Chapter 16
Low-cost Simulation in Urology

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16.1 Introduction

Simulation as a means of learning or rehearsing surgery has a rich history, which is as old as surgery itself. Sushruta, an ancient Indian physician—2600 years ago, widely believed to be the "Father of Surgery," is credited with the use of fruits, vegetables, pieces of cloth/ skin/ hides, and cadaver-based experimental modules for teaching surgical skills [1–3]. These were the forerunners of modern low-cost simulation in which surgical residents practice tying knots, suturing on clothes, and train on animal organs.

Surgical skills, like any other motor skills, can only be acquired by repetitive practice, *i.e.* simulation; which consists of cognition, integration, automation, and finally, mental cognitive rehearsal of the proposed surgery [4, 5]. Simulation provides a much needed bridge between theoretical learning and real-life operating experience for a trainee and has become the foundation of modern surgical training. A recent bibliometric analysis of surgical education's 100 most cited articles found that the majority of publications were on surgical skill acquisition by simulation and its assessment and highlighted its importance [6].

Traditionally, simulations for surgical training were practiced in an autodidactic manner in rudimentary wet labs using animal parts procured from local butcher's shops or on cadavers. The advent of minimally invasive surgery demanded an upgrading of the science of simulations for learning new surgical skills, which had

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a significant learning curve due to impaired depth perception as visualization is on a two-dimensional screen, impaired tactile feedback, 2-handed choreography for dissection, non-dominant hand dexterity, accurate instrument targeting, intracorporeal suturing, different hand–eye coordination, familiarity with the fulcrum effect and, last but not least, working in a less ergonomically friendly position leading to earlier fatigability [7, 8]. Training opportunities in modern surgical skills centers were and are limited due to cost and availability [9–12]. This prompted the surgeons to unleash their ingenuity and led to the development of low-cost, easily available, and sustainable alternatives for simulation of surgical training. This was and remains very important in low- and middle-income countries.

16.2 Humble Beginning of Low-cost Simulation Systems

This revolution had humble beginnings in the form of "laparoscopy box trainers" which are made from the self-assembly of locally available/off-the-shelf/bought from online shopping portals components and even using used/discarded/expired disposable instruments (Table 16.1) [8, 13–16].

16.3 Advantages and Qualities of Low-cost Simulation Systems

Low-cost trainers are designed basically for novice surgeons to practice generic skills required for urological surgery. A low-cost simulation system has most of the advantages of a high-fidelity system: it allows repetitive practice of skills; can be used many times by multiple users; it permits the trainee to become familiar with anatomy (to scale, tissue texture, and accurate replication of anatomy), equipment, and techniques of surgery being practiced, so the learning curve associated with real

Table 16.1 Anatomy of low-cost box trainers for minimally invasive surgery

Component of simulator	Low-cost substitute
Abdominal cavity and wall	Plastic/cardboard storage box/metallic basket, two acrylic plates with hinge joints, plastic document holder case (Fig. 16.1)
Port site	Hole in the abdominal wall material (by cutting, drilling, or piercing)
Light source	External lighting (in case of transparent box), desk lamp, light-emitting diodes, fluorescent lights, inbuilt webcam, fiber optics
Visualization	Webcam, video camera, digital cameras, tablet/smartphone camera, and small camera mounted on a plastic pipe.
Camera monitor	Laptop/ desktop computer, TV/ video monitor, tablet, or smartphone.

From Sharma D, et al. [14]

Fig. 16.1 Abdominal wall model to simulate the Hasson open access technique [13]

patients can be avoided as much as possible; allows learning in a low-pressure atmosphere, without undesired interference while training in dedicated teaching time rather than patient care time; it allows a range of difficulties so training can be tailored to individuals; it is easily modifiable for various procedures and allows multiple learning strategies with defined outcomes; objective assessment of trainees is possible; it allows for judging the technical skills among participants of varying expertise; it permits refresher training of skills for senior trainees; it provides a facility for feedback and can be integrated within a training curriculum; and it can be reliably reproducible and valid [14, 15, 17–20]. In addition, it is low cost, low maintenance; with easy and cheap construction so as to be accessible to trainees worldwide. Trainees can better understand the "science" of skills to be acquired if they are involved in designing such systems [21].

