Technology Insight: surgical robots—expensive toys or the future of urologic surgery?

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SUMMARY

There is an increasing demand for minimally invasive surgery, despite any controversy over whether patients benefit from minimally invasive procedures rather than undergoing open surgery. In the field of urology, the performance of more complicated procedures is still a challenge even for experienced laparoscopic surgeons. Recently, robots have been introduced to enhance operative performance, increase applicability and precision of laparoscopy, and improve the learning curve for complicated minimally invasive procedures. With the introduction of master–slave systems where the surgeon is seated remotely from the robot and uses controls to maneuver the mechanical arms placed inside the patient, a new development in robot-assisted surgery has commenced. Several authors have suggested that surgical robots similar to the da Vinci Surgical System® (Intuitive Surgical, Sunnyvale, CA), which have three-dimensional (3D) vision and wristed instruments thus giving a greater degree of freedom than rigid laparoscopic instruments, will facilitate the outcome of these more challenging laparoscopic procedures. Whether these features will translate into better functional and oncological results remains to be evaluated. Data published so far clearly suggest that the patient will benefit from less postoperative pain, decreased bleeding and a shorter hospital stay compared with open surgery, and that the surgeon benefits from a faster learning curve than for conventional laparoscopy. For the benefit of our patients and for the development of urology it is vital that we understand both the limitations of telerobotics and when it is appropriate to incorporate these new techniques in day-to-day urologic surgery.

KEYWORDS robotic surgery, laparoscopy, robot-assisted laparoscopic radical prostatectomy, telesurgery

REVIEW CRITERIA

PubMed and Medline were searched for records up to June 2004, using the terms "robotic surgery", "robot-assisted", "laparoscopic", "laparoscopic radical prostatectomy", "laparoscopic radical cystectomy", "telesurgery" and "telerobotics". Papers were selected on the basis of importance to the urological field, clinical relevance and scientific value. Only papers published in English are cited

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INTRODUCTION

Laparoscopy has revolutionized urology over the last decade and the number of applications of laparoscopic surgery in this field has steadily increased during recent years.[1,2] Nevertheless, performing some of these procedures such as radical prostatectomy and cystectomy remains a challenge for surgeons. There is a long learning curve, even for experienced laparoscopic surgeons, and complications are a risk, all of which slow the introduction of the more complicated laparoscopic applications.[3–6] Recently, robots have been introduced to enhance operative performance, increase applicability and precision of laparoscopy, and improve the ease of learning complicated minimally invasive procedures. A 'true' robot is an enslaved device under human control that accomplishes its assignment without human assistance.[7] There are a number of these true robots already in clinical use, in neurosurgery and orthopedics, that can perform some simpler surgical procedures.[8,9] In urology, the term 'robot-assisted surgery' usually refers to the use of endoscopic manipulators such as the Automated Endoscope System for Optimal Positioning (AESOP®, Computer Motion Inc., Santa Barbara, CA) or master–slave robotic systems such as the da Vinci Surgical System® (Intuitive Surgical, Sunnyvale, CA) and ZEUS® Robotic System (Computer Motion Inc., Santa Barbara, CA). The AESOP® Endoscope Positioner is designed to manipulate a laparoscope and may be controlled by foot, hand or voice commands.[10,11] With the introduction of master–slave systems, where the surgeon is seated remotely from the robot and uses controls to maneuver the mechanical arms placed inside the patient, a new development in robot-assisted surgery has commenced. More complicated surgical procedures may now be performed.

Like the AESOP®, the ZEUS® and da Vinci® systems are not true robots because they require the surgeon to guide every movement performed by the robot.[12] The ZEUS® robot provides four degrees of freedom, which is similar to

