REVIEW

Current Status of Simulation Training in Urology: A Non-Systematic Review

Andrei Adrian Kozan [iD][1]
Luke Huiming Chan[2]
Chandra Shekhar Biyani [iD][3]

[1]Department of Urology, Hull University Teaching Hospitals NHS Trust, Castle Hill Hospital, Cottingham, UK; [2]Department of Urology, Sheffield Teaching Hospitals NHS Foundation Trust, Royal Hallamshire Hospital, Sheffield, UK; [3]Department of Urology, The Leeds Teaching Hospitals NHS Trust, St James's University Hospital, Leeds, UK

Abstract: Simulation has emerged as an effective solution to increasing modern constraints in surgical training. It is recognized that a larger proportion of surgical complications occur during the surgeon's initial learning curve. The simulation takes the learning curve out of the operating theatre and facilitates training in a safe and pressure-free environment whilst focusing on patient safety. The cost of simulation is not insignificant and requires commitment in funding, human resources and logistics. It is therefore important for trainers to have evidence when selecting various simulators or devices. Our non-systematic review aims to provide a comprehensive up-to-date picture on urology simulators and the evidence for their validity. It also discusses emerging technologies and future directions. Urologists should embed evidence-based simulation in training programs to shorten learning curves while maintaining patient safety and work should be directed toward a validated and agreed curriculum.

Keywords: simulation, education, learning, skills, innovation, urology

Introduction

"I fear not the man who has practiced 10,000 kicks once, but I fear the man who has practiced one kick 10,000 times." – Bruce Lee

To perform safe and effective surgery, a urologist must undergo countless hours of surgical training in order to overcome learning curves and attain proficiency in a wide range of operations. While surgical training had traditionally been based on Halsted's apprenticeship model of "see one, do one, teach one",[1] the evolution of the surgical environment over the past few decades have rendered this model obsolete.

Regulations on working hours by the European Working Time Directive have limited the amount of time trainees spend in the operating theatre.[2] Shortening of shifts have also led to reduced continuity of the trainer–trainee relationship. Other changes such as an increased emphasis on patient safety, growing patient expectations and increased litigation, all influence the amount of time and opportunity novice trainees receive in the operating theatre.

Simulation has emerged as an effective solution to these challenges. The growing recognition of simulation in urology is reflected by the development of formal simulation training programs across the world. In the United Kingdom, a national simulation-based Urology Bootcamp forms a mandatory part of residency training.[3] The European Basic Laparoscopic Urological Skills (E-BLUS)[4] program is a validated laparoscopic simulation skills course that is frequently taught across

Correspondence: Chandra Shekhar Biyani
St James's University Hospital,
Department of Urology, Lincoln Wing,
Beckett Street, Leeds LS9 7TF, UK
Tel +44 113 2433144
Email shekharbiyani@hotmail.com

the continent. Similar simulation-based courses have been developed in Asia by the Asian Urological Surgery Training and Education Group (AUSTEG)[5] and there is growing interest in Sub-Saharan Africa.[6]

Simulation is defined as a technique to "replace or amplify real experiences with guided experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner."[7] A simulator is a device or model used for the training of an individual by imitating real-life scenarios. Simulation training is not achieved simply by purchasing a simulator and allowing the trainee to practice unsupervised. To achieve optimal educational outcomes, McGaghie et al outlined that simulation must be integrated into the curriculum and encompass education principles such as feedback, deliberate practice, mastery learning, outcome measurement, skill acquisition and maintenance.[8]

It is not surprising that a larger proportion of surgical complications occur during the surgeon's initial learning curve.[9] While it is understood that trainees will eventually overcome these learning curves by treating patients, it is our ethical imperative to limit patient harm by using alternative methods of training for skill acquisition. Simulation comes into play by taking the learning curve out of the operating theatre and facilitating training in a safe and consequence-free environment. Errors can be made, learned from and reflected upon without harming a single patient. The simulation that is readily accessible also allows for greater flexibility of training around restricted working hours and limited operating theatre time. There is also evidence for simulation to improve performance when used preoperatively as a warm-up exercise based on a randomized-controlled trial in laparoscopic surgery.[10]

A simulator should be assessed for its validity before it is integrated into a training curriculum. Studies included in our review classified validity using the following types: face, content, construct, concurrent and predictive (Table 1).[11]

The range of urology simulators has grown rapidly, from low-fidelity bench-top models to high-fidelity virtual reality consoles, covering various subspecialties. While simulation is likely cheaper than running an operating theatre, the cost is not insignificant and requires commitment in funding, human resources and logistics. It is therefore important for trainers to select the best evidence-based simulators for their trainees.

A non-structured search strategy in MEDLINE databases and reference tracking has been performed resulting in a non-systematic review. The studies included were

Table 1 Types of Validity

Type of Validity	Definition
Face validity	Extent of a simulator's realism assessed subjectively through surveys of user opinion, usually with Likert scale
Content validity	Extent to which a simulator's content reflects knowledge and skills required in real life, based on surveys of expert opinion
Construct validity	Ability of the simulator to differentiate between the levels of experience of users or groups. This is proven when experts must outperform non-experts during standardized simulated tasks
Concurrent validity	Comparison of the new simulator's performance against a gold standard
Predictive validity	Ability of a simulator to predict performance in real life. This is assessed by correlating task performance on the simulator with the performance in the operating theatre

taken from PubMed or references cited therein. The last search was conducted in September 2019. The terms used to perform the search were "urology simulation". All English titles and abstracts were reviewed and included if they matched with the topic discussed.

This paper aims to provide a comprehensive up-to-date review on urology simulators and the evidence for their validity. We hope for it to serve as a guide for readers who are looking to implement evidence-based simulation in their urological training curriculum.