16.4 Low-cost Technical Skills Simulation Systems in Urology

A recent review has given an encyclopedic and scholarly evidence-based account of the current status of simulation training in urology; including models for open urology, biological and non-biological models for endo-urology, and various laparoscopic and robotic models [22]. Similarly, all low-cost simulation models in urology have been appraised by a recent comprehensive review which defined low-cost models as those costing 150 US$ or less [23]. Many low-cost simulation models in urology have been summarized in Table 16.2.

As Table 16.2 shows, several low-cost models are now available for adult circumcision (Fig. 16.2), dorsal slit, and paraphimosis reduction at a cost of <$10 (Chap. 14); some of which show good face and content validity. Before the advent of low-cost models for supra-pubic catheter (SPC) insertion, it was not easy to acquire this skill, prompting junior doctors to frequently persist with urethral

Table 16.2 Low-cost simulators in Urology (Modified from Sharma et al. [14] and Pelly et al. [23])

Surgical procedure	Simulated with the use of	Cost in US$	Ease of construction	Validity Construct/ Face/ Content	Educational impact[a]
Adult circumcision, dorsal slit, and paraphimosis reduction					
Abdulmajed et al. [24]	Model penis which is then covered with simulated bowel in which the 2 layers of the prepuce are simulated by folding the simulated bowel on itself; and corona is simulated by applying a rubber band	$5.5	Yes		
Campain et al. [25]		$8	Yes	Face + Content	
Kigozi et al. [26]	Wooden penile model; different colored cloth to simulate two layers of prepuce	$5–10	Yes		
Acute ischemic priapism					
Dai et al. [27]	Hot dogs and candy to simulate priapism	$1.25	Yes		Yes
Eyre et al. [28]	Household sponge, foam, simulated bowel, glue, medical tape, simulated blood	$130			Yes
Supra-pubic catheter insertion					
Nonde et al. [29]	Open wooden/ plastic box/ lunch box (simulating abdomen) covered with urethane foam/ abdominal open and closure pad/ covered with gelatin/ surgical tape (simulating abdominal skin and rectus sheath) and a party balloon, glove filled with water/ 3-L bag of irrigation fluid tied with two tourniquets to simulate a full bladder	<2 $	Yes	Face	
Shergill et al. [30]		NA	Yes		Yes
Gao et al. [31]		<$2	Yes	Face	Yes
Singal et al. [32]		$31	Yes	Face	Yes
Hossack et al. [33]		$10			
Olapade-Olaopa et al. [34]		NA		Face	Yes
Palvolgyi et al. [35]		$60			
Suprapubic catheter exchange					
Bratt et al. [36]	Porcine abdominal wall; a segment of small bowel stitched around a size 16F Foley catheter to form a tract which was anastomosed to a porcine urinary bladder	<$25			
Open prostatectomy and radical prostatectomy					
Rowley et al. [37]	Orange as prostate glued to a milk jug glued to a flat surface	<$10	Yes	Face and content	Yes

Table 16.2 (continued)

