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TOPIC PAPER

Cost, training and simulation models for robotic-assisted surgery in pediatric urology

F. O'Kelly[1] · **W. A. Farhat**[1] · **M. A. Koyle**[1]

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Abstract

Introduction Laparoscopic procedures in pediatric urology have been shown to be safe and effective over the last number of years. Coupled with this is the technological trend to provide minimally invasive options for even the most complex pediatric patients. Whilst robotic platforms continue to try to demonstrate superior patient outcomes in adults with mixed results, the utilization of robotic platforms for pediatric urology is increasing.

Methods A review of the current literature was undertaken to assess the evidence for training models and cost-effectiveness of robotic-assisted pediatric urology.

Conclusions A growing body of evidence in this field has demonstrated that robotic platforms are safe and effective in children and can provide additional reconstructive benefits due to motion scaling, magnification, stereoscopic views, instrument dexterity and tremor reduction. The main drawbacks remain the financial implications associated with this platform through purchase, maintenance, and disposable costs. This review addresses some of the addresses issues pertaining to cost, training and simulation for robotic-assisted surgery in pediatric urology.

Keywords Robotics · Pediatric urology · Simulation · Training · Cost

Introduction

The introduction of the da Vinci robotic surgical system (Intuitive Surgical, Sunnyvale, CA, USA) has led to persistent and lively discussion regarding its cost-effectiveness. This system has well-known capital and maintenance costs, as well as extra costs depending on the robot-assisted procedure. Opponents of the robotics movement claim these costs to be prohibitive, whilst proponents of robotic surgery describe easier learning curves, easier laparoscopic reconstruction due to three-dimensional endo-wrist magnification, improved surgeon ergonomics, potentially shorter hospital stays, and equivalent measurable outcomes. Indeed, attempts to demonstrate the performance of robotic-assisted operations in adults through randomized controlled trials have met with mixed results. One of the first randomized controlled phase 3 trials in robotic urology was published by Yaxley et al. who reported similar functional outcomes at 12 weeks in those undergoing open versus robotic-assisted radical prostatectomy [1]. It should be noted, however, that one of the main unintended benefits was how quickly surgeons from the robotic arm reached such similar outcomes to highly experienced open surgeons. The CORAL randomized controlled trial examining open, laparoscopic and robotic-assisted radical cystectomy demonstrated no overall difference in 90-day complications; however, the robotic arm operations took significantly longer to perform. The major limitation of this study was the small sample size [2]. This was later also shown by Lauridsen et al. who performed a systematic review of four randomized controlled trials considering open versus robotic-assisted radical cystectomy and showed no advantage of robotic-assisted surgery over open surgery with respect to complications [3]. Wijburg et al. argue that centralisation of robotic-assisted surgery can facilitate improved economical usage of the technology for both upper and lower tract urological surgery [4]. It has also been demonstrated that shorter learning curves achievable with the robotic system can lower the risk of patient complications and that this from a patients' perspective is a far higher metric than cost [5, 6]. Ramsey et al. have reported that the use of robotic-assisted radical prostatectomies in the

F. O'Kelly
fokelly@rcsi.ie

[1] Division of Pediatric Urology, The Hospital for Sick Children, Toronto, ON, Canada

United Kingdom would be self-sufficient and cost effective with a volume of 100–150 operations annually [7]. There is currently little known as to the optimal role for robotics in pediatric urology, where the index case is the robotic-assisted laparoscopic pyeloplasty (first performed in 2002) as opposed to the radical prostatectomy. Early published data by van Haasteren et al. had suggested that robotic-assisted surgery in children was safe with advantages due to small access spaces in children requiring suturing and reconstruction [8]. A more recent review by Spinoit et al. (2017) concluded that whilst the robotic and anesthetic platforms are now considered safe and adapted for pediatric patients, challenges remain regarding optimal trocar placement and which operations to perform. The three most accepted applications are pyeloplasty, heminephrectomy, and ureteric reimplantation, with the formed being in the overwhelming majority. There are also opportunities for specific high-risk populations such as spina bifida which could benefit from a robotic-assisted approach [9].

