Robotic Laparoscopic Radical Prostatectomy

Assaad El-Hakim, MD
Ashutosh Tewari, MD

Prostate cancer is the most common non-skin cancer in the United States and is the second leading cause of cancer-related death among men.[1] The goals of treating prostate cancer include complete eradication of the cancer with minimal morbidity and maximal preservation of patients' quality of life. Radical prostatectomy (surgical removal of the prostate gland and seminal vesicles) is the gold standard treatment of prostate cancer.[2] However, radical prostatectomy can be associated with adverse events that affect patients' quality of life, including impotence and incontinence. The surgical technique is paramount for achieving complete removal of the cancer with negative surgical margins and meticulous dissection to preserve the erectile nerves and the urinary sphincter.[3] Robotic prostatectomy offers the potential for precise surgical technique, which we believe has a positive impact on long-term functional outcomes, cancer control, and quality of life.[4,5]

Robotic prostatectomy represents the latest advancement in surgical treatment of prostate cancer. In the United States, the technique of robotic prostatectomy was described and standardized by the Henry Ford Hospital team, Detroit, MI.[4,5] Several institutions in the United States and Europe have recently adopted this technique.[6] This article presents an overview of robotic prostatectomy and summarizes the current literature on this new technologic advancement in the surgical treatment of prostate cancer.

HISTORICAL OVERVIEW

Telerobots traditionally have been developed for use in hazardous environments and for space exploration. Using robots to perform surgery was first explored in the mid 1980s at the National Aeronautics and Space Administration (Ames Research Center, Palo Alto, CA) in collaboration with a plastic surgeon.[7] The first commercial clinical robotic surgical system was the RoboDoc surgical system (Integrated Surgical Systems, Davis, CA), which was used to core the femoral shaft for total hip replacement.[8] The first application of a clinical robotic system in laparoscopic surgery was a voice-controlled robotic arm that held the laparoscope. The Automated Endoscopic System for Optimal Positioning (AESOP) (Computer Motion, Goleta, CA) was the first robotic device to receive approval from the US Food and Drug Administration, and it launched the movement toward robotics in urology and general surgery.[9]

Further developments in robotic technology led to the design of the first prototype "master-slave manipulators" in 1996, known as the Advanced Robot and Telemanipulator System for Minimally Invasive Surgery (ARTEMIS).[10] The system consisted of a user station (master) and an instrument station (slave). With this system, the surgeon sits at a console that integrates endoscopic monitors, communication facilities, and 2 master devices to control 2 slave arms mounted to the operating table. Surgical practicability was demonstrated in animal experiments;[11] however, the system has not yet been commercialized.

In 1995 Intuitive Surgical (Sunnyvale, CA) was founded based on robotic surgery technology developed at Stanford Research Institute International. This company thereafter produced and introduced to the market the da Vinci Surgical System. Within a year, Computer Motion produced the ZEUS Robotic Surgeon. The 2 systems are currently the only commercial master-slave robotic systems for laparoscopic telesurgery. Initially, the da Vinci system was unique because its wristed instruments (EndoWrist technology) offered 7 degrees of freedom, similar to a human hand; however, in July 2001 Computer Motion enhanced the ZEUS robot with similar MicroWrist technology. In March 2003, Intuitive Surgical and Computer Motion announced their merger into one company. Since the merger, the ZEUS robot is no longer available for purchase and is not supported to a significant degree.

At the time of submission, Dr. El-Hakim was a fellow in robotic urologic oncology at New York Presbyterian Hospital–Weill Cornell Medical College, New York, NY. He is now an assistant professor, Department of Urology, McGill University, Montreal, Canada. Dr. Tewari is Director of Robotic Prostatectomy and Prostate Cancer Outcomes, and associate professor, Department of Urology, New York Presbyterian Hospital–Weill Cornell Medical College, New York, NY.