Surgical procedure	Simulated with the use of	Cost in US$	Ease of construction	Validity Construct/ Face/ Content	Educational impact[a]
Lawrentschuk et al. [38]	The SP model used a ripe clementine fixed on foam or cardboard, the skin represented compressed normal prostate, the pulp represented benign tissue, the pith mimicked fibrous adhesions, and a party balloon inserted into the center of the fruit as the urethra.				
	The Radical Prostatectomy model used a Foley catheter with ballistics gelatin in the balloon and mesh fabric (as neurovascular bundles) and balloons (as prostatic fascial layers) on either side for the practice of inter- and intrafascial techniques.				
Diagnostic and therapeutic cystoscopy					
Schout et al. [39]	A white plastic box in which a prepared pig bladder is placed				
Teoh et al. [40]	Porcine bladder training model for transurethral resection of bladder tumor			Construct, Face, and Content	Yes
Grimsby et al. [41]	Porcine bladder with urethra fixed on an acrylic platform			Face	Yes
Persoon et al. [42]	Glass globe model of urinary bladder	$8	Yes		Yes
Bowling et al. [43]	A round balloon to simulate the bladder marked with markers for the demonstration of vessels and different pathologies.	$10	Yes		Yes
Bowling et al. [44]	Fresh frozen cadavers	NA	Yes	Construct	Yes
Hammond et al. [45]	Pumpkins and green peppers to simulate urinary bladder	$10	Yes		
TUR prostate					
Hammond et al. [45]	Porcine liver submerged in irrigant within a cored out pumpkin	<$15			
Biyani [46]	Potato	$1	Yes		
Bach et al. [47]	A Tupperware box, 7 cm of a 30F garden hose and different meat types as prostatic tissue	$40	Yes	Construct and Content	Yes

(continued)

Table 16.2 (continued)

Surgical procedure	Simulated with the use of	Cost in US$	Ease of construction	Validity Construct/ Face/ Content	Educational impact[a]
Biswas et al. [48]	Potato as Prostate	<$1		Construct, Face, and Content	
Ureteroscopy					
Hammond et al. [45]	Porcine kidneys with intact ureters with pebbles inserted to simulate stones				
Matsumoto et al. [49]	Penrose drain, inverted cup, molded latex in portable plastic case and 2 embedded straws approximately 8 mm. In diameter as substitutes for urethra, bladder dome, bladder base, and bilateral ureters, respectively.	$15	Yes		
Percutaneous renal surgery					
Hammond et al. [45]	Porcine kidneys with intact ureters placed inside an eviscerated chicken carcass to simulate posterior abdomen wall	$12	Yes	Face	
Hacker et al. [50]	Ex vivo perfused porcine kidney surrounded by ultrasound gel placed in the eviscerated chicken carcass for ultrasound- and fluoroscopy-guided access.	$10	Yes		
Qiu et al. [51]	Porcine kidneys with intact ureters and chest wall to simulate the feel of 12th rib				
Vijayakumar et al. [52]	Porcine kidneys with intact ureters placed inside an eviscerated chicken carcass	$10	Yes		
Ewald et al. [53]	Ballistic gelatin mixed with radiographic contrast was poured into surgical gloves to create a radio-dense renal collecting system. The collecting system model was then embedded in a pure ballistic gelatin block resting upon a clear acrylic glass base. Finally, the model was covered by a visually opaque polyurethane foam cover with chalk sticks positioned to simulate ribs.	$10	Yes	Construct and Content	

Table 16.2 (continued)

Surgical procedure	Simulated with the use of	Cost in US$	Ease of construction	Validity Construct/ Face/ Content	Educational impact[a]
Sinha et al. [54]	A bottle gourd was used to mimic the posterior abdominal wall. Cotton pledgets dipped in intravenous contrast were fitted into 4 mm holes made at staggered levels in the bottle gourd which was strapped onto the operating table with the cotton pledgets facing away from the surgeon.	$60	Yes	Face	
Lezrek [55]	Glove fingers filled with saline and contrast media to simulate calyceal system covered by foam to simulate abdominal wall	$5	Yes	Construct	
Open/laparoscopic dismembered pyeloplasty					
Ooi et al. [56]	Reconfiguring and suturing chicken skin dissected off its muscle to create a model of the ureteropelvic junction		Yes	Construct	Yes
Ramchandran et al. [57]	Crop and esophagus of a chicken				
Jiang et al. [58]	Crop and esophagus of a chicken		Yes		Yes
Rod et al. [59]	A4 Kraft envelopes, catheter tip syringe filled with 30 mL of air, tape, modeling and party balloons		Yes	Construct	Yes
Teber et al. [60]	Porcine bladder		Yes	Construct, Face, and Content	Yes
Sekhon [61]	Rubber balloon and tube model (Fig. 16.4)				Yes
Thompson [62]	Foam sponge, glove, latex tubing	<$2	Yes		
Laparoscopic renal surgery training/difficult nephron sparing surgeries					
Smektala [63]	Silicone replicas of kidneys using 3-D printer	$22		Face	
Robotic pyeloplasty					
Timberlake et al. [64]	Silicone cast over 3-D molds	$1.32/ model		Construct and Content	