If one fervently believed that no role exists for robotic technology, and that current techniques of open and laparoscopic surgery will be herein sufficient, then this discussion would have been concluded years ago. The fact remains that there is an appetite amongst the pediatric urological and general surgical communities for robotic-assisted operations. Therefore, the question remains how best to apply this new and developing technology to current pediatric urological use, and whether there is any evidence aside from patient outcomes to justify its current support base through a review of cost, training and simulation.

The financial cost of robotic pediatric urology

Cost is a multifaceted descriptor which can include direct and indirect financial costs as well as those on a more tangential line such as emotional and professional/reputational costs. For the purpose of this discussion, we have limited our viewpoint to simple financial costs assumed by the healthcare institution, and those of the child's family. It is also important to highlight that whilst cost is most frequently used as an argument against robotic-assisted technologies, it is merely one aspect of the discussion which centers around the value of the robot (value = [quality (+ outcomes)]/cost). There are little data in the literature which claims that the robot is currently financially fully cost effective. Behan et al. described in the earlier literature on pediatric robotic-assisted laparoscopic pyeloplasty that there was a shorter length of stay, reduced hospitalization charges, and reduced loss of parental wages, which they described as human capital gains, but these could not offset amortized robot costs [10]. Rowe et al. described in 2012 that direct costs for robotic-assisted laparoscopic procedure in children were 11.9% lower than for equivalent open surgery, based primarily on length of stay. However, they landed a caveat that a consistent and trained robotic team, robotic experience, and a suitable population base were all key factors. This group was one of the few to describe cost savings with the robot, yet emphasized the importance of market competitors and team consistency [11]. Casella et al. described how robotic-assisted pediatric laparoscopic pyeloplasty consistently produced shorter operative time versus conventional laparoscopy, and no overall difference in costs ($15,337 vs. $16,067; $p = 0.46$); however, in those cases comparing robotic versus laparoscopic antegrade stent placement, both time and costs were significantly reduced with the robot [12]. A systematic review and meta-analysis of robotic-assisted versus open pyeloplasty in children in 2015 described shorter hospital stays in the robotic group, but higher mean ages at operation, longer operative times, and higher complication rates (RR 1.29; 95% CI 1.1–1.51), as well as higher costs [13]. It is an unusual comparison given that they are two completely different approaches with different population groups; however, if one considers open pyeloplasty to be the gold standard approach, then the robot appears to have fallen short based on their data. Varda et al. recently analyzed a large pediatric robotic-assisted pyeloplasty cohort in the USA assessing utilization, outcomes and cost. They found that despite an initial expectation that the financial gap between robotic-assisted and open pyeloplasty would narrow between 2007 and 2011, this, in fact, never happened. The equipment cost for robotic-assisted pyeloplasty was significant including the average $1600 amortization cost per robotic case [14]. In fact, to make the robotic console profitable, it was estimated that between 3 and 5 robotic cases would be required per week, which even in high-volume centers would be something of a challenge, unless, of course, the robot was shared with other pediatric sub-specialties, or even adult urology [15, 16].

The initial literature examining the role of robotic-assisted laparoscopy for pediatric ureteric reimplantation suggested a longer operative time (232 vs. 180 min), higher rate of any 90-day post-operative complications (OR 3.17; 95% CI 1.46–6.91) and direct costs versus an open approach ($9128 VS $7273). These results remained significant on multivariate analysis adjusting for demographic and regional factors [17]. It should be noted that practice variations and confounders would naturally exist across a large number of hospitals; however, the authors correctly point out that this operation should be implemented with caution, and in centers with good robotic experience. Interestingly, the value of robotic-assisted ureteric reimplantation could be increased by offsetting costs with significantly improved post-operative pain scores in children using this approach versus open surgery [18]. In a recent paper by Esposito et al., they describe successes with robotic-assisted extravesical ureteric reimplantation (REVUR), with no significant differences in operative time or complications, but a higher cost with the robotic-assisted approach which limits the feasibility. This, however, was offset by the short learning curve associated with the procedure [19]. A systematic review and meta-analysis of robotic-assisted versus open ureteric reimplantation for vesicoureteric reflux demonstrated a longer operative time and a higher rate of short-term complications (OR 3.17; 95% CI 1.72–5.85), but significantly fewer days of hospital stay and post-operative Foley catheter placement, thus facilitating an earlier return to society for patients and their parents [20].

