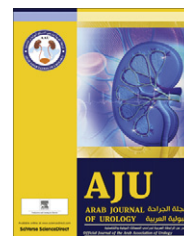




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REVIEW

Robot-assisted urological surgery: Current status and future perspectives

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Abstract Objectives: To discuss the current status of robot-assisted urological surgery.

Methods: We searched PubMed for articles published from 2008 using the search terms ‘advances’, ‘robotic surgery equipment’ and ‘instrumentation’. We also searched PubMed for articles describing the latest developments in reconstructive techniques for lower and upper urinary tract procedures. Finally, we searched PubMed for original articles containing the terms ‘robotic surgery training’ and ‘credentialing’.

Results: With each release of hardware or ancillary instrumentation, the reconstructive abilities of the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA) improve. Recent developments in reconstructive capabilities of robotic urological surgery include posterior reconstruction during robot-assisted radical prostatectomy, barbed sutures for urethrovesical anastomosis, sliding-clip renorrhaphy for robot-assisted partial nephrectomy, and repair of pelvic organ prolapse. The safe implementation of robotic surgery is aided by new guidelines in credentialing and proctoring, and the introduction of virtual reality simulators for training.

Conclusion: Robotic urological surgery is rapidly developing and expanding globally. To achieve the highest levels of safety for patients, surgeons must ensure that the implementation of robotic surgery is an integrative and effective process.

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Introduction

Robot-assisted surgery (RAS) using the da Vinci surgical system (dVSS; Intuitive Surgical, Sunnyvale, CA, USA) has led to a revolution in minimally invasive urological surgery. As of 30 June 2011, there have been 1933 dVSSs sold worldwide, 1411 in the USA, 342 in Europe and 180 in the rest of the world [1]. The popularity of RAS has been partly due to the three main advantages it offers over conventional laparoscopy; magnified three-dimensional (3D) vision for precise vision, Endowrist™ instrument technology allowing exact excision and reconstruction, and a superior ergonomic environment for the operating surgeon. This year marks the 10th anniversary of the world's first robot-assisted radical prostatectomy (RARP) programme [2]. Within this short time the unprecedented growth of RARP has seen it replace both open and laparoscopic surgery as the surgical treatment of choice for prostate cancer in the USA.

In this review we discuss the current status of urological RAS. In particular, we highlight recent advances in equipment and instrumentation that have extended the capabilities of the RA technique. As state-of-the-art reviews on pelvic and upper urinary tract robotic surgery follow this article, we draw attention to some of the latest developments in reconstructive techniques pertaining to these procedures. Finally, as the dissemination of the dVSS continues rapidly, with two centres worldwide receiving a unit every week (personal communication, Intuitive Surgical), we consider the future of robotic surgery training and credentialing.

Advances in equipment

Hardware

Intuitive Surgical released its latest dVSS in April 2009, with the *Si* system. The first dVSS introduced in 1999, known as the *Standard*, had three robotic arms, whilst the second-generation *S* system offered a more streamlined patient-side cart with four robotic arms and a console with 3D high-definition vision. The new *Si* system offers a dual-console capability to support training and collaboration during robotic surgery. Surgeons can exchange control of the instrument arms and camera, whilst a built-in intercom system facilitates communication.

There are few, if any, studies evaluating the performance of robotic surgery using these different systems. A recent analysis of the *S* and the *Standard* dVSS for RARP showed significant reductions in operative time with the *S* model [3]. This effect was probably due to fewer arm-position changes necessitated by arm collisions because of improved docking, and a wider range of motion evident in the *S* model. The latest dual-console system might prove valuable in training, allowing a faster adaptation to robotic techniques, as the surgeon can be proctored from the other console [4]. However, the introduction of these new systems

comes at a considerable cost. The *Si* system is listed at \$1.65 million whilst the optional second console increases the total price to ≈\$2 million.

Software

TilePro® is a multi-image video display mode of the dVSS *S* and *Si* that allows the surgeon to simultaneously view up to two radiological images, as a picture-on-picture on the console screen and assistant monitors. The surgeon can switch back and forth from *TilePro* mode with a short tap on the camera pedal. It has proven particularly useful during RA partial nephrectomy (RAPN), especially when using live intraoperative ultrasonography to help locate tumours [5]. The surgeon is able to delineate the margins of resection without leaving the console to view external images. More recently, the dVSS has been modified to use an integrated near-infrared fluorescence imaging system to help identify renal vasculature and differentiate renal tumours from normal parenchyma during RAPN [6]. Although this method appears promising, its high cost is currently prohibitive.