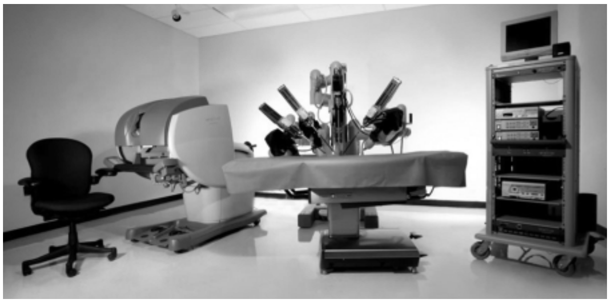

Figure 1. Robotic cart with 4 arms. (Reproduced with permission from Intuitive Surgical, Inc. Copyright © 2005.)

DA VINCI SURGICAL SYSTEM

The da Vinci surgical system has 2 major components: the surgeon's console (master console) and the surgical cart (slave effector), which is composed of 3 or 4 arms (**Figure 1**). The middle arm holds a binocular laparoscope (telescope) that provides stereoscopic 3-dimensional visualization of the operative field with tenfold magnification. The other arms are attached to wristed instruments (EndoWrist technology) that permit intracavitary manipulation of various 2- to 4-mm instrument tips through 7 degrees of excursion, emulating the human wrist (**Figure 2**). Seven degrees of motion freedom are provided by the combination of trocar-positioned arms (insertion, pitch, yaw) and articulated instrument wrists (yaw, pitch, roll, and grip). This range of motion enables surgeons to smoothly coordinate a myriad of complex instrument positions in an ergonomically correct fashion. The system incorporates a filter that eliminates any tremor. Recently, an arm with a computer-assisted instrument was added that allows the surgeon to provide retraction or exposure.

The surgeon operates from the master console placed 5 to 10 ft from the patient's side, providing continuous control of both the surgical environment and the internal operation. A patient-side robotic cart positions and drives the wrist-like devices, while an assistant adjusts and performs instrument exchanges. Operators essentially become immersed in the surgical landscape, which provides optimal access and dexterity. The features that give the robotic system an advantage over conventional open and laparoscopic surgery are summarized in **Table 1**.

PATIENTS' PERSPECTIVE ON PROSTATE CANCER TREATMENT

In a recent longitudinal study, Diefenbach and associates[12] examined the treatment decision-making process among 654 men diagnosed with early-stage prostate cancer. Patients were recruited into an assessment study after an initial treatment consultation with a urologic surgeon or radiation oncologist. The authors used a cognitive-affective theoretical framework to assess treatment and disease-relevant beliefs and affects as well as clinical variables. Patients who decided on surgery perceived prostate cancer as being significantly more serious ($P < 0.001$) and had greater difficulty making a treatment decision ($P < 0.005$) compared with patients receiving radiation therapy or brachytherapy. Patients were asked to rank from most to least important the following reasons for choosing the treatment approach they decided on: (1) less painful, (2) less invasive, (3) fewest side effects, (4) convenience, (5) best chance of cure, and (6) other people had it. The reason most frequently ranked as most important by patients who chose surgery was its perceived superior oncological efficacy. The reasons patients gave for choosing radiation therapy, brachytherapy, or watchful waiting instead of surgery were fear of pain, increased invasiveness of surgery, greater chance of side effects, and inconvenience.

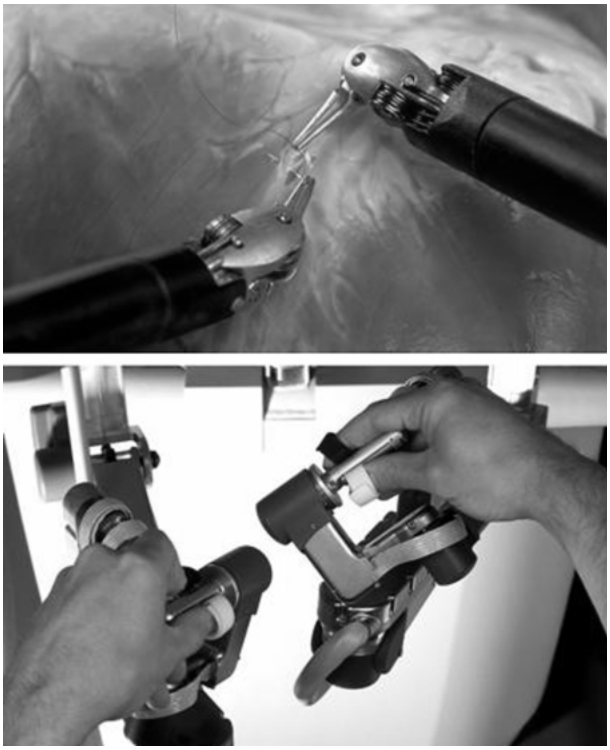

Figure 2. Robotic instruments emulate surgeon's hand movements. (Reproduced with permission from Intuitive Surgical, Inc. Copyright © 2005.)