Buse et al. recently performed a cost-effectiveness analysis of robotic-assisted versus open partial nephrectomy in the USA incorporating intra-operative and hospital-associated costs. They found that robotic-assisted procedures conferred a nominally lower cost and a lower rate of complications; however, this on sensitivity analysis was only present in higher volume centers [21]. Another multi-institutional paper exploring the differences in open versus minimally invasive (laparoscopic/robotic) approaches to retrocaval ureter repair in children demonstrated better cosmetic and analgesic requirements associated with a minimally invasive approach, with the robotic-assisted approach being technically easier, quicker and associated with fewer complications and reduced costs with a lower hospital stay [22]. The role played by costs as a hindrance to the implementation of robotic technology in hospitals is significant. This is also affected by the funding model used by hospitals. The overwhelming majority of robotic papers in pediatric urology are from the USA which adopts a multi-payer system with complex cascades of insurance companies, but which provide a model to allow hospitals to bill accordingly. The ability to implement these systems in a single-payer model such as in Canada or the UK is a much more difficult financial dialog as initial fixed asset and maintenance costs remain high with little foresight given to the potential long-term cost savings provided by lower return to hospital costs associated with complications, or societal costs from lost time at work, reduced parental productivity, and family stress. These initial costs have hindered the implementation of robotic programs in Latin America as well where up to 50% robotic urology programs across surveyed institutions have been definitely closed [23].

Training in robotic pediatric urology

The concept of structured, dedicated and focused training in robotic pediatric urology has long been a prerequisite for urologists in this field. The need for structured training was recognized early to allow for technical proficiency with an acceptance for initially longer operative times compared with similar open operations [24]. Intuitive has developed an online portal (https://davincisurgerycommunity.com) which mandate registration and completion of several online modules prior to skill simulation and peer–peer training. Much of the data concerning training in robotic-assisted urological procedures come from adult studies with a focus on the effect of several areas: the role of the bedside assistant, prior laparoscopic experience, and procedure-specific learning curves.

The role of the bedside assistant has been explored in a number of studies and their impact on the surgeon's learning curve during robotic-assisted radical prostatectomy. Cimen et al. found that it did not influence oncological outcomes during the learning curve but may reduce the potential complications by shortening the total operation time [25]. Abu-Ghanem et al. further found that the seniority of the assistant had no bearing on perioperative complications or length of stay during robotic-assisted radical prostatectomy, and that a less experienced assistant can be safely incorporated into this procedure [26]. One of the arguments put forward for both adult and pediatric urologists was that prior laparoscopy might confer an advantage for those training on robotic systems. Pimentel et al. described in their study using simulated tasks that there were no significant differences in the performance of simulated robotic surgical tasks between laparoscopically experienced surgeons and laparoscopically naïve surgical residents. This suggests that the 6° of movement and 3-D vision were sufficient to overcome the hand–eye coordination achieved by experienced laparoscopists [27]. Other studies have suggested that prior laparoscopic experience may shorten the learning curve for advanced procedures, but had no impact on basic skills, and that spatial cognitive ability positively influences the initial learning of robotic suturing skills [28, 29]. Wang et al. demonstrated that inclusion of a new surgeon joining a high-volume and established robotic program had no impact on overall outcomes and practice allowing for continuing mentorship [30]. Khene further showed that the time taken to train fellows in a time-sensitive procedure such as partial nephrectomy did affect operative time and warm ischaemia time, but did not hospital stay, blood loss, or perioperative outcomes [31]. For robotic-assisted radical prostatectomy and robotic-assisted upper tract surgery a learning curve of 8–150 procedures is quoted, with many proposing that 30–40 cases are required to carry out the procedure safely. There is no consensus about which endpoints should be measured. In the traditional proctored training model, the surgeon learns the procedure linearly, following the sequential order of the surgical steps. A more recent approach is to specify the relative difficulty of each step and to train the surgeon simultaneously in several steps of equal difficulty.