Instrumentation

A wide range of robotic instruments is now available offering different relative advantages for various operations. Devices such as the Hem-o-lok clip (Weck, Teleflex Medical, NC, USA), bulldog clamps and the Harmonic® (Ethicon Endosurgery, USA) energy source have all been recently adapted to work with the dVSS. The robotically enabled Hem-o-Lok applier can be used during RAPN for clipping vessels. This might be helpful when the bedside assistant is not experienced, or the vessels are at a challenging angle for the assistant to clip manually. A further advance has been the release of robotic bulldog clamps (Reliance bulldog clamps, Scanlan International, MN, USA), allowing the surgeon to use the precision and articulation of the robotic instrument to apply clamps to the renal vessels at optimal angles. In one report of over 50 RAPNs, robotic bulldog clamps were used safely for a range of tumours including hilar, endophytic, multiple tumours, and tumours with multiple renal arteries [7].

A robotic ultrasound probe (Aloka, Tokyo, Japan) has also been developed to facilitate identification of tumour and resection margins during RAPN [8]. Instead of the assistant, the console surgeon controls the probe and can use full robotic articulation to navigate the probe in several directions for precise tumour identification. A much smaller dedicated Doppler probe (Vascular Technology Inc., NH, USA) has also been released that can identify vasculature, isolate aberrant vessels, and confirm ischaemia before resection. Testing this device in 15 patients, Hyams et al. [9] found it altered management in seven patients by identifying accessory vessels that were not evident on preoperative imaging.

Advances in reconstructive RA techniques

Posterior reconstruction during RARP

The re-approximation of Denonvilliers' fascia and the posterior periurethral tissue (rhabdosphincter), often described as posterior reconstruction (PR) or the 'Rocco stitch', has been widely adopted at RARP with the aim to improve the early return to continence. This technique, initially described for retropubic RP by Klein [10] and popularised by Rocco et al. [11], has now been adapted to RARP, with mixed effects on continence. Indeed, several case-control studies reported improved early continence with PR during RARP [11–13]. Conversely, a randomised controlled trial from our institution failed to show an improvement in the rate of early continence with PR [14]. However, it is generally accepted that PR facilitates the next step of RARP, i.e. the urethrovesical anastomosis (UVA). The PR re-approximates the bladder neck and urethral stump into close proximity, reducing the tension on the delicate anastomosis. This increase in ease, coupled with a decreased cystographic leak rate [12,14], as well as no perceived risk, justifies the continued use of PR during RARP.

Barbed suture for the UVA

We reported the first safety and feasibility study of barbed polyglyconate suture (V-Loc, Covidien, Mansfield, MA), for the UVA during RARP [15]. A UVA with the barbed suture was found to be efficient, as the unidirectional barbs prevented slippage, precluding the need for assistance or knot tying. The use of barbed suture has become common practice at our institution and > 600 cases have been performed with it within the 12 months after the first use. Since then, two randomised controlled trials have assessed the merits of the barbed suture for UVA. Williams et al. [16] reported that a barbed suture UVA is associated with increased cost, as well as increased rates of cystogram leakage and prolonged catheterisation. By contrast, Sammon et al. [17] showed that a barbed-suture UVA was associated with a 26% decrease in the anastomotic time with no increase in adverse events, no instances of urinary retention and equivalent functional outcomes.

There were several differences between these studies; the technique described by Williams et al. incorporated three interrupted polyglactin sutures (Vicryl, Ethicon, Summerville, NJ, USA) along the posterior aspect of the UVA, with running barbed sutures along the lateral and anterior anastomosis, without PR. They experienced significant over-tightening in the first 29 barbed suture cases, which they hypothesised led to their high initial rate of cystogram leaks at 9 days. The need to modify the technique might have been in large part due to the learning curve, because the investigators had just incorporated the barbed suture into their technique at the

outset of the trial. Conversely, Sammon et al. described a technique using the barbed suture exclusively in a continuous running UVA, with PR. Moreover, the surgeons involved in that study had performed > 100 anastomoses with the V-Loc barbed suture before the trial, making the learning curve less of a concern.

Sliding-clip renorrhaphy for RAPN

The advantages of the dVSS for RAPN include magnified 3D vision and articulating instruments that help to facilitate precise tumour excision and reconstruction within the time constraints of warm ischaemia. However, one of the major technical innovations that has helped to advance RAPN is a refinement in the technique of renorrhaphy. Clip renorrhaphy during RAPN using standard laparoscopic techniques [18] requires the assistant to control the tension placed upon the closure. To overcome this deficit, a sliding-clip renorrhaphy technique using Hem-o-Lok clips was developed [19].

