Urology Robotic Surgery: Past, Present and Future

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Introduction

Despite making achievable a variety of complex operations, traditional laparoscopy has certain major limitations, for instance the 2-dimensional vision, instrumentation with restricted degrees of freedom, and reduced tactile feedback (haptics). All these factors make delicate dissections and anastomoses difficult if not impossible. As such, there was a need to have some mechanical apparatus to aid or augment what is not possible with the human hands. This idea of having a mechanical hand has been explored in diverse industry fields, including medicine; wherein the most significant utilization of this demand has been reflected in the fields of surgery, including urology.[1,2] As minimally invasive procedures increasingly found way into surgical domains, the advent of Robots allowed to further refine these procedures by overcoming many limitations of minimally invasive surgery, and thus allowing for enhanced surgical outcomes.[3-7] Robotic surgery offers some of the consistently reproducible advantages over open and laparoscopic approaches, such as smaller incisions, enhanced precision, reduced intra-operative blood loss, decreased post-operative pain, and shorter hospital lengths of stay and convalescence.[1,8-10]

As such, the introduction of robots has significantly altered the scenario of laparoscopic surgery in urology; being keenly adopted by surgeons and patients alike, and making robot-assisted urological surgery an emerging technology for most urologic operations.[11] Robot-assisted surgery operations are being performed more frequently in the world at present.[12] This trend will likely continue to have important effect in the future also as robotic systems allow alleviating the difficulty involved in performing complex procedures.[13]

There is presently a need for surgeons to acquire crucial skills (either in simulated or clinical environment) to maintain competence and assurance for patient safety. In this regard, while novice surgeons would need to acquire both domain as well as technical knowledge; the need for the latter, i.e., technical skills, remains equally relevant for experienced open surgeons to further increase their competence with robotic systems.[14] A variety of training programs and skill courses are available to adequately full-fill these needs and expectations of urology surgeons, while robots by themselves help to shorten the learning curve for both naïve and skilled surgeons aiming to perform robot-assisted urological operations.[15,16] The role of simulators, dry and wet laboratories, bedside assistance, and modular (step-by-step) training at console represent relevant elements of robotic surgeon training.[17]

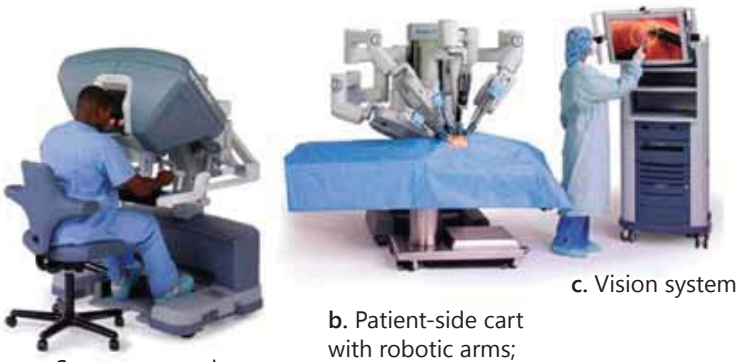
The Past

Development of robotics in Urology

"PROBOT" – the first robot utilized in urology – is an example of the last type where the robot performed transurethral resection of prostate (TURP) based on directions programmed into the controlling computer.[3] Overtime, the technique has however witnessed significant technological evolution, and the currently used systems are telesurgical or master–slave systems, wherein the robot acts merely as an instrument during the procedure and the surgeon controls the robotic arms from a remote console. Given the lack of automation, procedures performed with these newer robots are better categorized as "robot-assisted surgery" rather than robotic surgery.[18,19]

In 2003, Intuitive Surgical Inc., which had developed and introduced the "da Vinci" surgical system in 1999, acquired Computer Motion Inc., the company which developed the

Figure 1. The "da Vinci" system - most widely utilized surgical robot worldwide



a. Surgeon console; **b.** Patient-side cart with robotic arms; **c.** Vision system

ZEUS surgical system (consisting of three robotic arms attached to operating table and controlled remotely by operating surgeon) and the AESOP (designed to control the endoscope using either voice or hand/foot control).[3] This acquisition rendered a significant position to the Intuitive Surgical as lone producer of robotic surgical devices.[20]

The "da Vinci" system - most widely utilized surgical robot

The da Vinci system was launched in 1999 as the sole commercially available robotic surgical unit, making it the most widely utilized surgical robot worldwide. One year later, in 2000, the system received approval from the US Food and Drug Administration (US FDA) for use in both adult and pediatric surgeries; since then, several upgrades and revisions have been made with intent to extend its use for diverse medical applications.[1]