Open Urology Models

As a specialty, Urology branched from General Surgery with operations mainly done via an open approach in its infancy. However, it is now clear that urology is at the forefront of technology embracing the new and optimizing and updating the old.

Simulation models in open urological surgery are relatively limited in contrast to minimally invasive urology (Table 2). Perhaps seen as the "surgery of the past", not many simulators have been developed and those available are either bench models or cadaveric ones.

Bench models are more prevalent in open urologic simulation. Basic clinical examination can be practiced using the Male Rectal Examination Trainer (Limbs & Things) where the user learns to differentiate between benign and malignant prostates and evaluate anal tone.

Table 2 Models for Open Urology

Type of Model	Name	Skill	Provider	Validity
Bench	Male Rectal Examination Trainer	DRE prostate exam, anal tone and rectal exam	Limbs & Things UK	None
	Clinical Male Pelvic Trainer	Pelvic exam, testicular pathologies, penile cancer, indirect inguinal hernia	Limbs & Things UK	Face[12]
	Clinical Female Pelvic Trainer	Abdomen, pelvis, vagina, cervix, anus, different uterine modules (optional)	Limbs & Things UK	Face and Construct[13]
	Advanced Catheterization Trainer	Urethral and SPC	Limbs & Things UK	None
	Penile model + foreskin integrated in UroEmerge	Circumcision, penile ring block, priapism, paraphimosis	Pharmabotics + Limbs & Things	Face and content[14]
	Adult Male Circumcision Trainer	Circumcision	Limbs & Things	Face and content[15]
	Non-Scalpel Vasectomy Simulator	Vasectomy	Advanced Meditech International	Face[16]
	UroEmerge SPC Model	SPC	St Bartholomew Hospital London	Construct and predictive[17]
	SPC Model	SPC and urethral catheterization	Northwestern University Feinberg School of Medicine, Chicago	Face and content[18]
	SPC Model	SPC and urethral catheterization	Western Hospital, Melbourne, Australia	Face[19]
	VesEcho	SPC under US guidance	Dept. of Urology, Univ. of California, Sacramento	Face and content[20]
	US-SCIT	SPC under US guidance	Univ. of the Witwatersrand, Johannesburg, South Africa	Face and content[21]
	SPC Model	SPC	Xuanwu Hospital Beijing, China	None
	Ischemic Priapism Model	Ischemic priapism	University of Washington School of Medicine	Face and content[22]
Cadaveric	Fresh frozen	Emergency procedures, andrology	BAUS	Face, content[23]
	Thiel embalmed	Renal transplant	-	Face[24]

Abbreviations: DRE, digital rectal examination; SPC, suprapubic catheterization; US-SCIT, ultrasound-guided suprapubic catheter insertion trainer; BAUS, British Association of Urological Surgeons.

The advance model costs £1600. The same company offers an advanced Male (£3920) and Female Pelvic Trainer (£3780) each simulating pathologies according to sex ranging from penile cancer, testicular tumor, cyst, varicocele, epididymo-orchitis, hydrocele, inguinal hernia to vaginal vault, cervix and interchangeable uterine modules (of more interest to the gynecologist) but also important in Urology as all females presenting with visible hematuria should undergo a pelvic exam.[25] The female pelvic trainer has shown face and content validity.[13]

Adult circumcision is easily taught by simulation and is a core skill tested in the UK National Selection for residency training in urology. The model from Limbs & Things, UK comprises a penile model with replaceable foreskin made of synthetic bowel. It costs £170 and comes in a dark or light version with a pack of 5 foreskins, but these can also be bought separately. It has demonstrated face and content validity.[15]

The No-Scalpel Vasectomy Simulator costing US $225 (Advanced Meditech, USA) is a reusable simulator comprising 2 scrotal skins, 2 testicles and 2 long vas assemblies. The vas assembly can be changed at US $58 per pair. It has shown face validity in a small group.[16]

There are several suprapubic catheterization bench models available, of low and high fidelity. The main advantages of the low-fidelity ones are the low cost and availability. By contrast, high-fidelity SPC models are limited by their high price. Both have demonstrated various levels of validity.

UroEmerge is a low-fidelity model with the highest level of validity, having achieved construct and predictive validity in a group of 36 candidates.[17] Cheap and easily reproducible models for SPC have been developed either from a microwave container with a lid and a latex glove[26] costing US $2 or from a box and a party balloon simulating the bladder at around AU $2.67.[19]

Models for suprapubic catheterization with ultrasound guidance have also been advanced. VesEcho consists of an ultrasound compatible gelatin mold that contains a water balloon, a pelvic bone replica and a non-rebreather mask (rectus fascia) that has demonstrated face and content validity among 13 urology residents.[20] A cheaper option is US-SCIT (ultrasound-guided suprapubic catheter insertion trainer) constructed from common disposables (glove box, glove, infusion bag, trauma head blocks for stabilization) which showed the same level of validity among 50 participants.[21]

Another inexpensive, low-fidelity simulator with face and content validity has been created from hot dogs and red vines candy to simulate acute ischemic priapism. It costs US $1.25 and can be assembled in 10 mins.[22]

Fresh frozen cadavers have been used to teach open common urological operations under the BAUS cadaveric operative modules[23] such as circumcision, vasectomy hydrocele repair and testicular fixation, radical orchidectomy and prostate biopsy. The same course offered sling procedures for male and female incontinence, artificial urinary sphincter insertion, colposuspension and rectus sling procedure. Cadaveric training on fresh frozen cadavers was also used for emergency and trauma urology including management of bladder perforation with bladder repair, ureteric reimplantation, emergency nephrectomy, open packing of the pelvis. Face and content validity were shown among 102 participants.[23] At the time of this article being written, BAUS only confirmed upcoming dates for the Emergency Urology Cadaveric Course consisting of open cystostomy and SPC insertion, emergency exploration and nephrectomy, ureteric reimplantation, psoas hitch and Boari flap and scrotal exploration, testicular fixation and repair of rupture. It also features andrological emergencies such as penile block, treatment of priapism, dorsal slit, penile fracture repair and Fournier's gangrene debridement.[27]