LITERATURE REVIEW

We searched MEDLINE for all articles on robotic prostatectomy using the search terms *prostate cancer*, *robotic*, *robot assisted*, *laparoscopy*, and *radical prostatectomy* and compiled a total of 10 series with 373 patients (**Table 2**).[13–22] Early results demonstrate favorable operative and pathologic outcomes. The mean operative time was 222 minutes plus 32 minutes of installation time. With experience, the set-up time is expected to decrease to 15 minutes or less. The overall estimated blood loss was 231 mL, with no transfusions in most reported series. These figures are below reported blood losses during open retropubic prostatectomy and are in the range of laparoscopic prostatectomy. The mean hospital length of stay was 1.4 days. The positive surgical margin rate was acceptable, with a mean of 15%. The positive surgical margin rate was 8.5% for organ-confined cancers (pT2) and 57.3% for non-organ confined cancers (pT3). The overall complication rate for all reported series was low, with a 4.55% rate of minor complications and a 3.75% rate of major complications. There was no perioperative mortality.

None of these series had long-term follow-up, and much of the cancer control and functional data are still immature. Ahlering et al[19] showed that at 3 months 81% of patients used no pads, 14% used a security pad or 1 pad daily, and 5% used 1 to 3 pads daily. Menon and Tewari[23] reported that at 6 months 96% of patients no longer needed to wear pads or were using a liner for security reasons and 4% were using 1 or more pads. At 6 months, 82% of men younger than 60 years had returned to sexual activity and 64% had sexual intercourse; 75% of men older than 60 years had returned to sexual activity and 38% had sexual intercourse.

Table 1. Advantages of Robotic Surgical Systems

3-Dimensional stereoscopic image with ten- to twelvefold magnification
Wrist action of the robotic arms providing 7 degrees of freedom compared with 5 degrees of freedom for standard laparoscopic instruments
Tremor elimination
Optional motion scaling up to 3 to 1 or 5 to 1 (eg, a 3-in movement made by the surgeon at the console translates into a 1-in movement of the robotic arm)
Improved ergonomics
Ability to transform the surgical act into digitized data, which will facilitate surgical simulation and training

Robotic versus Open Prostatectomy

There are 2 published prospective nonrandomized studies that compared robotic and open radical prostatectomy.[20,21] Ahlering et al[20] compared outcomes from one surgeon's open radical prostatectomy (N = 60) and robotic prostatectomy (N = 60) procedures after this physician had gained experience with robotic prostatectomy. Tewari et al[21] compared the outcomes of 100 patients who underwent radical retropubic prostatectomy performed by 8 urologists with the outcomes of 200 patients who underwent robotic prostatectomy performed by a single surgeon at the same institution. These comparative studies accrued a total of 260 patients in the robotic arm and 160 patients in the open radical retropubic prostatectomy arm. We analyzed the results of both studies based on the key patient preferences regarding prostate cancer treatment identified in the Diefenbach study[12]: oncological control (margin and prostate-specific antigen [PSA] recurrence), pain, convenience (catheter duration and hospital stay), complications, and functional outcomes (incontinence and sexual recovery). We also compared variables such as baseline characteristics and operative details, while less important from a patient perspective, to provide objective data on patient population, operative time, and blood loss. Currently, no prospective studies comparing robotic to laparoscopic prostatectomy are underway.

Baseline parameters. Both the open radical prostatectomy and robotic prostatectomy groups were comparable in terms of baseline characteristics, including age, serum PSA level, prostate volume, and body mass index (BMI) (**Figure 3**).[20,21]

Oncological control. Pathologic stages were comparable between the groups. Tewari et al[21] reported a lower positive surgical margin rate for the robotic prostatectomy group, and Ahlering et al[20] reported a comparable rate for open and robotic groups (**Figure 4**). Margins were defined as cancer on the inked surface of the specimen in the open prostatectomy arms of both studies and in the robotic arm in the Ahlering et al study.[20] In the robotic arm of the Tewari et al study,[21] apical margins were considered positive if cancer was seen in the intraoperative distal biopsies.