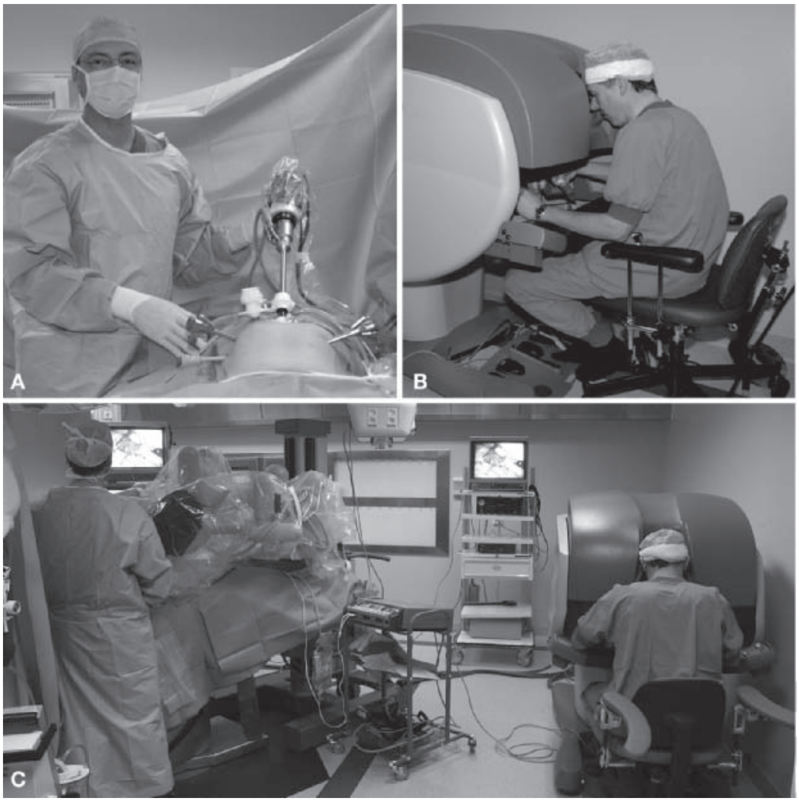

Figure 1 Operating room setup for robot-assisted surgery. (**A**) Positioning of the five ports used during robot-assisted prostatectomy with the robotic camera in the paraumbilical port. (**B**) Surgeon's console with finger-controlled handles which control the robotic arms and camera. (**C**) The overall setup in the operating room showing the assistant surgeon and the cart with surgical arms holding the camera and instruments and the surgeon with the console.

standard laparoscopy instruments, whereas the da Vinci® system offers six degrees of freedom and 3D visualization. In a comparison of the da Vinci® and the ZEUS® systems for laparoscopic nephrectomy, adrenalectomy and pyeloplasty, the operative times and learning curve were more favorable with the da Vinci® robot.[13] It has been suggested that the features of the da Vinci® system translate into more easily learned laparoscopic operations than the conventional laparoscopic approach.[14] Our experience at the Karolinska University Hospital in Stockholm, Sweden, is in agreement with this notion. Most published series concerning robot-assisted surgery in urology relate to the use of the da Vinci® system in advanced prostate and bladder cancer surgery and our experience is also based on the use of this system. Although the feasibility of using robots to assist in laparoscopic procedures such as nephrectomy, adrenalectomy, and pyeloplasty has been shown[15,16] the main indication for robotics in urology is probably in more technically advanced procedures, such as laparoscopic radical prostatectomy, laparoscopic cystectomy and urinary diversions.

THE TECHNOLOGY

There is no need for any major modification of the surgical approach with the da Vinci® robotic technique compared with conventional laparoscopy. The wristed (EndoWrist®, Intuitive Surgical) instruments enable the surgeon to dissect with ease around corners and angles, allowing better preservation of delicate structures such as the neurovascular bundles and a more precise dissection than with standard laparoscopy or with open surgery. The 3D and 10× magnification visualization system (InSite® Vision System, Intuitive Surgical) and the good eye–hand coordination enabled by the robotic system is also an important advantage for the surgeon who is learning how to carry out minimally invasive procedures. It is clear that surgeons who have extensive experience in open radical prostatectomy surgery will benefit from these features.[14,17] A potential disadvantage of robot technology is the lack of tactile sensation, but the 3D visualization allows the surgeon to partially compensate for this drawback.