Thiel embalmed cadavers can be used as high-fidelity simulators and indeed a multispecialty evaluation for surgical training found them suitable, realistic, with reduced odor and more cost effective.[28] Face validity has been demonstrated in a model for renal transplant proposed by Cabello.[24]

Endourological Models

The field of endourology with its confined environment lends itself well to simulation training and consequently many simulators have been developed. We have categorized them into nonbiologic (Table 3) and biologic models (Table 4). The nonbiologic ones are bench and virtual reality.

Bench Models

Most of the bench models are high-fidelity and expensive. Cystoscopy and BOTOX injection has proven face and content validity[29] on the ETXY-URO simulator. The same device can be used for ureteroscopy and has interchangeable male and female genitalia. It has established face, content and construct validity.[30]

Several models for ureteroscopy and resection from Limbs and Things, UK such as Uro-Scopic trainer, Bristol TURP and TURBT models with proven validity[31–35] are no longer commercially available (AK enquired with the company July 2019).

The Resection Trainer LS10 from Samed, Germany utilizes a substrate for resection similar to human tissue and can be used in conjunction with all resectoscopes. It also has its own irrigation system. The model for TURBT has established face, content and construct validity in study of 76 subjects.[36] A synthetic model replicating a hypertrophied prostate developed by Matsuda et al[69] was used for HoLEP training (Kansai Medical University, Osaka) and demonstrated face and content validity. The prostate models can be replaced as needed.[37]

A number of models for ureteroscopy have been developed. The K-Box is a low-fidelity simulator for flexible ureteroscopy that replicates the upper tract. It requires a flexible ureteroscope to be navigated through the device, thus enabling the student to become accustomed to the movements required in flexible URS: in-out, pronation-supination, deflection, grasping-releasing. It has shown content[38] and construct[39] validity in a group of medical students that outperformed the control group. The Cook URS model was validated during a 2-week flexible URS course for 15 urology trainees. They performed significantly better in skills, time and the simulator demonstrated face, content and construct validity.[40] With the EndoUro-Trainer apart from simple URS, stone extraction and basketing the candidate can also destroy

Table 3 Nonbiologic Models for Endourology

Type of Model	Name	Skill	Provider	Validity
Bench	ETXY-URO Simulator	CYS, Botox injection	ProDelphus, Brazil	Face and content[29]
		CYS, URS		Face, content and construct[30]
	Endoscopic Urinary Tract Model	CYS, URS	SimPortal, University of Minnesota, USA	None
	Resection Trainer LS10	TURBT	Samed GmbH, Dresden	Face, content and construct[36]
		TURP	Samed GmbH, Dresden	None
	Holmium laser enucleation simulator	HoLEP	Kansai Medical University, Osaka	Face and content[37]
	K-Box	URS	Coloplast	Content[38] and construct[39]
	Cook URS	URS	Cook Medical USA	Face, content and construct[40]
	Advanced Scope Trainer	URS	Mediskills UK	Face, content, construct and concurrent[41]
	EndoUro-Trainer	URS	Samed GmbH, Dresden	None
	SIM-PCNL model	PCNL	University of Rochester, New York	Face, content and construct[42]
	iPERC	PCNL	Hospital de Especialidades, Mexico	Construct[43]
	PCNL trainer LS40	PCNL	Samed GmbH, Dresden	None
	Perc Trainer	PCNL	Mediskills UK	None
Virtual Reality	URO Mentor	CYS, Bladder biopsies	3D Systems formerly Simbionix	Face, content, construct and predictive[44–50]
		URS		Face, content, construct, and predictive[50–54]
	PERC Mentor	PCNL	3D Systems formerly Simbionix	Face, content, construct and predictive[55–57]
	Uro Trainer TURBT	TURBT	Karl Storz, Germany	Face, content and construct[58]
	TURP Mentor	TURP	3D Systems formerly Simbionix	Face, content and construct[59,60]
		TURBT		None
	SurgicalSIM TURP	TURP	HelSim Ltd, USA	Face, content and construct[61,62]
	PelvicVision	TURP	Melerit Medical, Sweden	Face, content and construct[63,64]
	VirtaMed UroS	TURP	VirtaMed, Switzerland	Face, content and construct[65]
		TURBT		None
		ThuLEP		None
		HoLEP		Face, content and construct[66]
		Diode PVP		Construct[67]
	GreenLight SIM	GreenLight PVP	UMN CREST for American Medical Systems, USA	Face, content and construct[68]
	RezumSim	Rezum	VirtaMed for NxThera	None
	UroLiftSim	UroLift	VirtaMed for Neotract	None

Abbreviations: CYS, cystoscopy; URS, ureterorenoscopy; TURBT, transurethral resection of bladder tumour; TURP, transurethral resection of prostate; HoLEP, holmium laser enucleation of prostate; PCNL, percutaneous nephrolithotomy; ThuLEP, Thulium laser enucleation of prostate; PVP, photoselective vaporization of prostate.