The entire procedure is only performed after all the steps are mastered in a timely manner [32].

There are specific considerations for pediatric urology which can affect training and learning curves. Cundy et al. convened a dedicated pediatric robotic surgery workshop was convened to address initial education and training requirements. Pre- and post-workshop survey responses were evaluated to reflect on the quality of the educational experience and scope for improvement. The majority of delegates (94%) indicated they were "very satisfied" with the overall program. Delegates almost unanimously expressed preference and satisfaction for hands-on content. Qualitative feedback favored a stepwise and modular workshop structure, transitioning from didactic teaching to progressively more advanced training [33]. Similar results were demonstrated by Beulens et al. who concluded that courses on robotic training would inform trainees about their results to enhance learning and inform them of their competence levels [34]. One of the key steps to performing robotic procedures in children lies in correct docking of the robot and arm positioning. Ashraf et al. found a learning curve of 30 cases to demonstrate a significant reduction in learning and maintenance phases for robotic-assisted pediatric urological procedures. This was further emphasized by the variability in port placement in children [35].

As robotics become have more integrated into urological practice, structured training has become crucial to overcome obstacles facing the development of robotic training programs such as the high cost of training and the increased operative time during the initial period of the learning curve, which, in turn increases operative costs. The need for a standardized and validated robotic training curriculum continues to grow with training including aspects of proctorship, mentorship or fellowship, telementoring, simulators and video training [36]. Most data concerning robotic training demonstrate that early proficiency is achievable even for minimally invasive naïve trainees without an overall increase in perioperative complications or wore functional outcomes; however, studies consistently stress the importance of high-volume, established robotic programs with an emphasis on consistency and dedicated robotic operating room teams. Lovegrove et al. reviewed the current evidence on robotic-assisted surgical training methods which included dry and wet labs, mentored training, and non-structured pathways. They found that the current limited available evidence suggests that they affect learning curves differently and are rarely used alone. They concluded that the different methods of training appeared effective only when combined [37]. With an unspecified learning curve for robotic-assisted pediatric urological operations, but an emphasis on structured training and case-volume acquisition, this may represent a problematic situation for residents and fellows with respect to placements and scheduling [38]. As a result, to ensure seamless transition in robotic programs, simulation models have become increasingly important.

Simulation models for robotic pediatric urology

The evidence for simulation models comes from adult practice as to date there are no specific studies in robotic pediatric urology. Robotic surgical simulation training can be broadly classified into virtual reality (VR) and non-virtual reality-based models. Initial VR simulator models were validated by Lendvay et al. back in 2008 looking at task time, economy of motion, and time spent outside the center of the platform's workspace [39]. A further simulation model (Mimic da Vinci Trainer) was then developed in 2009 using repetitions of the following tasks: (1) Ring and Cone, (2) String Walk, and (3) Letter board. Satisfaction was found to be high amongst trainees with reasonable workload parameters to try to bridge the gap to in vivo procedures [40]. A health economic evaluation of the robotic surgical simulator by Rehman et al. described it to be a cost-effective method of training with a prevention of potential OR losses of $600,000, and savings of more than $72,000 in animal facilities [41]. It was further found that VR robotic warm-ups prior to robotic surgery tasks such as suturing could lead to improvements in task time, tool path length, economy of motion, technical, and cognitive errors [42]. This led to the development of simulation models to train for life-threatening emergencies, where time to the start of chest compressions, undocking and removal of the robotic system and time to first defibrillation were measured and found to be improved in the simulation arm [43]. This was also demonstrated in open conversion simulation during robotic-assisted radical prostatectomy [44]. There have been a small number of reports which have not advocated for simulation. Phe et al. found that simulation with robotic dots and skin-suturing platforms did not improve robotic tasks across all ability cohorts [45]; however, interestingly there have been positive associations between recent and regular video game use and higher scores on robotic simulation models [46]. These findings were not shared by Shee et al. who found that prior experience in high-level athletics, but not videogames or musical instruments, significantly influenced surgical proficiency in robot-naive students, but that these initial differences could be overcome by task repetition [47]. Harrison et al. have found using a urethro-vesical anastomotic VR model that 5.5 h of simulation training led to significant learning curve improvements with good construct validity between expert and novice surgeons [48].