As is the case for all laparoscopic operations, optimal preparations are necessary when robot-assisted surgery is scheduled. Training the team, patient selection, setup of the robot, patient positioning, port placements, instrument choice and surgical technique must all be considered. At our hospital, a total of five ports are placed for a radical prostatectomy (Figure 1A). It takes about 20–30 min from the introduction of the first port to the actual beginning of surgery. The operating surgeon is seated at the console and does not 'scrub up' (Figure 1B). One of the robotic arms controls the binocular endoscope and the other arms control the robotic instruments. Two finger-controlled handles (masters) control the robotic arms and camera, and relay the surgeon's movements to the robotic arms and instruments. This scaling allows for fine and precise execution of the operation and tremor is eliminated.

Conventional laparoscopic instruments are used by the assistant surgeon. We perform the dissection using two robotic instruments: bipolar forceps (left hand) and round-tip scissors (right hand). A needle driver is used during the anastomosis. The set up of the operating theatre is shown in Figure 1C. A detailed description of the technique of da Vinci® robot-assisted prostatectomy has been published.[18]

When a radical cystectomy is performed, we place an additional port on the left side to allow for the introduction of a stapling device. For experienced laparoscopic surgeons the cystectomy is relatively easy to perform, but the construction of the ileal conduit or the neobladder are technically sophisticated procedures. The neobladder can be constructed by conventional surgery on the outside after retraction of the intestines through a minilaparotomy[19] or the whole procedure can be intracorporeal.[20] We have performed the intracorporeal procedure in eight cases to date and have used either an ileal conduit or a Studer neobladder. The bladder specimen may be retracted through the vagina in women[21] and through a small skin incision in men.

LEARNING CURVE

We began a robot-assisted prostatectomy program in January 2002. Two urologists, who had extensive experience in open retropubic prostatectomy but no laparoscopic experience, were started on a training program. After performing almost 100 robot-assisted radical prostatectomies the operating time is now less than 2 h (Figure 2), allowing for three procedures during a normal working day if theatre turnover can be kept under 1.5 h.[22] Similar operating times have been achieved by other groups using the da Vinci® robot.[17,22] In series where conventional laparoscopy has been used, even experienced surgeons will have operation times of more than 3 h.[14,23–25] It has been suggested that the outcome of robot-assisted laparoscopy after 10 operations is comparable to the experience of skilled laparoscopic surgeons after more than 100 conventional laparoscopic cases.[17] This is supported by the findings of Sarle *et al.*[26] who showed that the da Vinci® system allowed surgeons to complete laparoscopic training drills faster than the time taken for traditional laparoscopy. Even novice laparoscopic surgeons performed the drills faster robotically than did expert laparoscopic surgeons.

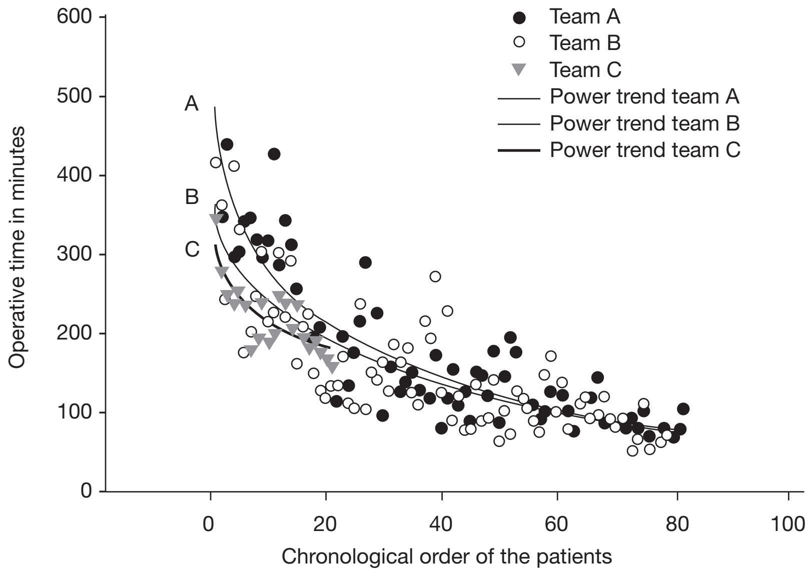

Figure 2 Operation times for three surgeons performing robot-assisted prostatectomy at the Karolinska Hospital, Stockholm, Sweden. Surgeons A and B had extensive experience of open prostate surgery whereas surgeon C was less experienced. Surgeon C started operating under the supervision of surgeon A. Note that the learning curve is already almost horizontal after 20 procedures, indicating that the procedure is relatively easy to learn. Mean operating time is <100 min after approximately 60 procedures.

