and able to provide feedback on performance metrics such as economy of motion, procedure time and error rates. These metrics have potential utility in assessing progression and setting benchmarks for training curriculums.

4.2. Partial nephrectomy

With the advent of widespread cross-sectional imaging, there has been a surge in incidental detection of small renal masses. This has subsequently led to increased utilisation of partial nephrectomy (PN) in order to preserve normal renal parenchyma in these otherwise well patients [51]. PN is a technically challenging operation with a significant learning curve and variability unrivalled by almost any other frequently performed kidney procedure [52]. Perhaps, most challenging, however, is the *time-critical* nature of PN. The vast blood supply to the kidney means bleeding is a significant intraoperative risk and efficient excision, and renorrhaphy is therefore crucial. Furthermore, prolonged warm ischaemia is deleterious to healthy renal tissue and can impact post-operative renal function [53, 54]. Finally, each tumour is highly variable in size, location and relation to critical structures, making oncological excision a persistent challenge even for experienced surgeons. For these reasons, training in PN is subsequently fraught with complexity, and mentors must try and negotiate sometimes the discordant goals of training with patient safety. Simulation for PN has rapidly progressed in response to this dilemma, and the availability of PN models is becoming more widespread.

4.2.1. *Physical simulation*

Tumour-mimic models for PN rose to prominence in the initial laparoscopic era in response to the technically challenging nature of the procedure and associated learning curve. Taylor and colleagues [55] described one of the earliest models in 2004, whereby a pigmented mixture was injected into a series of ex-vivo and in-vivo porcine kidneys. The authors were able to create a variety of lesions both endo- and exophytic with a mean size of 10 mm. This model was not formally assessed as part of a training programme but established the feasibility of artificial tumour creation. Hidalgo et al. [15] similarly described the creation of an in-vivo porcine PN model through the percutaneous injection of a liquefied plastic solution into the subscapular renal space to create exophytic lesions. This model was evaluated as part of a laparoscopic training programme and found to enhance the learning experience in 96% of participants. While advantageous for the novice, the inability of these techniques to create large endophytic or central lesions may limit the utility to more advanced surgeons.

Yang et al. [27] described an ex-vivo porcine model, whereby the kidney was secured to a specifically designed box for use with a laparoscopic trainer. The renal vessels were preserved, and simulated vascular perfusion was achieved through infusion of red-dyed water through the artery. Urology trainees were requested to excise a 2 cm spherical piece of renal parenchyma and then complete renorrhaphy. The model was validated by five urology trainees, each of whom completed 10 attempts at the LPN model over a 20-day period. Trainees demonstrated a decrease in the total operative and renorrhaphy times with progressive attempts, as well as increase in the quality of the PN as assessed by two blinded experts. Trainees also reported an improvement in their confidence to perform a LPN, particularly with respect to tissue manipulation, intra-corporeal suturing and knot tying.

The proliferation of robotic-assisted surgery has helped overcome many of the barriers associated with LPN, resulting in shorter learning curves and subsequent growth in this area [56]. Eun and colleagues [57] described a novel technique for creating renal tumour mimics for RAPN in addition to a renal vein/inferior vena cava (IVC) tumour model for tumour thrombectomy. A tumour-mimic mixture was percutaneously injected into eight live pigs and one human cadaver in order to create 33 renal pseudotumours. A renal vein thrombus model was also created by injecting the material into the renal vein while clamped and allowing this to solidify. In addition, a renal-vein thrombus with extension into the IVC was created through partial clamping of the IVC with a long, curved bulldog clamp. Subsequent robotic radical nephrectomy with excision of the involved IVC cuff and IVC reconstruction was performed. This model was not validated by the authors but was the first demonstration of the feasibility of artificial renal vein and IVC tumour thrombus creation. While all procedures in this paper were performed robotically, such a model could be beneficial in both laparoscopic and open surgery.

Hung and colleagues [16] devised a novel robotic specific model for RAPN using an ex-vivo porcine kidney embedded with a 3.8 cm Styrofoam ball to mimic an exophytic renal tumour. The model task included tumour excision with a parenchymal margin but did not incorporate renorrhaphy. Forty-six participants were classified into 3 groups for validation, 24 novices

(no robotic cases), 9 intermediates (1–100 robotic cases), and 13 experts (>100 robotic cases). Among expert surgeons, the model demonstrated excellent face and content validity. Experts rated the applicability for advanced surgeons as lower, however, which likely reflects the lack of renorrhaphy and haemostasis component associated with the simulation.