Table 4 Biologic Models for Endourology

Type of Model	Name	Skill	Provider	Validity
Cadaveric	Fresh frozen cadavers	CYS, Bladder biopsy, Botox injection, URS, TURP	BAUS	Face and content[23]
		CYS	–	Construct[77]
	Thiel embalmed cadavers	CYS, URS	–	Face and content[78]
		URS	–	Face and content[79]
		URS, TURP	–	Face[80]
		TURP, UroLift	University of Leeds, UK	None
Animal	Live porcine model	URS	–	Face, content and construct[81]
	Ex vivo porcine urinary tract	URS	–	Face, content and construct[81]
	Porcine kidney and ureter	PCNL	–	Face[82]
	Porcine bladder	Transurethral bulking	University of California, Irvine	Face, content and construct[83]
	Boar bladder	CYS, bladder biopsy	–	Construct[84]

Abbreviations: CYS, cystoscopy; URS, ureterorenoscopy; TURP, transurethral resection of prostate; BAUS, British Association of Urological Surgeons; PCNL, percutaneous nephrolithotomy.

the stone through either laser, electrohydraulic or electrokinetic lithotripsy. It has yet to be validated. Mediskills Advanced Scope Trainer is a high-fidelity validated model for face, content, construct and concurrent validity.[41] The model is framed in an acrylic case containing a distensible bladder, ureteric orifices and even a distorted ureter designed for rigid and flexible URS. It also has the potential to be paired with a percutaneous access trainer for use in PCNL simulation.

SIM-PCNL is a high-fidelity model that uses 3D-printed molds to respect anatomically correct pelvicalyceal system, kidney and relevant adjacent structures such as thoracolumbar spine, adipose tissue and all layers of the posterior abdominal wall. It has been validated for face, content and construct validity in a group of 15 participants (5 experts and 10 novices) in a full-simulation environment with the greatest realism including percutaneous access, dilatation, lithotripsy and nephroscopy. Ultrasonographic appearances were rated low.[42]

Construct validity has been demonstrated for iPERC (a radiation-free training model) in 30 participants; however, neither face nor content validity was evaluated in the study.[43] The Perc Trainer from Mediskills has been used to teach renal access via ultrasound or fluoroscopy, nephrostomy, tract dilatation, stone extraction/fragmentation and nephrostomy siting. Although reported in the literature it has not yet been validated.[70]

The C-Arm fluoro-less trainer from SimPORTAL, Minneapolis was designed using 3D printing and accommodates two webcams connected to a computer. The images obtained are processed to give a simulated on-screen image. According to Noureldin and Andonian, it has not yet been validated.[71] More recently, Yoshida et al[72] have developed an artificial kidney model, the T-box. This proved to be a feasible alternative to the biological porcine model showing similar intrarenal pressure and back-flow rates and that use of a smaller ureteral access sheath 10/12-Fr could result in a more rapid increase in intrarenal temperature during lasering. No endourological experiments have been performed yet on the model.[72]

Ballistic gel has also been used to create a kidney puncture model with an additional iPAD-guided puncture. This design was evaluated by five novices and three experts, showing good face, content and construct validity.[73]

Virtual Reality (VR) Models

The UroMentor, 3D Systems (previously Simbionix, USA) remains the most evaluated and validated VR system. Instruments include rigid and flexible cystoscopes, ureteroscopes, guidewires and baskets. A variety of preprogrammed

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tasks and cases of stones and strictures can be practiced with a real-time simulation of fluoroscopy and C-arm utilization. It has demonstrated face, content, construct and predictive validity, and a randomized controlled trial also showed transfer of skills from VR to OR (operating room).[44–54] From the same company, the PERC Mentor is the only VR simulator validated for training and assessment of percutaneous renal access.[55–57] It costs around US $100,000.[71]

Many VR resection simulators have emerged. The Uro Trainer (Karl Storz, Germany) offers modules for TURP with prostate resections increasing in difficulty and ranging from 55 to 90 g, as well as TURBT. Validation exists only for the later module in the form of face, content and construct in a group of 22 participants including residents and consultants.[58] The TURP Mentor (3D Systems) offers platforms for TURP, TURBT and laser BPH, the manufacturer advertising it as the most advanced training simulator. The TURP element has been validated for face, content and construct.[59,60]

SurgicalSIM TURP (HelSim, USA) is a simulator that tracks the learner's progress and compiles performance data over time issuing a detailed evaluation report. Studies have shown face, content and construct validity.[61,62]

The UroS platform from VirtaMed offers multiple BPH simulators such as TURP, ThuLEP, HoLEP, Diode PVP and TURBT simulation. The system has eight TURP full cases, four TURBT modules with various locations and difficulties including the risk of bladder perforation. The TURP component has demonstrated face, content and construct validity.[65] Out of the laser BPH sections, HoLEP has been validated for face, content and construct validity in 53 participants[66] and the diode PVP for construct validity.[67] The same VirtaMed platform can be adapted and customized for specific procedures for other businesses and indeed it is being used for training for Rezum and UroLift.[74,75]

GreenLight SIM is another VR simulator used to teach GreenLight laser prostatectomy. It contains part-task exercises to familiarize the student with the device and technology and six operative procedures. It has shown face, content and construct validity.[68]

Biologic Models

The BAUS Cadaveric Modules had an established curriculum however future dates have yet to be confirmed. Another fresh frozen cadaveric (FFC) simulation program to teach ureteroscopy was validated for face and content by Huri et al[76] in their study group. Twenty-nine obstetric residents confirmed construct validity for cystoscopy on similarly treated cadavers.[77]

Thiel embalmed cadavers (TEC) have good tissue color, consistency and malleability without the odor or infection risk and thus are used successfully for surgical training. Lower and upper tract endoscopy on Thiel cadavers has been evaluated by 12 urologists demonstrating face and content validity.[78]