Aside from the high-fidelity simulation models used for robotic-assisted urological procedures, smaller dry-lab and ex vivo animal models have also been used with live animals and human cadavers generally used for complete procedural training [49, 50]. Non-VR trainers have been shown to positively correlate with robotic surgical performance [51, 52]. Cadaveric 3-D models have been used successfully for robotic simulation; however, their use is curtailed by availability and financial costs [53]. The da Vinci skills simulator™ has also been used to demonstrate that the learning curve in performing robotic tasks is not affected by age or prior experience using a linear mixed effects model [54]. Thakre et al. demonstrated the importance of training in confined spaces where they performed drills in different sizes of cubic boxes (40–150 mm) using the da Vinci surgical system. The drills were based on the McGill Inanimate System for Training and Evaluation of Laparoscopic Skills. They found that significant collisions occurred while working with the smaller cubes (40–45 mm), preventing the surgeon from performing drills. Drills were performed with difficulty in the 50–60-mm-size cubes, and could be accomplished uniformly with ease in the larger cubes (70 mm and greater) [55]. The use of integrated video recording and playback on a mimic da Vinci trainer has also been positively correlated with an improved learning curve and trainee feedback compared with conventional training [56].

The final aspect of non-VR robotic simulators consists of three-dimensional printing, which has been described by a number of groups predominantly for radical prostatectomies, partial nephrectomies, and robotic-assisted kidney transplantation [57–59]. These models have been found to facilitate preoperative planning, and enhanced precision with an enhanced "warm-up" prior to performing the case. To date, they have not demonstrated any significant improvement in functional or oncological outcomes, but have been associated with successful extirpation of large, complex lesions through a robotic-assisted approach [60].

Whilst simulation in robotic-assisted urology is a growing field without any risk to patient safety, it should be noted that there are few studies which contain high levels of evidence demonstrating transferability of skills to live operations. More evidence is required to demonstrate the efficacy of simulation, particularly with an emphasis on childhood simulators (Table 1).

Summary

Robotic-assisted surgery in kids has been proven to be safe and effective though a technological platform which provides a precise and accurate minimally invasive approach as well as being ergonomically robust. However, is it possible to justify the increased costs associated with robotic platforms for the sole demonstrable benefit of reduced length of stay in pediatric cases? The fact that the open versus robotic debate in urology has achieved Level 1 evidence (in adult cohorts) is a significant start. Fossati et al. in their appraisal of randomized controlled trials for robotic surgery feel that it is unlikely that radical prostatectomies will ever revert back to a simple open approach, but advise that hospitals need to be cognoscente of the financial impacts [61]. Changes to training, and the impending development of newer technological advances and fusion with imaging technology will all but ensure this.

Pediatric urologists must, therefore, attempt to focus on cost-saving strategies. These may be provided by reducing console time through the increased use of structured training and simulation models, improving operating room turnover through the presence of a dedicated robotics team, and increased utilization of the robot by multiple specialties to ensure its continuous usage which can help drive down costs. It should also be noted that with the emergence of market competitors to the current system, it is likely that costs will be driven down. The alternative to these measures is to increase laparoscopic training amongst pediatric urology residents and fellows; however, given the current expansion of robotic platforms in North America, and their ability to perform fine suturing and complex minimally invasive cases, as well as complex patient selection, this would be an unlikely possibility.