Technically, the da Vinci robotic system is composed of 3 main elements: (i) a surgeon console with an integrated 3-D stereoscopic viewer; (ii) a patient-side cart comprising 3-4 robotic arms; and (iii) a vision system (Figure 1).[21] The surgeon performing the operation sits at the console where an immersive, 3-dimensional (3-D) view of the surgical field is provided, and operates instruments using two master controls. Extremities of the instruments are aligned on the display screen by master controls in order to ensure natural and predictable movements of the instruments. Control of instruments is achieved by free-moving finger controls using a kinematic system at the console (based on the principles of articulated movements); this kinematic system translates the physical motion of the fingers and wrists into electrical and computerized signals so that the mechanical arms of the robotic emulate these movements for minimally invasive surgery at the surgical field.[2,3] The electronic components of the robot allow scaled reduction of surgeon's hand movements to proportionally smaller movements of the extremity of instrument in the surgical field, and this helps to achieve enhanced precision. In all, the 3-D vision (augmented with high-definition video) and seven degrees of freedom of movement combine complex and dexterous movement with gentle tissue handling. This together with tremor filtering and motion scale allow for minimally invasive surgery even in areas that were previously considered difficult, and to dissect, suture and tie knots endoscopically much like that would be possible in open surgical interventions.[13,22,23]

The Present

Expansion of robot-assisted urological surgery

Since May 2000, when the first descriptions of robot-assisted radical prostatectomy (RALP) in Frankfurt were made, robotics has become increasingly more common in the armamentarium available to urologic surgeons.[24] The procedure has since achieved extensive clinical use,[25] and unverified estimates suggesting it to account for most of the radical prostatectomies in United States.[22,26,27] Such an extensive use in fact made it the second most performed robotic-assisted surgical procedure worldwide, yielding better 12-month potency rates than open and laparoscopic radical prostatectomy.[13,28,29] Surgeons however have been constantly trying to refine and improve upon current technical aspects of the systems and its use, with intent to broaden robotic utilization in both adult and pediatric urology.[18] In this regard, emerging areas of modifications include procedures like bladder neck anastomosis and reconstruction, bladder drainage, and nerve sparing approaches and techniques.[20]

Robotics for improved visualization

While at one end approaches were developed for improved dissection and operation; in tandem, efforts have also been directed to apply robotic systems for better visualization of tissues under dissection. This need is though significant since improved visualization and localization is imperative for approaches at all stages; however, the need is especially significant during the initial experience of surgeons with robots.[30] As an instance, a peroperative transrectal ultrasonography (TRUS) has been introduced as a tool to ease learning curve of surgeons performing RALP.

This peroperative use of TRUS during RALP has been observed to decrease the positive surgical margin rate at the base of prostate during the initial experience of RALP.[31] Furthermore, intra-operative TRUS with doppler ultrasound can allow improved localization of the neurovascular bundles, preservation of what is important for post-operative recovery of continence and potency. Consistent with need, TRUS robots have been developed to hold and manipulate the TRUS probe together with 3-D reconstruction software and the da Vinci surgical robot to provide intra-operative guidance in identifying and preserving the neurovascular bundles.[22,32-35] The TRUS robot comprises a robotic orientation remote center of motion module, which is attached to an ultrasound probe, and an arm attaching to the operating table. The system allows four degrees of freedom and is controlled remotely by the surgeon through a joystick located near to the da Vinci console.

Robots for microsurgical interventions

The benefits offered by robotic platforms are particularly augmented when using these systems for complex microsurgical procedures. Robotic assisted microsurgery has therefore been utilized to a considerable extent in andrology and several other microsurgical operations in some centers.[6] In tandem, modifications have also been made in the original robotic system with intent to make it better suited for such microsurgical interventions.[36] The right and left arms of the 4-armed da Vinci type Si robotic system are loaded with Black Diamond Micro Needle Drivers, and an additional fourth arm provides the microsurgeon with one additional tool best suited to dynamic retraction. This application was further modified by Parekattil and colleagues, who developed a unique 5-arm approach for robotic microsurgical procedures.[6] This modified system has a 16–18 times optical high magnification lens camera system attached to the patient table. The VITOM camera system of Karl Storz Inc. is held by nitrogen powered 5th arm (Point setter arm).[6] The camera provides real-time video images that are incorporated into the surgeon console view by using the TilePro (Intuitive Surgical) software system; the software allows for displaying up to three simultaneous real-time images to the microsurgeon. In all, the typical cockpit view of the microsurgeon in the surgeon console thus has following images:

- The da Vinci Si 3D HD camera view in the middle (the main image)
- The 16–18 times optical magnification camera view from the VITOM
- A 40–100 times optical magnified microscopic view from the intra-operative andrology laboratory microscope (Nikon Inc).