(continued)

Table 16.2 (continued)

Surgical procedure	Simulated with the use of	Cost in US$	Ease of construction	Validity Construct/ Face/ Content	Educational impact[a]
Bendre et al. [65]	Silicone cast over 3-D molds			Face and Content	Yes
Urethro-vesical anastomosis in radical prostatectomy					
Yang et al. [66]	Chicken skin model				Yes
Laguna et al. [67]	Chicken esophago-stomach junction model		Yes	Construct	
Jiang et al. [68]	Chicken posterior trunks and porcine colon			Face	
Sabbagh et al. [69]	Latex model with Foley catheter			Construct	
Johnson et al. [70]	Silicone cast over 3-D molds			Construct, Face, and Content	Yes
Shee et al. [71]	Silicone cast over 3-D molds		Yes	Face and Content	
Laparoscopic ureteric re-implantation					
Singh et al. [72]	Chicken crop as urinary bladder and trachea as ureter placed in a box trainer		Yes	Construct, Face, and Content	
Thompson [62]	Foam sponge, glove, latex tubing, IV set				

[a]Educational impact = Use of model showed improvement in trainees' performance, TUR = Transurethral Resection

catheterization, with an increased risk of urethral injury [33]. Low-cost SPC models are few (<10 in number), with material costs ranging from <$2 to $60 per model. The lack of their validity and incorporation into structured curricula remain their main limitations [73]. Simple, low-cost models for training in TUR Prostate using potatoes (Fig. 16.3) or apple have been shown to be realistic with proven face, content, and construct validity [48, 46]. Similarly, low-cost diagnostic and therapeutic cystoscopy models have used porcine bladder, glass globe, round balloon, fresh frozen cadavers, and pumpkins and green peppers to simulate urinary bladder; many of which have shown improvement in trainees' performance (Table 16.2).

Many low-cost simulations use porcine, chicken, and beef models; as these have inherent natural tissue properties important for the acquisition of higher surgical skills such as dissection, suturing, and use of energy sources with the same instruments that are used in clinical practice [39, 40, 47, 50, 72, 74–76]. The creative imagination of surgeons has led to even using the folding of the chicken skin in various shapes for various urological simulations. Many of these models have the potential for various degrees of face, content, and construct validity as teaching and learning tools in urology (Table 16.2).