Conclusion

Robotic-assisted laparoscopic procedures in children predominantly characterized by pyeloplasty are still in their infancy. Performing operations in these small cavities, with complex robotic docking, and non-standardized trocar and port placement, makes intuitive adaptation necessary. Financial costs remain a significant issue with this platform; however, with contemporary structured training and simulation models, cost-saving measures such as reduced console time and more efficient operating room turnover, as well as the impending potential for market competitors are expected to drive down costs. Further studies are required as experience grows to determine perioperative and cost-effectiveness outcomes.

Table 1 Summary of studies demonstrating costs and outcomes of patients undergoing robotic-assisted procedures in pediatric urology

Author	Year	Patient number	Procedures	Findings	Cost (US $)	Hospital stay
Yang et al.	2017	60	Robotic Video simulator	20% time improvement	n/a	n/a
Meier et al.	2016	28	Robotic video simulator	Global improvement with simulation	n/a	n/a
Aghazadeh et al.	2016	21	Robotic video simulator	Prior experience correlates with ability	n/a	n/a
Harbin et al.	2017	75	Robotic video simulator	Robotic skills correlate with prior video gaming	n/a	n/a
Phe et al.	2016	39	Robotic VR simulator	No benefit to robotic skills	n/a	n/a
Lendvay et al.	2013	51	Robotic VR simulator	53.5 s task improvement increased movement efficiency	n/a	n/a
Rehman et al.	2013	105	Robotic video simulator	Reductions in operating time and costs with simulation	$6,00,000 saving	109.5 d
Ashraf et al.	2018	55	Robotic docking time	30-case learning curve	n/a	n/a
Abe et al.	2018	21	Robotic video simulator	Prior visuospatial ability impacts robotic trainee learning	n/a	n/a
Sorensen et al.	2010	50	Robotic learning curve	Robotic reimplants associated with higher morbidity and time	n/a	n/a
Escolino et al.	2018	4	Retrocaval ureter repair	Robotic approach superior to lap/open	n/a	16% shorter
Buse et al.	2018	2000 (inc. adult patients)	Partial nephrectomy	Robotic approach not cost-effective with low volume	$4000 saving with high-volume robot	n/a
Deng et al.	2018	7122	Ureteral reimplantation	Robotics had longer operative time > 67 min	17.8 h reduced stay with robot	Robotic mean increase $1855
Esposito et al.	2018	55	Extravesical ureteral reimplantation	No increase in operative time/complications with robot	2.2 d mean stay with robot	$14100 per robotic procedure
Kurtz et al.	2016	108	Ureteral reimplantation	Higher 90-d complications (OR3.17) and 42 min increased operative time with robot	2.0 d mean stay with robot	Robotic mean increase $1855
Varda et al.	2018	1818	Pyeloplasty	Robotic operative time 1 h longer than open; equivalent results and complications	2.0 d mean stay with robot	Robotic mean increase $2866
Chang et al.	2015	1956	Pyeloplasty	Higher costs and complications with robotic approach	0.95 d shorter stay with robot	Robotic mean increase $3260
Casella et al.	2013	23	Pyeloplasty	> 120 min shorter operative time; equivalent outcomes	Discharge on post-operative day-1	Robotic retrograde stent:$1876 more expensive robotic antegrade stent:$4118 less expensive

Table 1 (continued)

Author	Year	Patient number	Procedures	Findings	Cost (US $)	Hospital stay
Rowe et al.	2012	146	Nil specific	Lower direct costs and hospital stays with robot; 12 min shorter operative time with robot	1.6 d mean stay with robot (3.8 d open)	Robotic costs 11.9% lower (median $1183)
Behan et al.	2011	37	Pyeloplasty	No robotic cost savings achieved with amortized costs included	1.6 d mean stay with robot (2.8 d open)	Robotic mean saving $692

d day, *h* hour, *min* minutes, *OR* odds ratio, *VR* virtual reality

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