Mains et al[79] showed face and content validity in the first designated ureterorenoscopy course on Thiel cadavers with a high level of satisfaction among participants. So far only face validation exists for TURP on TEC.[80] Sixty trainees validated URS in both ex vivo and live porcine models while undergoing a two-day program consisting of lectures, dry lab and live porcine training.[81] Several animal models for teaching PCNL exist, however, they only have face validity at most. The majority consists of porcine kidney and ureter with skin flaps, subcutaneous tissue and muscles for fluoroscopic and/or ultrasound access. They are relatively simple and cheap to construct.[71]

More recently face, content and construct validity have been demonstrated for transurethral bulking for stress urinary incontinence. Female porcine bladders were mounted in a modified hysteroscopy trainer. Six experts and six trainees completed the simulator's evaluation.[83] Boar bladder can be used as a high-fidelity tool for teaching core cystoscopic skills in novice residents. Construct validity has been shown for the model.[84]

Laparoscopic Urology Models

Many simulators exist to teach basic laparoscopic skills. These are either box trainers, commercially available or "handmade" endotrainers, or virtual reality (VR) trainers. However, only few urology procedure-specific simulators have been developed so far (Table 5).

A bench model for laparoscopic partial nephrectomy made of polyvinyl alcohol incorporated in a SimMan mannequin was used for validation in a theatre environment and also coupled with non-technical skills; interestingly urology residents consistently rated themselves higher for non-technical skills.[85,86] The group from Cleveland Clinic, Ohio developed and established face, content and construct validity for a ureteric reimplantation model made of hydrogel in 12 trainees and 5 experts.[87] A randomized prospective, controlled study evaluated a latex model and showed face and concurrent validity, concluding that skills learned on their urethrovesical model transfer to a live porcine model. The live pig model was also assessed for

Table 5 Laparoscopic Urology Models

Type of Model	Name	Skill	Provider	Validity
Bench	Partial Nephrectomy model	Lap. Partial Nephrectomy		Face, content and construct[85,86]
	Ureteral anastomosis model	Ureteroneocystostomy	Cleveland Clinic, Ohio	Face, content and construct[87]
	Urethrovesical model	Urethrovesical anastomosis	University of Sherbrooke, Canada	Face and concurrent[88]
	Urethrovesical model	Urethrovesical anastomosis	Minimally Invasive Centre of Surgery Jesus Uson, Spain	Face, content and construct[89]
Virtual Reality	Lap Mentor	Lap. Radical Nephrectomy	3D Systems formerly Simbionix	None
	LapSim	Lap. Radical Nephrectomy	Surgical Science, Sweden	None
Animal	Rabbit model	Lap. Nephrectomy	–	Construct[90]
	Porcine bladder	Pyeloplasty	–	Construct[91]
	Chicken crop model	Pyeloplasty	–	Construct[92]
	Chicken model	Ureteric reimplantation	–	Face, content and construct[93]
	Chicken chest model	Urethrovesical anastomosis	–	Contruct[94]
	Chicken skin model	Urethrovesical anastomosis	–	Construct[95]
	Porcine intestine model	Urethrovesical anastomosis	–	Construct[96]
	Live female pig	Urethrovesical anastomosis	–	Face[88]
	Live pigs	Lap. radical nephrectomy, cystectomy	University of Medicine and Pharmacy Cluj-Napoca, CLERU, Romania	None
Cadaveric	Thiel embalmed cadavers	Lap. Radical Nephrectomy	University of Leeds, UK	Face, content and construct[98]

face validity.[88] Another synthetic model demonstrated face, content and concurrent validity in a group of 22 (10 experts and 12 novices).[89]

The virtual reality simulators are expensive; LapMentor (US $60-100,000) and LapSim (US $55,000) and procedure-specific modules have not yet been validated. Their basic skills modules, however, have been validated.[11]

Animal models are the primary teaching vector for urological procedure training. There are ex vivo and in vivo models with main drawbacks being ethical constraints and variances in anatomy. A rabbit model has been used to train for laparoscopic nephrectomy showing a decrease in duration of surgery and complications after 20 procedures.[90] Pyeloplasty can be taught on a model made of porcine bladder or chicken crop and esophagus to simulate the renal pelvis and ureter. Both models have been evaluated for construct validity.[91,92] A group of 50

participants (30 novices and 20 trained laparoscopists) assessed a chicken model designed for Lich-Gregoire ureteric reimplantation. The trachea simulated the ureter, the esophagus the common iliac and the crop simulated the bladder. The authors demonstrated face, content and construct validity.[93] A key step in radical prostatectomy, urethrovesical anastomosis, has been simulated in a chicken chest or skin model and a porcine intestinal model. They all have shown construct validity.[94–96]

Live pigs are being used for training on full procedures as part of a laparoscopic course teaching radical nephrectomy and cystectomy or for more advanced participants inferior vena cava suture. The models have not undergone any validation.[97]

A course on Thiel embalmed cadavers for UK trainees is also running at the University of Leeds based on the model validated by Rai at al.[98] for laparoscopic radical nephrectomy. Each trainee performs the procedure under

supervision after attending a live demonstration in the operating theatre.

Robotic Urology Models

There has been a trend in recent years of developing new models for robotic surgery (Table 6) or refining and establishing a curriculum for training. Virtual Reality (VR) simulators are the mainstay for basic and procedural skills.

Weiner et al[123] suggested 10 hrs of simulator training for basic and advanced skills may be optimal for an acceptable level of surgical ability. Interestingly, however, Mills et al[124] concluded in a study of 10 attending surgeons that there was no correlation between basic skills simulator performance and intraoperative performance. The clinical implications of this remain unestablished.