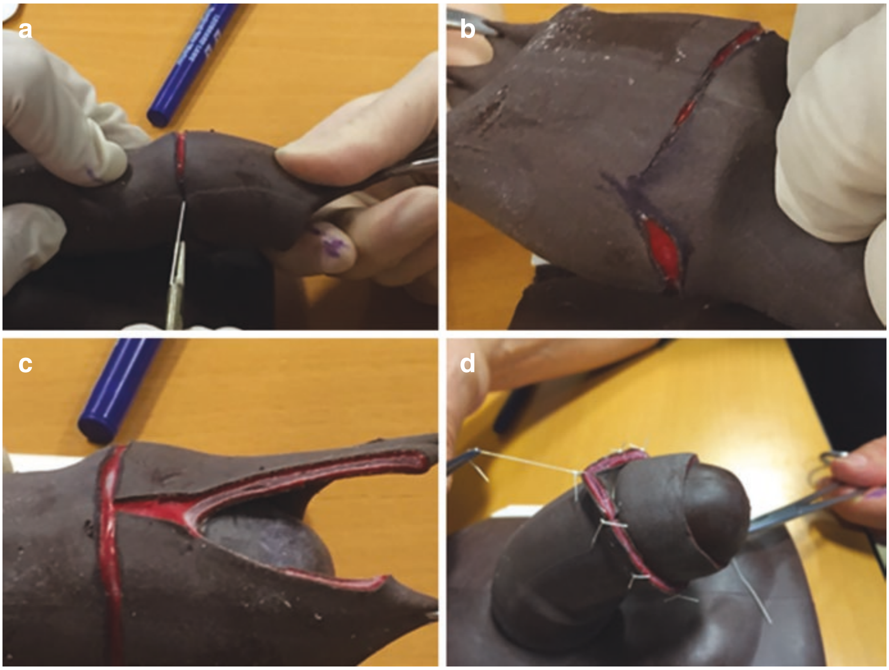

Fig. 16.2 Circumcision model, circular incision on the synthetic foreskin (**a, b**), dorsal slit of the foreskin and demonstration of the inner layer (**c**), suturing of both layers to complete the circumcision (**d**) [25]

Fig. 16.3 Use of a potato to teach basic resection skills in Hawassa Ethiopia [46]

Rapid and precise percutaneous renal access is a challenging step during percutaneous renal surgery [77]. Many bench, animal, and 3D printed models are available to overcome this challenge [78–80]. These have shown that they can improve the efficiency of training punctures in a cost-efficient manner [81]. Both animal and 3D printed models are available; animal models have been rated better than silicon models by users in one study [79]. Training on bench models for ureteroscopy

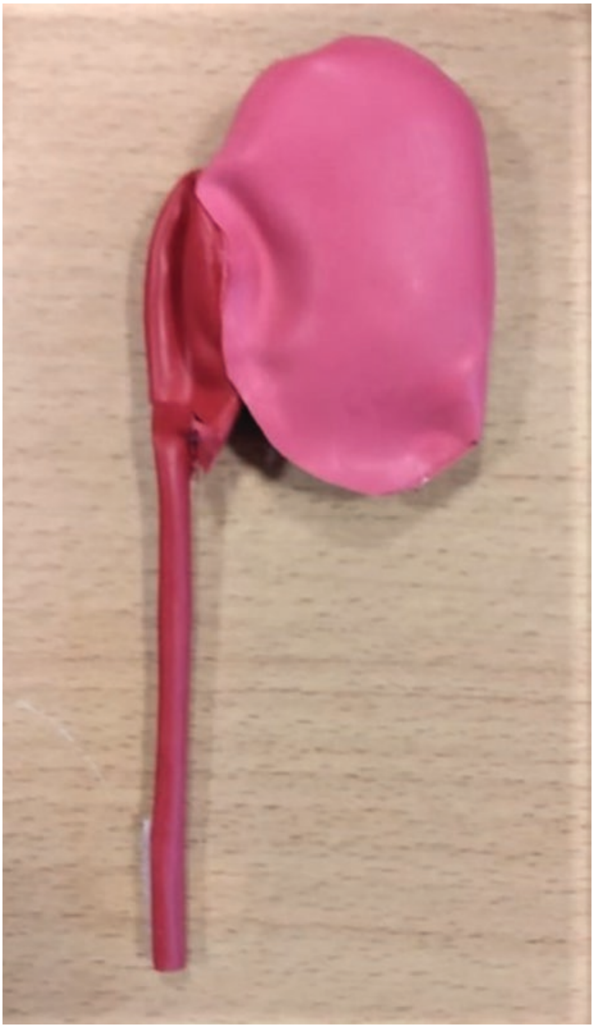

Fig. 16.4 Use of Rubber balloon and tube model for Dismembered Pyeloplasty [61]

allows enhanced manual dexterity as well as familiarity with the method and is recommendable before operating on patients [82, 83]. Similarly, several low-cost, high-fidelity models for pyeloplasty exhibit acceptability and content validity; and improve participant speed (Table 16.2) [64, 65].