The recent advent of rapid prototyping (3D-printing) has allowed the formation of synthetic surgical renal tumour models. Several groups have already demonstrated that high-fidelity 3D printed renal models can be created using specialised software to import diagnostic cross-sectional imaging [26, 58]. Monda and colleagues [14] recently developed and validated a silicone tumour model from a 3D printed cast of a kidney with a tumour. A medium complexity tumour was selected from a patient who had previously undergone RAPN at the authors' institution, and a 3D printed negative-volume mould was created. Following this, tumour models could be repeatedly cast with silicone using this mould. The model was validated by surgeons of different training levels and demonstrated face, construct, and content validity. Through the use of a 3D printed mould, the authors were able to subsequently reproduce multiple models reliably with minimal cost.

Von Rundstedt et al. [26] used advanced 3D printing to create a high-fidelity, patient-specific, synthetic renal tumour model for the purposes of surgical rehearsal prior to actual RAPN. Surgical models were created for 10 patients and the same surgeon performed all rehearsals and actual RAPNs. The resection times and resection volumes were compared between rehearsal and live procedure and found to be predictive. Being able to predict, excision time has significant implications and could be utilised in assessing the feasibility of more complex masses for PN within an acceptable warm-ischaemia time. Furthermore, the authors reported altering their actual surgical approach in several patients based on difficulties encountered with tumour excision in the simulated rehearsal.

Maddox and colleagues [13] used a slightly different process to construct patient-specific tumour models by 3D printing an outer polymer 'shell' which was subsequently filled with an agarose gel solution to resemble normal renal parenchyma. The renal mass of interest, as well as critical structures such as renal vasculature and collecting system, was able to be pigmented to distinguish them from the normal parenchyma. It is very conceivable that 3D-printed bench models may ultimately decrease the learning curve and potentially improve surgical outcomes; however, further studies are needed to fully elucidate this effect. Current limitations include the lack of 'real-life' confounders such as perinephric fat and an active blood supply; however, it is very possible that these could be overcome in the future.

4.2.2. *Virtual reality*

No PN specific whole procedure VR simulation is commercially available at present. In an attempt to bridge the gap, Hung and colleagues [22] developed and validated an augmented reality platform now commercially available as Maestro AR (Mimic Technologies, USA). In this 'hybrid' model, augmented reality and virtual reality were combined to create a procedural specific platform that aimed to teach surgical anatomy, procedural steps and operative skills. High-definition actual surgical video of a full length RAPN was embedded with

interactive VR exercises and virtual instruments in five modules: colon mobilisation, kocherisation of duodenum, hilar dissection, kidney mobilisation, tumour resection and renorrhaphy. In the final module, an embedded VR exercise was developed, whereby a mobile sponge could be manipulated around a central pivot point (renal hilum) and sutured. This platform was internally validated throughout development, and concurrent validity was assessed by comparison to an in-vivo porcine model. Expert surgeons rated the platform a useful tool for training residents and fellows particularly with respect to teaching the steps of the procedure and surgical anatomy. Performance in the VR renorrhaphy task correlated with that of the in-vivo porcine model in the intermediate and expert groups. While this platform is a significant progression towards procedure-specific VR simulation, further advances are needed before this could feasibly replace wet lab training. Allowing the user to alter the surgical view and perform embedded tasks for each step of the procedure would likely increase validity.

5. Training in renal cancer surgery

With substantial progress having been made in surgical simulation, the next challenge is formally integrating this into surgical training programmes. At present, access to simulation is often limited and certainly is not routinely incorporated into trainee assessment and technical skill development [59]. The learning curves for minimally invasive renal cancer surgery and in particular partial nephrectomy are well documented, and subsequently complications early in the surgical experience are more likely [43]. Progressing training surgeons along the learning curve in the safety of the simulation environment has obvious benefits to patient outcomes. Simulators can also be utilised at the convenience of the trainee accommodating theatre and on-call commitments and local work-time directives. Furthermore, multiple studies have demonstrated the positive attitude of trainees towards simulation with benefits reported in learning anatomy, procedural steps, skill acquisition and confidence for subsequent performance in the operating theatre [19].

An ideal training programme needs to match the trainee with appropriate levels of simulation and operating theatre exposure [60]. Initially, trainees should acquire basic skills on lower fidelity VR simulators, with higher fidelity bench models and whole procedure simulation on live animals or human cadavers introduced with subsequent progression [10]. Advancement through simulation platforms should be coupled with, or followed by, a modular training programme for live operative cases. Modular training involves the breakdown of a procedure into sequential steps of increasing difficulty. Novice trainees begin with a period of observation and assistance and subsequently progress through each graded step of the procedure [61]. Under this structure, a whole procedure shall only be attempted once a trainee has individually mastered all steps of the procedure.

The European Association of Urology (EAU) Robotic Urology Section (ERUS) training curriculum has been endorsed by British Association of Urological Surgeons (BAUS) and incorporates such an approach (**Figure 1**) [62]. This programme has already been validated for robotic-assisted radical prostatectomy [63].