In the original description by Bhayani and Figenshau [19], a LapraTy™ and 10-mm Hem-o-lok clip is placed above a knot tied at the end of the suture, and the assistant places a second Hem-o-Lok clip on the loose end of the suture, after the suture has been placed through the opposite ends of the renal parenchyma. The clip is applied so that the suture is in the centre of the jaws of the clip, as this helps it to slide smoothly. Using a robotic needle driver with the jaws slightly open, the console surgeon slides the clip down the suture towards the kidney until tightly apposed to the renal parenchyma. This allows tension adjustment but does not definitively lock the suture in position. After further sliding the clip firmly against the renal parenchyma to achieve haemostatic closure, a LapraTy clip placed by the assistant secures the closure [19].

This technique has supplanted the use of traditional tied-suture closures and assistant-placed clips, as it provides the console surgeon with precise control over the tension placed on the renorrhaphy and allows it to be readjusted without placing additional sutures. Furthermore, eliminating the need for knot-tying decreases the time required for reconstruction. In a study by Benway et al. [20] the sliding clip technique resulted in a 13-min reduction in the warm ischaemia time when compared to a tied-suture or assistant-placed clip closure method. In a further *in vivo* porcine study this technique proved to be the strongest closure method when compared to suture-closures or assistant-placed LapraTy closures [21]. The larger footprint of the Hem-o-Lok clip permits tension to be distributed over a greater surface area and leads to a lower risk of renal violation.

Repair of pelvic organ prolapse (POP)

POP is estimated to affect 30% of women aged 50–89 years, with 11% of women undergoing surgical repair

by age 80 years [22]. Currently there is no consensus on the ‘best’ operation for POP. RA sacrocolpopexy (RASC) offers a promising advance in the treatment of POP. The technique involves dissecting the planes between bladder and vagina anteriorly, and vagina and rectum posteriorly. The sacral promontory is exposed by excising the peritoneum, with the incision extended to the vaginal apex. A polypropylene Y-shaped mesh is then sutured to the anterior and posterior surfaces of the vagina with the tail-end sutured to the sacral promontory. The peritoneal incision is closed to cover the mesh with a running suture. Intracorporeal knot-tying is used for all sutures.

RASC is currently being performed in a few centres, with the technique in its infancy. Operative times average 3–4 h [23,24] whilst the major complication rate can be as high as 6% [23]. In the largest study of 80 patients, the success rate was 95%, albeit after a mean follow-up period of only 4.8 months [23]. In a smaller series of 31 patients with a 2-year follow-up, the success rate was 100% [25]. However, mesh erosion remains a concern, with a reported rate of 6% in the study by Akl et al. [23].

Lately we modified our technique of RASC to include the following: port placement and docking identical to RARP, use of a uterine positioning system (Cooper Surgical Inc., CT, USA) for vaginal vault adjustment instead of a sponge-vaginal pack, applying a softer mesh (PelviSoft, Bard Medical, GA, USA) to reduce the risk of erosion, and a barbed continuous suture (V-Loc) for securing the mesh and closing the peritoneal incision. These modifications have significantly reduced our operating times to an average of 120 min. We await long-term data to assess the durability of this emerging minimally invasive approach to POP repair.

The future: robotic surgery training

With the expansion of RAS in urology the focus in this coming decade will shift towards training the next generation of urological surgeons. In a worldwide survey of both practising and trainee urologists, 78% of respondents felt it was required or beneficial to have training in RAS [26]. However, training in RAS poses unique challenges when compared with conventional laparoscopic surgery. For example, the absence of tactile feedback during RAS requires the development of visual cues with 3D depth perception. Although RAS is now included in the AUA Core Curriculum for urology residencies, guidelines for robotic surgery training have not yet been produced.

Recently, Lee et al. [27] published a best-practices model for training and credentialing in RAS. This consists of a structured curriculum incorporating preclinical and clinical components in a competency-based format (Table 1). Requirements of the preclinical stage include familiarity with the workings of the various dVSS

Table 1 Structured RAS training curriculum (from [27]).