The versatility of three-dimensional (3D) printing has a special place in simulations as it allows rapid translation of medical imaging into tangible replicas of patient-specific anatomy, which can simulate the elasticity and mechanical strength of the living organ [84–86]. Its potential has been used for practically all types of urological simulations and showcases its spectrum [84]. However, it is widely considered as an expansive modality for simulation. Paradoxically, it is a great boon for low-cost simulation systems as the actual cost of the models is not much if a 3D printer is already available; which is now available in many educational institutions. Including 3D printed models as low cost is analogous to the use of various expansive operating endoscopes along with imaging modalities while using various low-cost alternatives. Improvements in the science of 3D models are expected to provide even better replication of viscoelastic properties of tissues, various tissue planes and physiological tissue responses to surgical insults, along with more cost-effectiveness [87]. And finally, there is encouraging news on the front of low-cost virtual reality simulation platforms; which will be promising for resource-constrained settings [88].

16.5 Feasibility and Effectiveness of Low-cost Simulating Systems in Urology

Feasibility and effectiveness of low-cost simulating systems on the development of urological skills have been shown in many studies (Table 16.2). Both the low-fidelity, locally made, low-cost trainers and the high-fidelity simulators are equally effective means of teaching basic skills to novice learners [49, 89–93]. In fact, a few studies have found that for basic minimally invasive surgery training, low-fidelity models are superior to high-fidelity models; especially in resource-constrained training programs [94, 95].

16.6 Comparison of Various Simulation Systems

It is important to compare various types of simulation systems to gain a real perspective of what the low-cost alternatives actually offer (Table 16.3) [96, 97].

Table 16.3 shows that the costs shoot up when an attempt is made to upgrade a low-cost training system with high-fidelity physical reality experience, augmented with virtual assessment, explanation of tasks, appropriate feedback, and prompting. Cost is the most important determinant of access to technology and low-cost alternatives will always be needed for those who train and work in resource-constrained milieu. It must be remembered that both low-cost low-fidelity and high-cost high-fidelity systems are a continuum—two ends of the same spectrum—and not dichotomous different approaches [17]. The low-cost system is the more easily and widely available, cost-effective workhorse which can lay the foundation of basic generic surgical skills; over which the edifice of advanced skills can be then easily constructed with high-cost high-fidelity systems [14].

Table 16.3 Comparison of various simulation systems

Simulation model	Advantages	Disadvantages
Cadavers	• Accurate anatomy. • When fresh: gold standard for surgical simulation because of its approximation to living tissue. • Perfused cadaveric tissue creates high-fidelity models.	• Expensive, limited availability. • Require regular maintenance and special facilities. • Formalin fixed cadavers are hard and inappropriate for coelomic simulation. • Not reusable following certain procedures. • Ethical/ infection issues.
Live animals (Wet lab)	• Live experience, may share some features as human surgeries. • Living anatomy and physiology. • Tissue feel and haptics. • Requires adequate control of bleeding, thus replicating human surgery with high-fidelity. • Can practice every element of an operation: technical skills, avoiding complications and their management as and when they arise.	• Possible structural differences between human and animal anatomy. • Ethical concerns over the use of live animals as surgical simulators. • Expensive, requires a big setup, large team including Surgical assistants, Anesthetists, care takers for the animal lab. • Only for single use. • Potential to transmit lethal organisms responsible for zoonotic diseases.
Animal parts (Modified wet lab)	• Economical. • Easy availability from abattoir. • Minimal ethical issues.	• Sterilization requirements need to be strict. • Disposal has to be regulated.
Bench-top and laparoscopic box simulators (Low-fidelity) (Physical reality, PR)	• Allow practice of basic individual skills/ technique. • Economical and simple. • Portable, easy availability. • Multiple uses possible. • For use of novice surgeon.	• Teach "only" basic surgical skills. • May not allow simulation of all steps. • Limited realism. • Lack of interactivity and automated correction advice as seen in virtual reality.
Bench-top 3D printed modules and human mannequin (High-fidelity, Physical reality, PR)	• 3D printing, can accurately recreate complicated procedures under realistic condition. • Largely for advanced surgeons. • Not expensive if a printer is already available	• Expensive than PR, but cheaper than Animal and VR • Limited availability. • Skills difficult to assess.