Pain. A Visual Analogue Scale was used to measure pain in the Ahlering et al study[21]. Patients undergoing robotic prostatectomy reported an average pain score of 3 out of 10; open prostatectomy patients had a significantly higher mean pain score of 7 out of 10.

Inconvenience and lifestyle issues. Mean hospitalization stay and duration of catheterization were shorter for the robotic group (1.2 days and 7 days, respectively) than for the open prostatectomy group (3 days and 13 days, respectively).[20,21] Some investigators consider hospital stay a soft measure because it may vary between practices and institutions. For instance, patients have longer hospital stays in Europe compared with patients in the United States following minimally invasive procedures due to prevailing practice patterns.

Blood loss and transfusion rate. Patients in the

Table 2. Worldwide Experience in Robotic Prostatectomy

Series	Number of Patients	Mean Age (range), y	Mean PSA Level (range), ng/mL	pT2a-b, n (%)	pT3a-b, n (%)	SM+, n (%)	pT2/SM+, %
Abbou et al[13]	1	63	7	0	1 (100)	0	—
Pasticier et al[14]	5	58 (55–63)	12.4 (8.7–23.6)	5 (100)	0	1 (20)	20
Rassweiler et al[15]	6	64.2 (57–71)	8.4 (2.4–12)	2 (33)	4 (67)	0	0
Bentas et al[16]	40	61.3 (45–72)	11.5 (0.5–53)	25 (63)	15 (37)	12 (30)	8
Gettman et al[17]	4	62 (61–70)	11.3 (3.6–24)	3 (75)	1 (25)	1 (25)	0
Kaouk et al[18]	1	48	12.5	0	1 (100)	1 (100)	—
Ahlering et al[19]	45	61.4 (46–71)	7.3 (1.1–24)	27 (60)	16 (35)	16 (35)	14.8
Ahlering et al[20]	60	62.9 (43–78)	8.1 (0.1–62)	45 (75)	14 (23)	10 (17)	4.5
Tewari et al[21]	200	59.9 (40–72)	6.4 (0.6–41)	174 (87)	26 (13)	12 (6)	—
Samadi et al[22]	11	67 (58–71)	8.9 (3.9–32)	8 (73)	3 (27)	3 (27)	—
Weighted means	**373**	**61**	**7.6**	**18**	**14**	**15**	**8.5**

EBL = estimated blood loss; OR = operating room; PSA = prostate-specific antigen; pT2a-b = pathologic stage T2a and T2b; pT3a-b = pathologic stage T3a and T3b; SM+ = positive surgical margin.

*The weighted mean of hospital stay is 3.1 days for all reported series and 1.4 days if Bentas' series is excluded. Patients in this study were discharged home after catheter removal (range, 6–32 days).

robotic prostatectomy groups had significantly less blood loss in both studies (mean loss of 141.5 mL versus 726.5 mL). No patient in the robotic group required blood transfusion, whereas 42.3% of patients in the open group required blood transfusion. In the Ahlering et al study,[20] 1 patient (2%) in the open group received blood transfusion, whereas 67% of open surgery patients required blood transfusion in the Tewari et al study;[21] however, the majority of these patients (84%) received autologous blood.

Complications. Complications were reported for both groups in both studies during a similar postoperative duration, encompassing early events within 30 days of surgery. In both studies, the complication rate was lower in the robotic versus open prostatectomy groups. In the Ahlering et al study,[20] there were 4 (6.7%) complications in the robotic group (1 pulmonary embolism, 1 urine leak, 1 prolonged ileus, and 1 delayed bleeding episode) and 6 (10%) in the open group (3 deep venous thromboses, 1 pulmonary complication, and 2 ureteral injuries). In the Tewari et al study,[21] there were 10 (5%) complications in the robotic group (2 abortion of procedure, 3 prolonged ileus, 3 wound dehiscence/hernia, 1 deep venous thrombosis, and 1 delayed bleeding) and 19 complications in the open group (3 prolonged ileus, 4 postoperative fever/pneumonia, 4 delayed bleeding, 2 lymphocele, 2 obturator neuropathy, 1 rectal injury, 1 wound dehiscence/hernia, 1 deep venous thrombosis, and 1 myocardial infarction).