This triple-view real-time imaging allows the surgeon to use the da Vinci camera for overall tissue and suture handling at a medium zoom, while at the same time using the high zoom VITOM 16–18 times magnification view to look for fine ultrastructural details. The overall enhanced real-time view of the operating site thus provides substantial advantage when compared to standard microscopic microsurgery, in which the microscope has to be zoomed in or out for different components of the procedure because of limited depth of focus. Use of the triple-view robotic system allows the surgeon to see the field simultaneously at two different focal lengths, and thus improves operative efficiency by obviating the need to zoom in and out during microsurgery. Overall, the new platform with enhanced optics appears to provide the surgeon with an enhanced range of options in microsurgery for urological conditions.

Robotic surgery in pediatric urology

Similar to its adult applications, robotic surgery in pediatric urology has seen considerable growth since its first application in 2002 and is still evolving (Table 1).[22,37] Robotic assisted laparoscopic pyeloplasty was the first pediatric robotic procedure performed at majority of institutions; and it has since become increasingly and commonly performed, especially as a standard of care in older children.[38] The relatively high-incidence of ureteropelvic junction obstruction together with surgeons familiarity with laparoscopic pyeloplasty was perhaps responsible for making it the natural first choice for robotic procedure in children. Nonetheless, this was soon followed by widespread use of robotic-assisted laparoscopic ureteral reimplantation and uretero-ureterostomy into the clinical practice. Other robotic procedures performed in children include heminephroureterectomy, urachal cyst excision, bladder diverticulectomy, and bladder reconstructive procedures such as augmentation, appendicovesicostomy, antegrade

Table 1. Evolution of robotic surgery in children		
2002-2008	2008-2014	2014 onwards
• Defined applications • Established feasibility	• Reports on outcomes • Comparative series • Training programs • Improved simulation	• Mature outcomes research • Global access to robotic technology • Centers of excellence and instruction • Technological refinements (miniaturization, haptics, telesurgery)

Source: Kearns JT, Gundeti MS. Pediatric robotic urologic surgery. *J Indian Assoc Pediatr Surg.* 2014;19(3):123-8.

continence enema, bladder neck reconstruction and sling, as well as other procedures.[38]

Technological refinements and increased exposure, experience and ease of the surgeons with use of robotic systems is possibly accounting for this trend being now adopted towards describing more complex reconstructive urological procedures, such as:

- Rrobot-assisted laparoscopic Mitrofanoff appendicovesicostomy (RALMA)[39]
- Robot-assisted laparoscopic augmentation ileocystoplasty and Mitrofanoff appendicovesicostomy (RALIMA)[40]
- Robot-assisted bladder neck reconstruction[41]
- Robot-assisted laparoscopic retroperitoneal lymph node dissection (R-RPLND).[22,42]

Rather than just focusing on relatively straight-forward pyeloplasties and ureteral reimplantations; these above mentioned procedures seem to expand the scope of complex robotic reconstruction in children. Though large-scale series and long-term outcomes on these applications of pediatric robotic urological surgery might be required, early data seems promising as a proof of principle that robotics can be used to perform complex reconstructive surgeries in children.

The Future

Currently, various modifications are being made in the consoles, robotic arms, cameras, handles and instruments, and other specific functions such as haptic feedback that make up the robotic surgery system. In addition, with the advent of artificial intelligence, a more practical form of robotic surgery system is likely to be introduced and will ultimately lead to the development of automated robotic surgery system.[43]

Several console-based robots for laparoscopic multi- and single-port surgery are expected to come to market in next few years, with future developments likely to focus on specific features of robotic arms, instruments, console, and video technology. Nonetheless, the high technical standards of da Vinci generations have set a high bar for upcoming devices, and ultimately, the implementation of these upcoming systems will depend on their clinical applicability and costs.[44]

There are still many areas with scope of further refinement when specifically considering the pediatric urologic applications of robotic surgery; for example: force-feedback mechanisms for haptics, or augmented reality for compensating haptics; and miniaturization of instruments, mainly that of robotic arms in form of table-mounted systems without compromising the level of control.[16]

In coming years, as more companies are expected to bring their own robots into the market, it can be envisaged that improvements in robotic instruments, in both hardware and software, will allow enhanced applications with improved precision. This will also help to minimize post-operative complications. There is great potential for next-generation surgical robotics to enable better ways to treat urological diseases through less invasive techniques that might not be possible now.[45] Future improvements in technology with production of pediatric-sized robotic instruments, along with increase in robotic-trained urologists, will help to further advance the field of robotic surgery in urology.[38]

Conclusion

As technological advancements provide more precision in addition to the ease to operating surgeons, robotic surgery seems to gain increasing application in different fields of urological surgery. At the same time, use of robots is also being equally accepted by patients for its overall benefits. Use of robots is now well-established in urology, being increasingly used for operations of different urological pathologies. However, the trend also underscores the need for surgeons to acquire necessary skill-sets in operating the robots in order to maintain competence and patient safety. With further improvements, exposure, experience and realization of longer-term benefits, robotic surgery will likely play an increasing role in several urological conditions in both adults and children.

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