Curr Urol Rep (2010) 11:87–92
DOI 10.1007/s11934-010-0093-9

Residency Training Program Paradigms for Teaching Robotic Surgical Skills to Urology Residents

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Published online: 23 February 2010

Abstract The advent of laparoscopic and robotic techniques for management of urologic malignancies marked the beginning of an ever-expanding array of minimally invasive options available to cancer patients. With the popularity of these treatment modalities, there is a growing need for trained surgical oncologists who not only have a deep understanding of the disease process and adept surgical skills, but also show technical mastery in operating the equipment used to perform these techniques. Establishing a robotic prostatectomy program is a tremendous undertaking for any institution, as it involves a huge cost, especially in the purchasing and maintenance of the robot. Residency programs often face many challenges when trying to establish a balance between costs associated with robotic surgery and training of the urology residents, while maintaining an acceptable operative time. Herein we describe residency training program paradigms for teaching robotic surgical skills to urology residents. Our proposed paradigm outlines the approach to compensate for the cost involved in robotic training establishment without compromising the quality of education provided. With the potential advantages for both patients and surgeons, we contemplate that robotic-assisted surgery may become an integral component of residency training programs in the future.

Keywords Robotic · Prostatectomy · Training · Education

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Introduction

For more than a decade, a laparoscopic approach has been the standard of care for many urologic disorders. The introduction of robotic assistance to laparoscopic surgery has further refined the approach to intra-abdominal and pelvic surgery. Today, most urologic robotic-assisted laparoscopic surgery (RALS) is done for localized cancers involving prostate (radical prostatectomy), bladder (radical cystectomy and urinary diversion for invasive cancer), kidney (nephrectomy, partial nephrectomy, and pyeloplasty), and adrenal gland surgery. Robotic-assisted radical prostatectomy (RARP), however, is the most commonly performed RALS. The number of RARPs performed annually in the United States is constantly rising. More than 8000 RARPs were performed in 2004; this number was projected to rise to 50,000 in 2007 and to 80,000 or more in 2008 [1].

Studies have demonstrated some immediate benefits for various RALS, including reduced surgical morbidity, decreased pain, increased quality of life, and decreased blood loss [2]. From the surgeon's point of view, RALS has an added benefit of three-dimensional (3D) visualization with 10-times image magnification, which allows for more precise incision. For example, the EndoWrist Instruments (Intuitive Surgical, Inc., Sunnyvale, CA) offer seven degrees of freedom, and the computer processing eliminates tremors. These added benefits have led to an increasing trend toward RALS, and subsequently, an increasing demand for skilled robotic urologists.

Duchene et al. [3] conducted a survey of residency training in laparoscopic and robotic surgery using an American Urological Association residency questionnaire, which was e-mailed to all the residents and program directors across the United States and Canada. According to their survey, robotic procedures are being performed at 54% of respondent facilities. Residents participate in most of the cases, but only 38% consider their laparoscopic experience to be satisfactory. Thus, a need still exists for increased robotic training for residents. Several proposals have been implemented to train urology residents for RALS. However, urology residency training programs still encounter challenges, including high cost involved in acquiring and maintaining the robot, cost involved in training, increased operative time, as well as the learning curve for residents and its effect on surgical outcomes. All of these challenges need to be addressed to meet the demand for skilled robotic surgeons.

This article presents the limitations faced by urology residency programs when incorporating robotics in their training schedule, as well as the proposed paradigms to overcome these challenges. Because RARP is the most common robotic surgery performed, most of the discussion here will be with regard to RARP.

Limitations and Challenges

Cost Involved in Acquiring and Maintaining the Robot

With the sudden boom in the field of robotics, there has been a need to establish a laparoscopic surgery program to train urology residents in order to address the ever increasing demand for skilled robotic surgeons. The dilemma faced by urology residency programs is the economic impact of establishing such a program. The cost of robotic surgery includes cost of the robot, annual maintenance fee, cost of surgical instruments, operating room time, medication, hospitalization cost, and heath professional cost. The cost of the original da Vinci Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA) is more than 1.2 million dollars, with an annual maintenance fee of $100,000 [4]. Three da Vinci robotic systems are currently available: the original three-arm system, the four-arm system (approximately 1.4 million dollars), and the new-S model (approximately 1.6 million dollars), each with different purchasing and maintenance costs (maintenance costs are approximately 10% of the purchasing cost).