Table 16.3 (continued)

Simulation model	Advantages	Disadvantages
Virtual reality (VR) simulators	• Create realistic environments that capture minute anatomical details with high accuracy. • Provide explanations of the tasks to be practiced. • Allow practice of a variety of different simulations on a single unit. • Interactivity. • Haptic metrics enable educators to assess trainee's improvement (under research).	• Lack realistic haptic feedback. Expensive. • Limited availability.
Patient-specific augmented reality (AR) simulators, *aka* Mixed reality (MR) as it is a bridge between PR and VR	• Augment pre-operative patient imaging data on top of the patient's anatomical structures. • Retain realistic haptic feedback. Provide objective assessment of the performance of the trainee. • Allows the trainee to use the same instruments that are currently used in the operating room. • Provides realistic haptic feedback.	• Expensive. • Limited availability.
Robot-assisted surgery (RAS) simulators	• Ease-of-use. • Readily available haptic metrics for assessment.	• Very expensive. • Limited availability. • Lack of high-fidelity surgical simulations.

Modified from Sharma et al. [14]

16.7 Low-cost Non-technical Skills Simulation

Non-technical skills (NTS), such as communication, team-work, and task coordination, are increasingly being recognized as vital to patient safety. Many simulation research studies on NTS have shown their educational benefits [98, 99]. High "psychological fidelity" can be ensured at a minimal cost to create a more realistic and acceptable scenario; and low-fidelity simulators have been shown as non-inferior to the more costly high-fidelity simulators for teaching NTS to postgraduate medical trainees [100]. This evidence has been strengthened by the successful delivery of courses for surgeons and anesthetists in Rwanda [101–103]. The success of these programs has led to worldwide interest in developing and teaching NTS to healthcare providers in various specialties including urology [104].

16.8 Limitations of Low-cost Simulating Systems in Urology

Surgical simulation is a "good idea whose time has come" [105]. However, except for a few randomized control trials, most published studies are observational in nature and lack rigorous science [42, 43, 49]. Moreover, most publications have not studied the cost, validity, and educational impact of their low-cost training models in terms of transferability of skills to operating theater (Table 16.2) [37, 38, 76, 106, 107]. This can be easily achieved if the surgeons designing these low-cost simulators do not stop at just designing them but take the extra small step of scientifically validating them [14]. Simulation based urological skills training has been accepted and is being used in various structured "boot-camps," programs, and curricula across the globe [13, 108, 109]. However, greater structured integration in formal training is needed to improve resident skills and ultimately, improve the quality of patient care [110, 111]. The resource constraints of developing countries are well known; however, even developing countries seem to be lagging behind in providing necessary simulation training in urology [11]. Sensitization of trainers is also needed as it is an equally important component for the success of any simulation program. There is no doubt that there is scope of improvement in "refinement of simulation techniques leading to better fidelity, better validation, better incorporation in curriculum, and better availability across the world" [112, 113].

Key Points

- Simulation as a means of learning or rehearsing surgery has a rich history, which is as old as surgery itself.
- Surgical skills, like any other motor skills, can only be acquired by repetitive practice, *i.e.,* simulation; which provides the much needed bridge between theoretical learning and real-life operating experience for a trainee and has become the foundation of modern surgical training.
- Training opportunities in modern surgical skills centers were and are limited due to cost and availability. This has led to the development of low-cost, easily available, and sustainable alternatives for simulation of surgical training.
- A low-cost simulation system has most of the advantages of a high-fidelity system; and in addition is low cost, low maintenance; with easy and cheap construction, so it is accessible to trainees worldwide.
- Several low-cost biological and non-biological models are available for many open, endoscopic, laparoscopic, and robotic urological surgeries.
- Low-fidelity locally made low-cost and high-fidelity simulators are equally effective means of teaching basic skills to novice learners.
- Most publications on low-cost simulating systems in Urology are observational in nature and have not studied the cost, validity, and educational impact in the form of transferability of skills to operating theater. Greater

structured integration in formal training and better availability across the world will improve resident skills and ultimately improve the quality of patient care.

- There is increasing acceptance of teaching non-technical skills in various specialties including urology, with the help of low-cost low-fidelity simulators, which have been shown as non-inferior to the more costly high-fidelity simulators.

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