<i>Preclinical</i>
(1) Understanding of disease pathophysiology
(2) Understanding of basic laparoscopy (physiology, technique, complications), e.g. AUA Handbook of Basic Laparoscopy and Robotic Surgery
(3) Introduction to components and functionality of da Vinci robot
(4) ‘Dry laboratory’ practice to acquire basic skills, e.g. models, VR simulators, etc.
(5) Animal practice, e.g. pig or cadaveric laboratory sessions
<i>Clinical</i>
(1) Procedure-specific familiarisation
(a) Observation (videos, live cases)
(b) Bedside assistance
(2) Console time (graduated, step-wise process)

models. This can be achieved through didactic sessions from clinical staff and industry representatives, as well as informal hands-on tutorials outside the operative setting. An online tutorial on the fundamentals of the dVSS has now been released by Intuitive Surgical and should prove helpful [28]. Completion of this module can help trainees be conversant in the docking of the patient-side cart, instrument insertion and exchange, as well as control of the various aspects of the robotic interface through the surgeon’s console.

RAS simulators

The recent development of the da Vinci Skills Simulator might help to bridge the gap between the safe acquisition of surgical skills and effective clinical performance during RAS. Incorporating virtual reality (VR) software (MIMIC Technologies, Washington, USA), the skills simulator is an add-on device to the console that allows VR training without the need for the patient side-cart or instruments. Face, content and construct validity have now been reported [29,30] and it is likely this system will become an integral part of robotic surgical training in the future.

One of the limitations of training with the dVSS system is that, unlike laparoscopy training where it is possible to construct box trainers for training at home, RAS training requires access to a fully functional robot. The release of the Robotic Surgical Simulator (RoSS[®], Simulated Surgical Systems, NY, USA) might go some way in addressing this drawback. RoSS is a novel VR simulator that affords trainees the opportunity to immerse themselves in a robotic interface similar to the dVSS [31]. Training with this product allows the robot-naïve surgeon to operate the clutch, use the fourth arm, manipulate the camera and properly remove a needle. Purchasing and maintaining RoSS costs less than ≈10% of the dVSS expense [32]. Furthermore, it can be placed in an environment that is more accessible than the dVSS, such as in a training centre, as opposed to the operating room.

Table 2 Curriculum requirements for practising urologists with no residency or fellowship training in urological RAS (AUA; [34]).

- (i) Completion of Intuitive Surgical's on-line training module and review of the patient preparation and operating room setup for laparoscopic and robotic surgery chapter in the 'Urologic Robotic Surgery Curriculum'
- (ii) Have granted privileges for the surgery via an open approach
- (iii) Observation of robotic surgery performed by an experienced robotic surgeon sufficient for familiarity of the differences between robotic and open approaches, with written confirmation that the procedure was performed safely
- (iv) Hands-on experience using the surgical robotic system with instruction by an instructor. This may include
 - (a) System set-up and docking
 - (b) Skills training using inanimate models
 - (c) Animal laboratory experience when available
 - (d) Familiarity of robotic setup and technique for either or both upper (renal) and lower tract (prostate) procedures depending on which the surgeon performs
- (v) Proctoring and written confirmation by the proctor that the surgeon is competent to use the robotic platform independently of a proctor
- (vi) Assistance by another urologist until the urologist is comfortable operating independently
- (vii) Presence of appropriate biomedical support until the urologist and the OR team are comfortable working with the robotic platform
- (viii) Review of surgical outcomes after the surgeon's initial experience by an unbiased group of peers at the same institution

Robotic surgery credentialing

Currently there is no standardised credentialing system to evaluate a surgeon's competency and safety with performing urological RAS. Expert groups such as the Society of Urologic Robotic Surgeons have lately dealt with training, credentialing and proctoring urological RAS, with the publication of guidelines for the initiation and expansion of urological RAS in institutions [33]. The AUA have also introduced their Standard Operating Practices for Urologic Robotic Surgery [34]. Urologists with no formal training in RAS are recommended to complete a structured training programme before being granted privileges (Table 2). Those exposed to RAS training in their residency or fellowship must provide evidence of experience with a minimum of 20 robotic cases. However, two important principles must be followed if RAS is to be successfully practised and taught [35]. First, care must be provided in the context of a close-knit surgical team. Second, there is no substitute for practice. 'Learning by doing' is simply not good enough and puts the patient at risk.

Conclusion

Urological RAS is rapidly evolving and expanding globally. The relatively short learning curve of RAS is providing a comparative advantage over laparoscopic techniques and slowly making robotics the minimally

invasive method of choice. With each release of hardware or ancillary instrumentation, the reconstructive abilities of the dVSS improve. Surgeons must ensure that the implementation of robotic surgery is an integrative and effective process to achieve the highest levels of safety for patients.

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