In 2004, Lotan et al. [5] analyzed the economic impact of RARP and compared it with radical retropubic prostatectomy (RRP) and radical laparoscopic prostatectomy (RLP). They noted that RRP has a cost advantage of $487 and $1726 over RLP and RARP, respectively. If the initial cost of purchasing the robot was excluded, the cost difference between RRP and RARP was still $1155. This large difference in cost for RRP and RARP resulted from a cost of $857 per case (based on the annual input of 300 RARP cases at their institute) to pay for purchase and maintenance of the robot and high equipment cost of $1705. The authors proposed that in order for RARP to become cost-equivalent, there is a need to decrease both the purchase price of the robot and the cost of the equipment per case. The operating time (140 vs 160 min for RARP and RRP, respectively) and the duration of hospitalization (1.3 vs 2.5 days for RARP and RRP, respectively) are favorable for RARP, but they do not compensate for the added expenditure.

Mouraviev et al. [6] compared the cost of different surgical options for localized prostate cancer and found that there was no difference between the direct cost for RRP and RARP ($5,259 vs $5,386, respectively), but the initial cost of acquisition and maintenance of the robot was not included. The length of hospitalization was shorter for RARP (n = 137) than that for RRP (n = 197)—2.15 versus 2.79 days, respectively.

Recently, Bolenz et al. [7] studied 643 consecutive patients who underwent radical prostatectomy: 262 had RARP, 220 had RLP, and 161 underwent RRP. The median direct cost was higher for RARP than RLP or RRP: RARP, $6,752 (interquartile range [IQR], $6,283–$7,369); RLP, $5,687 (IQR, $4,941–$5,905); and RRP, $4,437 (IQR, $3,989–$5,141) (P<0.001). The main difference in the cost of RARP compared with RLP and RRP was due to surgical supply cost and operating room cost. Thus, addition of robotics to the residency training program definitely adds to the financial burden of teaching institutes.

Learning Curve

Increased Operative Time and Learning Curve

Although the da Vinci Surgical System is relatively user-friendly, mastering it requires time and experience; thus, it has a definite, unavoidable steep learning curve. The *learning curve* refers to the diminishing amount of time it takes to perform a task, as the task is repeated, until a steady state is researched and repetition no longer yields improvement. It includes the estimation of total operative time and the number of cases required to achieve that plateau where no further improvement is expected.

The operative time is the total time from start of incision to closure. It is more at the beginning of the learning curve and decreases as the experience of the surgeon increases until it reaches the plateau. Menon et al. [8] described the initial operative time of 360 min, which decreased to 252 min with experience. Steinberg et al. [9•] studied various published series and found that the improvement between cases can range from just under 1 min per case [10, 11] to as high as 21 min per case [12], with an average rate of improvement of 6 min per case. Bhandari et al. [13] demonstrated that for the first 250 patients who underwent

RARP after the completion of the learning curve, the operative time decreased to 180 min. Many urologists have also shown that operative time for RARP ranges from 141 min [10] to 250 min [14] after the learning curve is achieved.

Similar to the operative time, the number of cases at which the learning curve is achieved also varies, ranging from 13 cases [15] to 200 cases [16], with an average of 74 cases [9•]. In their initial series, Menon at al. [17] achieved the learning curve for RARP after the first 18 cases. According to Herrell and Smith [18], the learning curve is anywhere between 20 to 150 cases, and it is unclear whether it is due to variation in learning ability and technical skills or due to differing definitions of expertise.

It is well established that there exists a necessary learning curve in RARP. Rashid et al. [19] examined a regimented program for RARP training of two chief residents over a period of 7 months and found that the operative time decreases with experience, and there was a significant reduction in time taken for the following steps of operation: bladder take-down, apical dissection with dorsal venous complex (DVC), neurovascular bundles (NVBs), and anastomosis ($P<0.05$). There was also a significant improvement in the analogue score of both residents over the period of time ($P < 0.001$).

In a similar study, Thiel et al. [20] evaluated the factors affecting operative time for RARP in a residency training program. They divided RARP into nine segments: port time, docking time, bladder time, endopelvic (E-P fascia) time, DVC time, bladder neck time, seminal vesicle (SV) time, NVB time, and anastomosis time. They found that port time, docking time, and E-P fascia time have a stable learning curve, whereas DVC time and SV time initially decreased and then achieved a plateau around the 30th RARP performed. Both bladder time and NVB time gradually increased with experience. Anastomosis time decreased initially, but later began to increase around the 35th RARP performed.