VR simulators are expensive tools in the arsenal of robotic training. The dVSS and dV-Trainer are the most extensively validated VR simulators, demonstrating all levels of validity.[99–102] The dVSS costs USD $89,000[101] works directly with the da Vinci console but cannot be used if the console is in use for operating thus greatly limiting training time. The Mimic dVT is a stand-alone simulator costing USD $158,000[101] that runs MSim software like the dVSS. It is the most validated robotic simulator.[11] Tube-3 module to teach urethrovesical anastomosis (UVA) has also been broadly validated.[106–108] FlexVR (Mimic Technologies) is a newer flexible and portable training platform design to teach fundamentals of robotic surgery. It has yet to be formally validated.

RobotiX Mentor is also a stand-alone simulator created by 3D Systems. The basic skills modules have shown face, content and construct validity[100,101,103] and the prostatectomy module has recently been validated for face, content and construct in a group of 13 novice, 24 intermediate and 8 expert surgeons.[104]

The Robotic Surgical Simulator (RoSS) by Simulated Surgical Systems is another stand-alone simulator that has basic skills and procedure-specific modules. It costs USD $120,000.[101] Studies have demonstrated face, content and construct validity for the fundamental skills.[100,101] So far only the augmented reality UVA module has confirmed construct validity.[105] The platform also offers robotic-assisted radical prostatectomy (RARP), robotic-assisted radical cystectomy (RARC) and lymph node dissection.

MaestroAR has been designed by Mimic Technologies to provide procedure-specific training in augmented reality media for both dV-Trainer and FlexVR. The partial nephrectomy module has face, content, construct and concurrent validity.[109] Mimic also developed the Xperience Team Trainer which functions as a complementary hardware unit for the dV-Trainer. It is aimed at assistant simulation, verbal communication and reaction to one another's actions and has shown face, content, construct and concurrent validity in 28 volunteers.[110]

In comparison to VR simulators, fewer bench models for robotic surgery have been validated. Three basic skills have been validated by Ramos et al[111] in a group of novices and experts using global evaluative assessment of robotic skills. 3D printed kidney and tumor models have been used for robotic-assisted partial nephrectomy (RAPN). SIMPLE-PN demonstrated face, content, construct and concurrent validity in two studies of small size (8 participants).[112,113] However, Monda et al[114] involved 24 participants in validating their model for RAPN measuring similar metrics of warm ischemia, preserved renal parenchyma and surgical margins. They established face, content and construct validity. Recently two new models for UVA simulation have emerged applying 3D-printed technology and silicone using the da Vinci system.[115,116] The larger sample group (20) of Johnson et al[115] consisted of experts, intermediates and novices and demonstrated face, content and construct validity for their low-cost ($2.50), high-fidelity model.

Various animal models have been used for robotic training however fewer than other disciplines. A porcine kidney with a Styrofoam ball to replicate a kidney tumor was used for a RAPN simulator. The authors showed face, content and construct validity among 46 participants.[117] Pig bowel was introduced in an abdominal trainer to simulate spatial constraints and using the da Vinci SI robotic system validated the model for face, content and construct.[118] Again using porcine material, a female genitourinary tract was employed to teach steps of RARP. Seminal vesicles and dorsal venous complex were mimicked by the fallopian tubes and the introitus was used as the prostate. The model showed face, content and construct validity.[120] The proventriculus and the proximal part of a chicken's esophagus stand to simulate UVA during RARP. Posterior fascial reconstruction was also performed between the tissues on the posterior surface of the esophagus and the serosa of the proventriculus. Face and content validity were demonstrated.[119]

Basic skills and RARP have been taught on cadavers and some studies showed validity[121,122] although robust evidence is lacking. The European Association of Urology

Table 6 Robotic Urology Models

Type of Model	Name	Skill	Provider	Validity
Virtual Reality	dVSS	Basic skills	Intuitive Surgical, USA	Face, content, construct, concurrent and predictive[99–101]
	dV-Trainer	Basic skills	Mimic Technologies, USA	Face, content, construct, concurrent and predictive[99–102]
	FlexVR	Basic skills	Mimic Technologies, USA	None
	RobotiX Mentor	Basic skills	3D Systems formerly Simbionix	Face, content and construct[100,101,103]
		RARP		Face, content and construct[104]
	RoSS	Basic skills	Simulated Surgical Systems, USA	Face, content and construct[100,101]
		Urethrovesical anastomosis AR*		Concurrent[105]
		RARP		None
		RARC		None
		Lymph node dissection		None
	Tube-3	Urethrovesical anastomosis	Mimic Technologies, USA	Face, content, construct, concurrent and predictive[106–108]
	Maestro AR*	RAPN	Mimic Technologies, USA	Face, content, construct and concurrent[109]
		RARP		None
	Xperience Team Trainer	Assistant skills	Mimic Technologies, USA	Face, content, construct and concurrent[110]
Bench	Mimic dry-lab exercises	Basic skills	Mimic Technologies, USA	Face, content and construct[111]
	SIMPLE-PN	RAPN	University of Rochester, USA	Face, content, construct and concurrent[112,113]
	RAPN Training	RAPN	Washington University, St Louis USA	Face, content and construct[114]
	Urethrovesical model	Urethrovesical anastomosis	University of Texas, Dallas USA	Face, content and construct[115]
	Urethrovesical model	Urethrovesical anastomosis	Geisel School of Medicine at Dartmouth	Face and content[116]
Animal	Porcine kidney with an embedded Styrofoam ball	RAPN	–	Face, content and construct[117]
	Porcine bowel	Intracorporeal bowel anastomosis	–	Face, content and construct[118]
	Chicken model	Urethrovesical anastomosis	–	Face and content[119]
	Porcine genitourinary tract	RARP	–	Face, content and construct[120]
Cadaveric	Fresh frozen cadavers	Basic skills	–	Face and content[121]
		RARP	–	Face[122]

Abbreviations: dVSS, da Vinci Skills Simulator; RARP, robotic-assisted radical prostatectomy; RoSS, Robotic Surgery Simulator; AR*, augmented reality; RARC, robotic-assisted radical cystectomy; RAPN, robotic-assisted partial nephrectomy.