Continence. Functional data have not yet matured in these series. Ahlering et al[20] reported similar continence (0 pads) rates at 3 months for robotic and open prostatectomy (76% versus 75%). Using survival analysis to compute probability of return of continence, Tewari et al[21] reported that patients in the robotic arm achieved continence much quicker than patients in the open arm and that 50% return of continence occurred in 160 days in the open arm versus 44 days in the robotic arm ($P < 0.05$).

Potency. Sexual function was only evaluated in the study by Tewari et al.[21] Analysis was limited to patients who had normal preoperative erections and sexual intercourse in both groups. Patient age and comorbidities were similar in both groups. Patients in the robotic group had more than 2 times quicker return of erection (50% return of erection occurred at mean follow-up of 180 days versus 440 days in the open group ($P <$ 0.05). The return to intercourse was also quicker in the robotic arm, with 50% of patients achieving intercourse at a mean follow-up of 340 days; at the time of publication, 50% of the open surgery group had not achieved intercourse.[23]

ADVANCES IN NERVE-SPARING ROBOTIC PROSTATECTOMY

Although the data on potency following robotic prostatectomy is still maturing, a good anatomic foundation of robotic nerve-sparing surgery has been demonstrated.

Table 2. (*continued*)

pT3/SM+, %	Mean OR Time, min	Mean EBL, mL	Mean Hospital Stay, d
0	420	300	4
—	222	800	5.5
0	315	—	—
67	500	570	17.1
100	274	1013	5.3
100	285	300	2
62.5	209	145	1.6
50	—	103	1.1
—	160	153	1.2
—	300	900	—
57.3	**222**	**231**	**1.4 (3.1)***

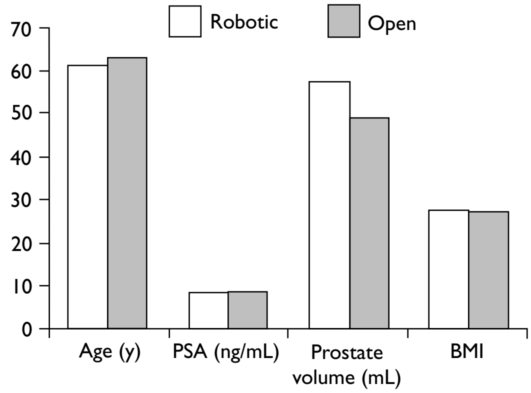

Figure 3. Baseline parameters of patients in the robotic prostatectomy groups (N = 260) and open prostatectomy groups (N = 160) in the Ahlering et al[20] and Tewari et al[21] studies. Bars represent weighted mean values for each variable. BMI = body mass index (kg/m^2); PSA = prostate-specific antigen.

Tewari et al[24] performed dissections of 12 male cadavers using a combination of laparoscopic equipment and open surgical dissection. Dissections mimicked various steps of robotic and laparoscopic prostatectomy and provided a detailed operative map for nerve preservation. They described a potential triangular space containing the neurovascular bundles: the inner layer of the periprostatic fascia (also called prostatic fascia) forms the medial vertical wall of this triangle, the outer layer of the periprostatic fascia (also called lateral pelvic fascia) forms the lateral wall, and the anterior layer of the Denonvillier's fascia forms the posterior wall. Accordingly, the neurovascular bundle was located within this triangle approximately 1.5 mm posterolaterally at the base and about 3 mm at the apex. Cross-connections between branches of the pelvic plexus on each side were also noted. Because of the 3-dimensional, high-resolution image magnification and precision of surgical instruments used in robotic prostatectomy, bilateral nerve-sparing robotic prostatectomy can be performed in almost all low-risk candidates. The quality of the operative image with depth perception, in addition to the bloodless surgical field, makes nerve preservation an easier task.