Complications and Surgical Outcomes During the Learning Curve

The success of any surgical procedure is determined by its outcomes. These outcomes can be short-term (eg, duration of hospitalization, time to catheter removal, time to return to work, continence, potency, and positive surgical margin) or long-term (eg, biochemical recurrence). Other complications can be the amount of blood loss, transfusion rates, and rehospitalization rates. Link et al. [21•] studied the impact of an RARP training program on surgical outcomes and found that margin positive rates, intraoperative and perioperative complications, transfusion rates, length of hospitalization, rehospitalization rates, Foley catheter removal time, 1-year continence rate, median time to continence, 1-year potency rates, median time to potency, and recurrence rates at 1 year were not impacted by the residents' and fellows' training. More recently, Schroeck et al. [22] studied 383 patients undergoing RARP in a structured training environment and concluded that trainees performing the procedure do not negatively affect the blood loss and positive surgical margins.

It is well established that resident training does not have a detrimental effect on surgical outcomes; rather, these outcomes continue to improve with experience during the learning curve. Herrell and Smith [18] defined learning curve as the number of cases needed to duplicate the outcomes and level of the surgeon's comfort as equivalent to RRP. They noted that the learning curve varies between 150 and 250 cases. Menon et al. [23] reported positive margin rates of 15% in the first 100 cases of RARP compared with 4% in the last 100 cases. Samadi et al. [24] reported in their initial experience that the learning curve to proficiency was achieved within 20 cases, but outcomes continued to improve at a slower rate throughout their entire experience.

The significant hurdle in assimilating robotics into the vanguard of mainstream urologic surgery is the obstacle of training robotic-naive surgeons with no prior experience at the robotic console. The high costs of purchasing and housing a dedicated dry lab—training da Vinci System, and the cost of surgical expendables used during training cases in wet labs, often mean that console experience obtained at various hands-on courses is limited and fleetingly transient. In addition, heightened expectations from patients undergoing robotic surgery, medico-legal implications of accountability of attending surgeons, and demands from hospital administrators to turn around robotic procedures, have resulted in limited opportunities for urology residents to gain operative maturity at the console.

Cost Involved in Training Urology Residents

Robotic prostatectomy is a reality of modern urologic practice; however, it is associated with massive cost expenditure on the heath care system. Not only is there a high initial cost associated with purchase and maintenance of the robot, there is also a huge cost associated with training the urologists.

Steinberg et al. [9•] determined the cost of the RARP learning curve in two parts: Part 1 was a theoretical model to determine cost of the learning curve for RARP, and Part 2 estimated costs of the learning curve in published series of RARP. In Part 1, the learning curve ranged from 24 cases to 360 cases. The total time required to complete the learning curve was calculated and multiplied by the total cost per min of operative time. The operative cost was directly related to the length of the learning curve; therefore, in Part 1 the cost of learning varied from $95,000 to $1,365,000. Part 2 of the study included learning curves from published series: the length of the learning curve ranged from 13 cases to 200 cases. The average rate of improvement was 6 min per case, and the average learning curve was 77 cases. The most expensive learning curve was $554,694 and least expensive was $49,613. The average cost of the learning curve in Part 2 of the study was $217,034. At a minimum, RARP costs $400,000 per year (exclusive of disposable instrument cost), in addition to an average of $217,000 of operative time during the learning curve. It was estimated that, in total, an average hospital faces an added cost of $617,000 in the first year of robotic ownership.

Proposed Paradigm

A robust robotic prostatectomy program should have a healthy balance between training residents/clinical fellows without compromising clinical outcomes of cancer control, urinary continence, and potency through stepwise acquisition of familiarity with the complexities of this procedure and competence at the robotic console.

Familiarity with the da Vinci System commences in the third year of a 6-year residency program, wherein the junior residents are encouraged to observe live robotic radical prostatectomy cases in the operating room using 3D stereoscopic glasses. This affords the residents the opportunity to appreciate technical and anatomic basics of the procedure, augmented by direct interaction with both the console surgeon and patient-side assistants. Further review of the operative videos by the surgical team facilitates communication on the roles of each assistant at each step of the procedure. The residents then advance to assist at the patient side.

In our training environment, we have two experienced physician assistants available to assist in the operating room, each of whom has substantial experience. The constancy of an experienced assistant on the right side for each case ensures smooth progress of the procedure as he/she guides the robotically naive resident stationed on the patient's left side through proper port placement, docking the robot, exchanging robotic instruments, and retraction using laparoscopic instruments. Importantly, instruments are introduced intracorporeally under direct vision when inexperienced assistants are involved to avoid inadvertent bowel/vascular injury from passage of instruments. Ongoing communication between the left-sided trainee and right-sided assistant throughout the case allows the trainee to fully grasp the technical nuances of each step.