has a validated robotic training curriculum that integrates cadaveric training.[125]

Remaining on the topic of prostate cancer, tissue diagnosis is essential. The Biopsym is a virtual reality simulator for transrectal ultrasound-guided (TRUS) biopsy consisting of a haptic device connected to a 3D ultrasound image library.[126] The haptic stylus mimics the movement of ultrasound probe while corresponding 2D image slices are projected in real-time. This model has demonstrated face, content and construct validity.[127,128] Another VR simulator uses an ultrasound probe inside a mock pelvis, synchronized with a 3D ultrasound image by a 3D magnetic tracking system. This was shown to have face, content and construct validity.[129]

With the growing popularity of transperineal biopsies, two simulators have been developed: an augmented reality simulator by the University of Florida[130] and a virtual reality haptics-enabled simulator by the University of Chester.[131] These simulators are not commercially available and no validation studies have been published to date.

Low dose-rate brachytherapy seed implantation and high dose-rate brachytherapy source positioning is technically very similar to transperineal prostate biopsy. A brachytherapy training program using a bench-top simulator (made from a prostate phantom and dummy seeds) showed promise at improving residents' skill acquisition by training residents to perform high-quality implants.[132] A virtual reality haptic simulator for seed implantation was developed using multiple haptic devices to represent an ultrasound probe and needle.[133] Advanced computerized simulation is also used in the treatment planning for high dose-rate brachytherapy to optimize radiation dose delivery and minimize source positioning errors.[134] These simulators are not yet validated in the literature.

Sehrawat et al[135] developed a computer-based simulation tool to train urology residents. Simulated prostate cancer cases were created, and residents had to plan the layout of probes as well as depth insertion to achieve the perfect treatment outcome. Trainees were allowed unlimited attempts to solve six cases within 50 mins. It was found that with just 50 mins of planning practice, novice resident performance in planning increased significantly from 2.2% to 31.1%.[135]

External beam radiation therapy for prostate cancer involves meticulous planning to maximize therapeutic benefit and minimize toxicity to surrounding organs. A prostate fossa contouring simulator was developed to teach and improve contouring accuracy during treatment planning. After sufficient practice with this simulator, novice medical students were able to contour the prostate fossa therapy with near "excellent agreement" with plans by expert radiation oncologists.[136]

Non-Technical Skills

Recently there has been more focus on non-technical skills (NTS) training in surgery. NTS is an emerging field of research. So far there is no standardized training and the subject is yet to be implemented in surgical training across specialties.

A systematic review by Anderson et al[137] showed that 14.4% of surgical patients will experience adverse effects of various severity, out of these 5.2% are potentially preventable. The same paper indicated more incidents were caused by errors in NTS than faults in the operating technique.[137] Similarly, a report to the National Patient Safety Agency in the UK found that almost half of the incidents had a failure in NTS.[138] Recently, however, a meta-analysis[139] failed to find a statistically significant improvement of patient's outcomes after NTS training of theatre staff. They did nonetheless recognize that their conclusion was drawn from a small number of heterogeneous studies.[139] Three separate categories of NTS have been recognized: social, cognitive skills and personal resource factors.[140] The metrics for assessments include NOTSS – Non-Technical Skills for Surgeons, NOTECHS – Non-technical Skills and OTAS – Observational Teamwork Assessment for Surgery.[141]

A high-fidelity simulated ward round has been used as part of NTS training and assessment in the UK Urology Simulation Bootcamp for newly appointed senior urology trainees. Forty-eight doctors participated and individually led a simulated ward round where distractions were introduced in an evolving urology-related scenario. Freeze-frames and whole-group structured debriefing and feedback were also offered. The mean NOTTS scores indicated that NTS performances could be improved.[142]

A prospective cohort study[143] using a team-training scenario where residents performed a laparoscopic partial nephrectomy on a validated simulator showed that non-technical skills performance (based on NOTSS score) was significantly affected by the residents' level of training therefore establishing construct and face validity. By contrast, another study which used a critical scenario during laparoscopic radical nephrectomy found that urology resident training correlated with technical performance but not with NTS. They also indicated face validity.[144]

In a prospective simulation study including 17 urology residents, significant improvement was noted on validated teamwork instruments between scenarios based on resident and expert evaluation. Face and content validity were also shown.[145]

Face, content and construct validity were demonstrated in a distributed simulation environment where participants performed a TURP in a portable, simulated operating room. NOTECHS scale was used for evaluation, debriefing and feedback was received. One of the advantages of this environment is that it can be set up in any open space.[146]

Brunckhorst et al[147] looked at the relationship between technical and non-technical skills in a simulation-based ureteroscopy training environment. They concluded that a strong correlation does exist between the two, which was demonstrated to be irrespective of training received. It was also shown that all non-technical skill sets are important in technical performance advancing the notion of training and assessing both skills simultaneously.[147]

Discussion
Reflections
This non-systematic review provides a comprehensive update on simulators used in urology and their validity. As outlined, there are many different simulators from the very basic to the extremely sophisticated and expensive. Different technologies present with different advantages and limitations each with their own field of application. It is therefore essential to establish the learning objectives from the outset where a simulator can help, thus identifying the most appropriate method of achieving the learning goal.

Simulation should complement essential urological training and be gauged at the beginning of the learning curve in a safe and protective environment where mistakes are not catastrophic, then practice should progress with clinical and skill acquisition. Simulation is no substitute for clinical practice.