LIMITATIONS

The da Vinci surgical system costs US $1.2 million, with a maintenance fee of $100,000 annually after the first year. The average cost of disposables is approximately US $1500 per case. Lotan et al[25] compared the costs of robotic, laparoscopic, and open radical prostatectomy using a computer model. Open prostatectomy was the most cost-effective approach, with a cost advantage of US $487 and $1726 over laparoscopic and robotic approaches.[25] The large difference in cost between open radical prostatectomy and robotic prostatectomy resulted from a cost of US $857 per case for robot purchase and maintenance and a cost of $1705 per case for equipment.

Indeed, cost issues remain a matter of debate. However, from a health care perspective, the uncalculated savings gained in hastened patient recovery and return to normal activity and productivity will have to be considered in future analyses. Ultimately, if long-term cancer control and functional outcomes are shown to be equivalent to standard open prostatectomy, cost issues will then be settled. In our opinion, the added advantages of minimal invasiveness alone justify the added costs.

Another commonly mentioned disadvantage of robotic prostatectomy is the lack of tactile (haptic) feedback. This seems to be of relative importance at the beginning of the learning process. However, high magnification and 3-dimensional-vision display widely compensate for it. To further compensate for the lack of tactile feedback, we routinely extract and examine the specimen intraoperatively before performing the vesico-urethral anastomosis and, if necessary, obtain wider margins accordingly.

LEARNING CURVE

Ahlering et al[19] demonstrated successful transfer of open surgical skills in radical prostatectomy to a laparoscopic environment using robotic interface in a

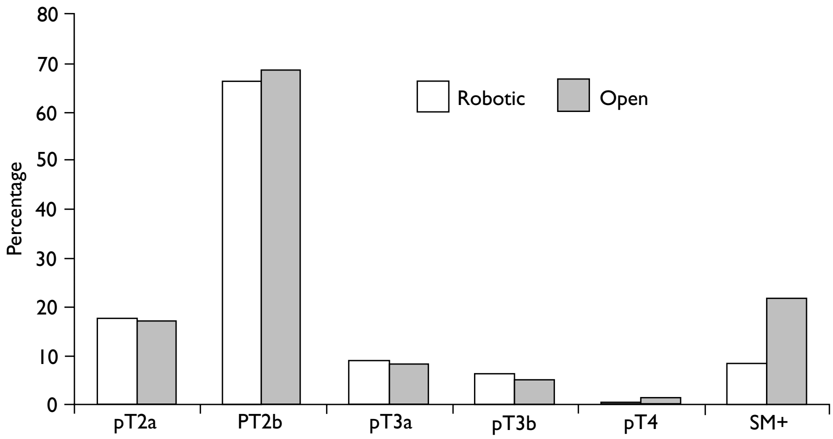

Figure 4. Pathologic stages (pT) and positive surgical margin rates (SM+) for patients in the robotic prostatectomy groups (N = 260) and open prostatectomy groups (N = 160) in the Ahlering et al[20] and Tewari et al[21] studies. Bars represent weighted mean values for each variable.

laparoscopy-naive surgeon. The learning curve to 4-hour proficiency was 12 patients, and mean operating time subsequently was 3.45 hours. Complications and operative time are expected to be higher during the learning curve; however, this could be surmounted by proper training in residency or fellowship programs. Urologists already in practice may need to consider intensive training in institutions performing a high volume of robotic prostatectomies.

CONCLUSION

Robot-assisted radical prostatectomy is a new treatment option for men with clinically localized prostate cancer. The current evidence suggests that robotic prostatectomy is comparable in efficacy to open and laparoscopic prostatectomy, including clinical and pathologic parameters. The concept of robotic surgery is not to replace surgeons but rather to enhance surgeon's abilities and improve what the surgeon is already able to accomplish. **HP**