Once the trainee is confident in anticipating the surgeon's next steps, he/she progresses to assist on the right side. This requires the trainee to be able to manipulate the suction/irrigation device confidently whilst retracting tissue to optimize the console surgeon's field of view. Considerable dexterity is also required to maintain the operative field of view while exchanging retractors for clip applicators, suture holders, etc. The right-sided assistant should also be able to troubleshoot technical problems arising at the patient side (eg, malfunction of robotic instruments) and direct the seamless flow of events within the operating room such as arranging the frozen section of apical margins.

Upon mastery of patient-side assistance, the resident is then advanced onto the surgical console (both in cadaver laboratory and operating room). In our observation, most trainees require about 25 to 30 cases before they can operate the masters and pedals intuitively to effectively execute intracorporeal dissection using robotic instruments and cautery. The constancy of an experienced assistant goes a long way in ensuring reproducible outcomes for every case. Regular review of video footage allows constructive analysis of our surgical technique to optimize clinical outcomes. At our institution, we routinely review all cases of positive surgical margins each month against their relevant operative footage to determine technical areas for improvement.

Future Directions

Cognizant of the variations in patient caseload and trainers' surgical maturity in robotic procedures among residency programs across the country, as well as hospital administrative mandates for rapid turnover of operating rooms, the dV-Trainer (Mimic Technologies, Inc., Seattle, WA) has been developed in collaboration with Intuitive Surgical, Inc., as a means of allowing residents and robotically naive surgeons to mimic console experience in a dry lab setting [25, 26•]. Comprising a master console with finger cuff telemanipulators connected to a binocular 3D visual output, the setup strives to reproduce the look and feel of the da Vinci console. Simulation includes exercises in EndoWrist manipulation, camera control, clutching, object transfer and placement, needle handling, needle driving, knot tying, and suturing, delivering haptic feedback in real time as the trainee executes surgical movements spatially. Among 15 subjects of varying experience with robotic surgery, Lendvay et al. [27] reported significant reduction of total task time, economy of motion, and time the telemanipulators spent outside of the center of the platform's workspace in the experienced group compared with the novice group.

Elsewhere, engineering teams are working to produce a da Vinci-compatible virtual reality simulator using kinematic data from the da Vinci console through LabVIEW (National Instruments Corp., Austin, TX) to drive simulation software (Cyberbotics Ltd., Lausanne, Switzerland) [28, 29]. Medical Education Technologies, Inc. (Sarasota, FL) has also made an attempt to produce a robotic surgery simulator for its SurgicalSIM package [30]. If successful, these virtual reality da Vinci simulators may significantly ameliorate the learning curve for urology residents in acquiring console competence in core skills of robotic instrument manipulation, needle control, and suturing despite the fluctuations of caseload and console exposure between various programs.

Another exciting development in this area has been the advent of the da Vinci Si HD Dual Console System [31]. Incorporating the latest technologies of 3D high-definition visualization of the operative field, Tilepro software for multi-input display, and improved user interface and instrument ergonomics, the dual console system permits the trainee surgeon to perform steps of the procedure at the second console under the watchful supervision of the trainer. Equipped with a built-in intercom for real-time communication between trainee and trainer while both are seated at the console, the trainer is able to assume control of the instrument arms and endoscope at any time from the console to avert the trainee running into complications. The dual console capability of the da Vinci Si System thus allows the trainee to execute the steps of the procedure to the best of his/her abilities while permitting seamless transfer of console control by the supervising surgeon in the interests of patient safety and surgical efficiency, should the need arise. Nonetheless, the cost of acquiring the second console remains prohibitive, running into hundreds of thousands of dollars, and it remains to be seen if this feature will be considered favorably by hospital administrators and program directors, who ultimately are responsible for delivering cost-effective procedures.

Conclusions

The phenomenal popularity of robotics in the past decade has resulted in an amazing renaissance in the craft of urologic surgery, enabling surgeons to perform hitherto difficult procedures with increasing precision and dexterity through a minimally invasive approach. As more program directors incorporate robotics training into their practice, organizations such as the American Urological Association and the Accreditation Council for Graduate Medical Education have begun formulating guidelines for standardizing robotics training curricula for residents. Coupled with the advances in robotic simulator and console technologies, we envision robotic urologic procedures becoming mainstream in most residency programs in the next decade, as the capabilities of robotics continually evolve and expand to improve clinical outcomes.

Disclosure No potential conflicts of interest relevant to this article were reported.

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