There is still ongoing expert debate as to whether simulation can be used for assessment purposes, especially for summative assessment. To our knowledge, there is no criteria to formally validate the training potential of individual simulators. Similarly, there is paucity of evidence supporting the use of simulation assessment tools for high-stakes assessments, which is a problem in the whole surgical literature. Perhaps the time has come when we should temper developing new simulators and further our

research on the educational impact such as establishing the transfer of skill from simulation into practice.

Unfortunately, we still lack an agreed universally accepted curricula despite some efforts such as EUREP (European Urology Residency Program) or FLS (Fundamentals of Laparoscopic Surgery). We certainly need future research that should result in a multicentre international agreement. Even so, it is likely that only large centres might be able to offer such program and we might be heading towards a centralised simulation delivery.

We should not take lightly that the delivery process is resource-demanding from time spent in organising and design, selecting expert tutors, logistical equipment to the appropriate venue to time that might not be remunerated or reimbursed. There are also inequalities in what can be provided, for example large teaching centres will have money and resources to engage in simulation or even simulation centres/hubs whilst other organisations might struggle with this.

Surprisingly, despite a lot of attention in recent time, non-technical skills training failed to improve complication rates in the operating theatre according to the latest meta-analysis.[139] Interestingly as well, surgeons and anaesthetists were the main actors failing to show improvements. However, it is of note to mention that most of the studies that looked at this were underpowered and heterogeneous. We still need well-designed and well-conducted prospective, randomised trials to better our understanding. Also, a standardized training curriculum is needed where the framework should combine the most useful and effective modalities tailored for individual specialties.

We believe simulation to be an important adjunct to a modern competency-based urological training, with residents receiving continuous exposure throughout their training and can also help in continuous professional development. In doing so trainers can also provide targeted learning and bridge the gap depending on training needs.

Limitations
We accept this is a non-systematic review and is by no means exhaustive of all simulators used in urology. A systematic review would have offered better focus and logical progressive sequence and perhaps even clarity. Nevertheless, this paper is providing a thorough, comprehensive and contemporary review on urology simulators and the evidence for their validity.

Future Directions

It is certain that urology is at the forefront of technology and so embracing the advancements and new developments only comes naturally. As simulation methods become increasingly realistic, virtual reality (VR) will continue to progress and augmented (AR) and mixed reality (MR) will have a more formalized and less futuristic role to play.

In the era of Snapchat and Pokémon Go it is almost inevitable not to find AR applied in surgery. For example, Gunner Goggles Series[148] features a mobile app to be used in conjunction with the medical books to enhance learning by integrating AR using animations, visuals and 3D models to clarify complex anatomy, conditions or various concepts. HoloHuman[149] is being advertised as the world's most complete anatomy application for mixed reality and HoloLens from Microsoft. It boasts more than 13,000 separate anatomical structures and offers a life-like alternative to the traditional cadaveric dissections.

We postulate that AR/MR are the best examples of symbiosis between simulation and its direct application in real life. It is not surprising then to see different head-mounted displays (HMD) already been utilized in practice. There are currently three types: see-through HMDs, heads-up HMDs and non-see-through HMDs. A recent systematic review[150] found that the primary use of HMD was for image guidance and AR and secondly for data display. Intra-operative education also featured either trainer or trainee directed. Overall, see-through HMDs were the most common type reported but in education and training, in particular, heads-up HMD led the way. There are of course limitations in the use of these devices and the same paper identified concerns about patient information security or privacy, heavy or cumbersome devices, battery life, lag time in AR and the dependence on wireless internet or Bluetooth connection.[150] It is however promising technology for simulation. The use of the headset display allows for portability and removes the need for multiple screens. The higher degree of immersiveness offered by holograms allows for better spatial awareness and can be experienced by multiple users simultaneously.

Porpiglia et al[151] compared outcomes between using AR vs standard procedure. Their hyper-accuracy 3D reconstruction software-based integration was used in 21 RAPN. They concluded that a higher number of patients were undergoing global ischemia in the control group (80%) as opposed to AR group (24%). The surgeons also adhered to the preoperative management plan of the renal pedicle in 90% of the AR cases vs 61% in the control group. Similarly, 3D elastic AR was found to correctly identify capsular involvement in RARP in 100% of cases when compared to 47% in the 2D MRI cognitive group.[152]

A systematic review of AR in urological interventions[153] ascertained that overall the available literature regarding AR is largely limited to reports without control groups and mainly adopted by larger or academic centers. A major limitation of AR-enhanced surgery, particularly in operations involving soft tissues that suffer deformations, is the inaccuracy in registration that translates into poor navigation precision. This is where improvement in technology is awaited. Importantly also, more simulation using AR could help reduce the anxieties in accepting and finding more clinical applications.[153]

Telemedicine AR is an exciting avenue where one surgeon is in the operating room and the other anywhere in the world. The expert surgeon can watch and potentially correct the surgeon operating in real-time. Proximie, a London-based company has gained prominence with its use of AR technology and telemedicine to democratize global surgical training. Their AR technology enables the trainer/expert to observe an operation remotely and provide real-time guidance by pointing or drawing over the operative field, which is then overlaid and visualized by the operating surgeon.[154]

Artificial intelligence (AI) has the flexibility and capability to work and learn from large data. Deep-learning methods make minimal assumptions and give better predictions compared to traditional data especially when dealing with huge dimensional data. AI can help in predictions with early, accurate and individualized decisions. However, there have been instances where traditional statistics outperformed AI making it hard to justify direct application in clinical life. AI needs rigorous quality control, regulations and external validation. AI systems require continuous training by data from clinical studies and independent validation to maximize their potential.[155] They can potentially be used for assessing and predicting training skill progression among surgical trainees.

With the ever-growing range of simulators and the exciting potential of new emerging technologies, we believe that there has been no better era to undergo urological training.

Disclosure

The authors report no conflicts of interest in this work.

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