RADICAL PROSTATECTOMY

It is clear that robot-assisted prostatectomy reduces bleeding and postoperative pain compared with open retropubic prostatectomy. This may translate into earlier discharge from the hospital. Menon reported that 95% of patients were discharged within 24 h.[22] Most of our patients are discharged the day after surgery and, again, in the series reported by Ahlering *et al.*[17] only a short hospital stay was reported. In most conventional laparoscopic prostatectomy series, in contrast, subjects were hospitalized for several days after surgery. This difference may be due to the fact that in standard laparoscopy the surgical procedure takes longer, but could also be related to other factors: it has been suggested that insurance systems might not give financial incentives to discharge patients early, or patients may wish to remain in hospital until catheters are removed.[27]

Several studies showed good outcomes in terms of cancer control when conventional laparoscopy was used.[23,28–30] Menon *et al.* published excellent results on cancer control in their series on robot-assisted prostatectomy,[31] but the status of positive margins was controversial because a different approach was used to detect them compared to open surgery. In the study by Menon *et al.*[31] positive margins were assessed by intraoperative distal biopsies in the apical region, whereas in our series (100 patients) 25% of the patients showed positive margins, of which most were detected dorsolaterally in the area of the neurovascular bundle. In the initial study by Ahlering *et al.*[17] a rather high rate (35%) of positive margins was reported, but as the technique was improved a positive margin rate of less than 20% has been shown.[32]

The risk of incontinence following open retropubic radical prostatectomy varies widely, for example from 5–10% when reported by surgeons from large series and from 20–30% when patients were evaluated by questionnaire.[33] Menon's group have found that patients achieve continence faster after robot-assisted prostatectomy than after open surgery.[31] In our series of robot-assisted radical prostatectomies at the Karolinska Hospital we have evaluated continence by use of a questionnaire given to patients before surgery and 6 months after surgery. We found that 87% of the patients reported that they did not use any type of pad after surgery and none of the patients used more than one pad per 24 h. Similar results were presented by Ahlering *et al.*,[17] of whose patients 81% did not use any pads at 3 months postsurgery. It is clear that the anastomosis between the urethra and bladder neck and dissection of the apex is easier to perform because of the improved vision and use of wristed instruments enabled by robotics.

One of the most important factors in reducing the morbidity of radical prostatectomy is to increase the number of men who recover their sexual function after surgery. Menon's group again reported that robot-assisted prostatectomy enhances the return of erections and the ability to have intercourse compared with open surgery.[31] In our study, before surgery 73% of subjects reported erections sufficient for penetration. At 3 to 6 months follow up 67% of the previous potent patients had erections sufficient for penetration with or without the use of phosphodiesterase inhibitors after bilateral or unilateral nerve-sparing surgery. Longer follow up is still required to evaluate whether robot-assisted prostatectomy will prove better at avoiding adverse events relating to sexual function than open surgery and conventional laparoscopy.

There are several large series reporting on the complications of laparoscopic radical prostatectomy,[23,28,29,34] whereas only limited reports on robot-assisted prostatectomy have been published.[27,31] After conventional laparoscopy, anastomotic leakage is a common problem.[23,24,28,29] Neither we nor Menon's group have encountered this problem in our patients,[31] perhaps because the 3D visualization system and the fine-wristed instruments enable a more refined surgical technique when creating the anastomosis to the urethra. In general, the complication rate is similar between conventional laparoscopic and robot-assisted procedures. The learning curve and the operating time do appear to favor robot-assisted prostatectomy, however, and this may translate into earlier discharge from hospital, a reduced postoperative pain score and less bleeding.[22]