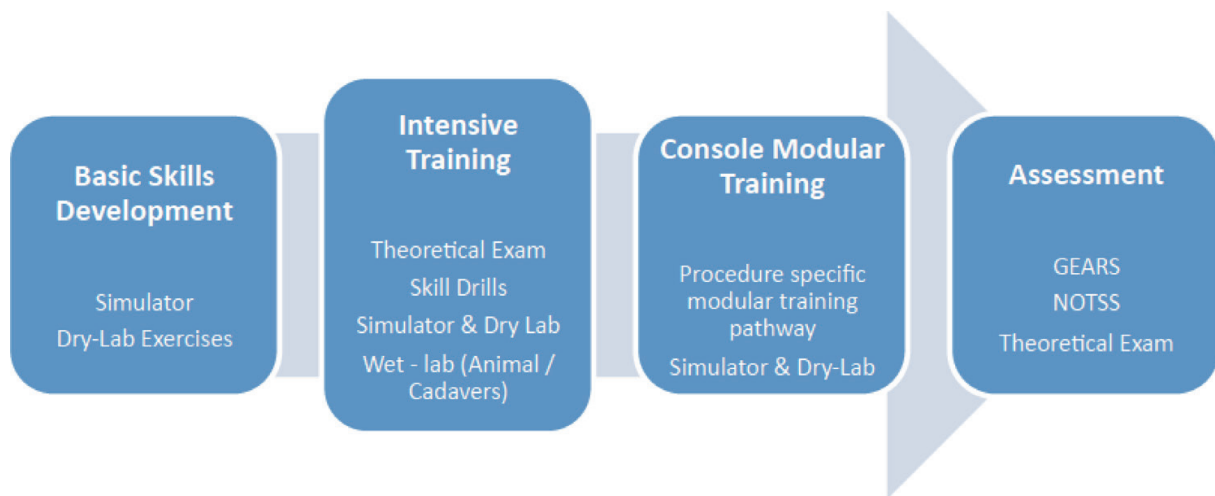


Figure 1. Proposed pathway for robotic training (reproduced with permission from BAUS robotic curriculum) [62].

Quality indicator	Proposed standard
Operative time	<200 min
Warm ischaemia time	<25 min
Estimated blood loss	<150 mL
Complication rate	<15%

Table 3. Proposed standards for outcomes on completion of robotic training.

At completion of the programme, mentors have a duty of care to the public to ensure trainees are competent. Accreditation of robotic programmes is not uniform, and formal assessment of the trainee on completion of many fellowships is not performed. Through the centralisation of programmes such as ERUS Robotic Curriculum, trainees can be assessed against a benchmark for safety and surgical quality. At a minimum, trainees should document the completed steps of procedures and meet minimum caseload requirements that correspond to the estimated learning curve for that procedure [64]. Outcome measures are a useful surrogate marker of surgical quality, and for RAPN, these are shown in **Table 3** [64].

6. Future directions

Robotic surgery is set to become even more widespread as new competitors enter the market and the demand for training will subsequently increase [65]. Surgical simulation will no doubt play a critical role meeting this demand, and an increase in the commercial availability of new platforms is anticipated. The ultimate simulation platform would be high-fidelity, low cost, readily available and translate to improved performance in the operating theatre. The validation process for new developments needs to be robust as resources are finite, and training time needs to be optimised. Even with the recent advancements in simulation, only limited

evidence exists to establish the correlation between simulation performance and actual intra-operative performance [66]. This is the ultimate end-goal of the simulation process, and future research needs to focus on establishing this link.

Patient-specific simulation has already arrived with the advent of 3D printing, and progress in this field is likely to be rapid as the technology becomes more readily available and cost effective [14, 26, 58]. It is conceivable that in the near future, patient's anatomical and oncological variations will be able to be reproduced in a model with incredible accuracy and detail. Advancements in model complexity are also anticipated, and the possibility of incorporating perinephric fat and vascular perfusion will no doubt increase the utility of this technology.

Finally, artificial intelligence (AI) has had large impacts outside of medicine and is starting to be adapted into the surgical field. From autonomous surgery to virtual assistants, the possibilities are seemingly infinite. Of particular interest in training and simulation is the use of machine learning algorithms to assess and track surgical performance. These algorithms are able to rapidly analyse vast quantities of data in order to determine relationships that may not be apparent to the human eye or traditional statistical methodology [67]. Recently, Hung and colleagues [68] were able to use intraoperative data captured from a recording device (dVLogger; Intuitive Surgical, Inc.) to develop automated performance metrics (APMs) for robotic prostatectomy. Using these APMs, the authors were able to predict clinical outcomes including length of stay, procedural time and catheter duration. Such sophisticated procedural feedback could be very beneficial for training purposes and allow bespoke tailoring of training based on the identified needs of the individual.

Conflicts of interest

None declared.

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