REFERENCES

1. Jemal A, Murray T, Samuels A, et al. Cancer statistics, 2003. CA Cancer J Clin 2003;53:5–26.
2. Walsh PC. Anatomic radical prostatectomy: evolution of the surgical technique. J Urol 1998;160(6 Pt 2):2418–24.
3. Eastham JA, Kattan MW, Riedel E, et al. Variations among individual surgeons in the rate of positive surgical margins in radical prostatectomy specimens. J Urol 2003;170(6 Pt 1):2292–5.
4. Menon M, Tewari A, Peabody J. Vattikuti Institute prostatectomy: technique. The VIP Team. J Urol 2003;169: 2289–92.
5. Tewari A, Peabody J, Sarle R, et al. Technique of da Vinci robot-assisted anatomic radical prostatectomy. Urology 2002;60:569–72.
6. El-Hakim A, Tewari A. Robotic prostatectomy—a review. MedGenMed 2004;6:20.
7. Satava RM. Surgical robotics: the early chronicles: a personal historical perspective. Surg Laparosc Endosc Percutan Tech 2002;12:6–16.
8. Cowley G. Introducing "Robodoc." A robot finds his calling—in the operating room. Newsweek 1992;120:86.
9. Sackier JM, Wang Y. Robotically assisted laparoscopic surgery. From concept to development. Surg Endosc 1994;8:63–6.
10. Schurr MO, Breitwieser H, Melzer A, et al. Experimental telemanipulation in endoscopic surgery. Surg Laparosc Endosc 1996;6:167–75.
11. Schurr MO, Buess G, Neisius B, Voges U. Robotics and telemanipulation technologies for endoscopic surgery. A review of the ARTEMIS project. Advanced Robotic Telemanipulator for Minimally Invasive Surgery. Surg Endosc 2000;14:375–81.
12. Diefenbach MA, Dorsey J, Uzzo RG, et al. Decision-making strategies for patients with localized prostate cancer. Semin Urol Oncol 2002;20:55–62.
13. Abbou CC, Hoznek A, Salomon L, et al. Laparoscopic radical prostatectomy with a remote controlled robot. J Urol 2001;165(6 Pt 1):1964–6.
14. Pasticier G, Rietbergen JB, Guillonneau B, et al. Robotically assisted laparoscopic radical prostatectomy: feasibility study in men. Eur Urol 2001;40:70–4.
15. Rassweiler J, Frede T, Seemann O, et al. Telesurgical laparoscopic radical prostatectomy. Initial experience. Eur Urol 2001;40:75–83.
16. Bentas W, Wolfram M, Jones J, et al. Robotic technology and the translation of open radical prostatectomy to laparoscopy: the early Frankfurt experience with robotic radical prostatectomy and one year follow-up. Eur Urol 2003;44:175–81.
17. Gettman MT, Hoznek A, Salomon L, et al. Laparoscopic radical prostatectomy: description of the extraperitoneal approach using the da Vinci robotic system. J Urol 2003;170(2 Pt 1):416–9.
18. Kaouk JH, Desai MM, Abreu SC, et al. Robotic assisted

laparoscopic sural nerve grafting during radical prostatectomy: initial experience. J Urol 2003;170:909–12.
19. Ahlering TE, Skarecky D, Lee D, Clayman RV. Successful transfer of open surgical skills to a laparoscopic environment using a robotic interface: initial experience with laparoscopic radical prostatectomy. J Urol 2003;170:1738–41.
20. Ahlering TE, Woo D, Eichel L, et al. Robot-assisted versus open radical prostatectomy: a comparison of one surgeon's outcomes. Urology 2004;63:819–22.
21. Tewari A, Srivasatava A, Menon M. A prospective comparison of radical retropubic and robot-assisted prostatectomy: experience in one institution. BJU Int 2003;92: 205–10.
22. Samadi DB, Nadu A, Olsson E, et al. Robot assisted laparoscopic radical prostatectomy—initial experience in eleven patients [abstract]. J Urol 2002;167:390.
23. Menon M, Tewari A. Robotic radical prostatectomy and the Vattikuti Urology Institute technique: an interim analysis of results and technical points. Vattikuti Institute Prostatectomy Team. Urology 2003;61(4 Suppl 1):15–20.
24. Tewari A, Peabody JO, Fischer M, et al. An operative and anatomic study to help in nerve sparing during laparoscopic and robotic radical prostatectomy. Eur Urol 2003; 43:444–54.
25. Lotan Y, Cadeddu JA, Gettman MT. The new economics of radical prostatectomy: cost comparison of open, laparoscopic and robot assisted techniques. J Urol 2004;172 (4 Pt 1):1431–5.