RADICAL CYSTECTOMY AND URINARY DIVERSION

A laparoscopic approach to cystectomy and urinary diversion for muscle-invasive bladder cancer is being developed in several institutions.[6] Various extracorporeal and intracorporeal techniques are evolving for the reconstructive procedures necessary for urinary diversion.[35–38] Although the cystectomy is challenging to perform for the expert laparoscopist, the urinary diversion is without doubt even more technically complicated to perform by intracorporeal technique. Several groups have used the da Vinci® Robotic System to enhance the performance during cystectomy and urinary diversion.[19–21,39] There is still little experience worldwide, with fewer than 300 cases having been performed using laparoscopy with or without the aid of the da Vinci® system: the experience after both conventional laparoscopic and robot-assisted cystectomy is equally limited.[40] To date, it has been shown that a completely intracorporeal cystectomy, with various types of urinary diversion, can be performed without complications; whether the improved vision and wristed instruments enabled by the use of robotics will translate into better oncological and functional outcome remains to be seen. Again, the limited data do suggest that the patient will benefit from less postoperative pain, decreased bleeding and a shorter hospital stay than after open surgery. Likewise, surgeons appear to benefit from faster learning curves than for conventional laparoscopy, as we have also experienced at our institution (eight patients). A potential weakness of the robotic approach to cystectomy is the lymph node dissection. It may prove difficult to reproduce the meticulous lymph node dissection described by Skinner *et al.*[41] Thus, at present, patients with superficial disease (Ta, T1, TIS) may be the best candidates for the robot-assisted approach, since a more limited lymph node dissection involving only the external iliac, obturator and internal iliac nodes may be appropriate in these patients.[42]

THE COST

The da Vinci® system costs US$1.2 million, with a maintenance fee of approximately $100,000/year after the first year. The average cost of related disposables is $1,500 per procedure in the US[22] and equivalent to $2000 per procedure at the Karolinska Hospital. These costs are at least in part balanced by savings because of decreased length of hospital stay, fewer blood transfusions and lower complication rates than seen with conventional open surgery. It has been suggested that the cost for robotic surgery is an average of $150 more per procedure than for open surgery in the US.[22] If the data on tumor-free margins, low incidence of incontinence and impotence, and reduced postoperative pain are further established, the cost of the procedure *per se* will be of lesser importance. At our institution the overall cost for a robot-assisted prostatectomy has been calculated to be approximately $1000 more for each operation than for conventional surgery.

FUTURE ASPECTS OF ROBOT-ASSISTED SURGERY

There is still controversy over whether patients benefit from minimally invasive procedures compared with open surgery.[43] It is reasonable to assume that there will be an increased demand for minimally invasive surgery in urology as has been the case in general surgery. Because less complicated urologic procedures can be performed by the use of standard laparoscopy, the place for robot-assisted surgery will be with the more complicated procedures such as pyeloplasty, radical prostatectomy and cystectomy with urinary diversion, which require long learning times and vast laparoscopic experience. The next generation of robots will probably be less expensive than current systems. New instruments that will allow more exact dissection are likely to be developed. This may increase the possibility of performing nerve-sparing surgery and reduce the morbidity inflicted by prostate cancer surgery. The option of performing remote surgery with robots is another future challenge. In theory it will be possible to be operated upon by leading surgeons, even in smaller institutions whose staff are less experienced.

CONCLUSION

Robot-assisted prostatectomy and cystectomy can be learned more quickly and easily by surgeons who are skilled in open urologic surgery than standard laparoscopic prostatectomy and cystectomy procedures.[3–6] The availability of surgical robots with 3D vision and wristed instruments with greater degrees of freedom than rigid laparoscopic instruments may also facilitate the performance of laparoscopic surgeons in the future. Whether these features will translate into better results regarding oncologic and functional outcome remains to be scientifically evaluated, but it already seems clear that patients will have less postoperative pain, decreased bleeding and shorter hospital stays than after open surgery.

Developments in urologic surgery fuelled by robotic techniques and their related medical benefits are expected to occur. The extent of these developments will be influenced by randomized studies and the involvement of dedicated medical staff and development-oriented hospital administrations.

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Competing interests
The author declared he has no competing interests.

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