Robotic Surgery of the Kidney, Bladder, and Prostate

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KEYWORDS

• Robotic • Laparoscopic • Partial nephrectomy • Pyeloplasty • Cystectomy
• Prostatectomy

KEY POINTS

- Minimally invasive surgery offers many advantages over the traditional open approach, including improved cosmesis, reduced blood loss, decreased pain, shorter hospital stays, and improved convalescence.
- Robot-assisted surgery offers the advantages of a minimally invasive approach with greater technical ease and a shorter learning curve than pure laparoscopy.
- Fueled by the success of the robot-assisted laparoscopic prostatectomy, Urologists are increasingly using the robotic platform for other advanced operations involving the kidney, ureters, bladder, and prostate.
- Robotic surgery has been shown to be safe and effective, with good perioperative, functional, and oncologic outcomes.
- Although cost continues to be a major concern regarding the use of robotic technology, improved efficiency and reduced hospital stays associated with the minimally invasive approach are allowing for better cost-effectiveness.

INTRODUCTION

Robot-assisted laparoscopic surgery has been one of the most important recent technological advances in the practice of surgery. In particular, urology has a long-standing history of embracing advances in surgical technology and many urologic procedures have been replaced with more minimally invasive techniques, both endoscopic and laparoscopic, with the goal of reducing perioperative morbidity (**Table 1**). Advantages of the minimally invasive approach include increased precision, smaller incisions, reduced intraoperative blood loss, decreased postoperative pain, shorter hospital stays, and improved convalescence while preserving functional and

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Table 1
History of minimally invasive urologic surgery

Year	Description
1870	Simon: First open partial nephrectomy
1886	Trendelenburg: First reconstruction for ureteropelvic junction obstruction
1887	Bardenheuer: First open cystectomy performed
1900	Freyer: First open simple prostatectomy
1905	Young: First perineal prostatectomy
1947	Millin: First radical retropubic prostatectomy
1949	Marshall and Whitmore: First open radical cystectomy, pelvic lymphadenectomy described in detail
1949	Anderson and Hynes: First open dismembered pyeloplasty
1982	Walsh: First nerve-sparing open radical retropubic prostatectomy
1983	Arthrobot introduced for orthopedic procedures
1985	PUMA 560 introduced for computed tomography–guided brain biopsy
1988	ROBODOC introduced for hip arthroplasty
1988	PROBOT introduced for transurethral prostate surgery
1992	Schuessler: First laparoscopic radical prostatectomy
1992	Parra: First laparoscopic simple cystectomy
1993	Automated Endoscopic System for Optimal Positioning (AESOP) introduced
1993	Winfield: First laparoscopic partial nephrectomy
1993	Sanchez de Badajoz: First laparoscopic radical cystectomy
1993	Kavoussi and Schuessler: First laparoscopic pyeloplasty
1998	ZEUS and da Vinci Surgical Systems introduced
2000	Approval by the Food and Drug Administration of the da Vinci Surgical System for use in laparoscopic surgery
2000	Abbou: First robotic prostatectomy
2002	Mariano: First laparoscopic simple prostatectomy
2002	Gettman: First robotic pyeloplasty
2002	Menon: First robotic cystectomy
2003	Intuitive Surgical, Inc buys Computer Motion, Inc
2004	Gettman: First robotic partial nephrectomy
2008	Sotelo: First robotic simple prostatectomy

oncologic outcomes. Although standard laparoscopy has been shown to improve outcomes for some urologic surgeries, for example, radical nephrectomy, its adoption for reconstructive procedures has been limited due to the technical challenges and steep learning curves. In addition, traditional laparoscopy may be associated with losses of depth perception, intuitive movement, and dexterity. Robotic surgery with the da Vinci Surgical System (Intuitive Surgical, Inc, Sunnyvale, CA) has grown rapidly through its use in operations that benefit from a minimally invasive approach, but are technically challenging to perform with pure laparoscopy. The robotic system overcomes many of the limitations encountered in standard laparoscopy and offers a reduced learning curve. The advantages of robotic assistance were first noted in urology with the robot-assisted laparoscopic prostatectomy,[1,2] whose wide acceptance and popularity has led to other advanced robotic surgeries, in both adults and children, involving the kidney, ureter, bladder, and prostate (Table 2).

Table 2
Advantages and disadvantages of the open, laparoscopic, and robotic approach for partial nephrectomy, radical cystectomy, and radical prostatectomy

Procedure	Advantages	Disadvantages
Partial nephrectomy		
Open (OPN)	Gold standard with proven oncologic outcomes Shorter operative time Decreased cost	Larger incisions Increased perioperative morbidity Increased pain Longer hospitalization Longer recovery
Laparoscopic (LPN)	Enhanced visibility Decreased perioperative morbidity Decreased pain Shorter hospitalization Shorter recovery Improved cosmesis Equivalent oncologic outcomes compared with OPN	Increased cost compared with OPN Additional training required Prolonged learning curve/technically challenging Increased operative time
Robotic (RALPN)	(Same benefits seen with LPN) Enhanced visibility, dexterity, ergonomics, and precision Shorter learning curve/technical ease Decreased warm ischemia time Decreased blood loss Shorter hospitalization than LPN	$\pm$ Cost Additional training required Limited instrumentation No tactile feedback
Cystectomy		
Open (ORC)	Gold standard with proven oncologic outcomes	Increased blood loss Increased transfusion rate Increased time to return of bowel function Longer hospitalization High complication rate (particularly high-grade, Clavien 3–5)
Laparoscopic (LRC)	Enhanced visibility Improved cosmesis Equivalent oncologic/perioperative outcomes compared with ORC	Cost higher than ORC Additional training required Prolonged learning curve/technically challenging Increased operative time
Robotic (RARC)	(Same benefits seen with LRC) Enhanced visibility, dexterity, ergonomics, and precision Shorter learning curve/technical ease Decreased perioperative morbidity Decreased blood loss Decreased rate of transfusion Decreased time to return of bowel function Shorter hospitalization	Cost higher than ORC/LRC Additional training required Need for an experienced robotic team Limited instrumentation No tactile feedback Increased operative time Less long-term oncologic outcome data available

(*continued on next page*)

Table 2 (*continued*)

Procedure	Advantages	Disadvantages
Prostatectomy		
Open (ORP)	Long-term data with proven oncologic/functional outcomes	Increased blood loss Increased rate of transfusion Longer hospitalization Increased complication rate
Laparoscopic (LRP)	Enhanced visibility Decreased blood loss Shorter hospitalization Shorter recovery Improved cosmesis	Cost higher than ORP Additional training required Prolonged learning curve/technically challenging Increased operative time No clear benefit over ORP
Robotic (RALP)	(Same benefits seen with LRP) Enhanced visibility, dexterity, ergonomics, and precision Shorter learning curve/technical ease Decreased blood loss Decreased rate of transfusion Decreased perioperative morbidity Shorter hospitalization than LRP Equivalent oncologic/functional outcomes Earlier return of urinary continence Higher rate/faster recovery of potency	Cost higher than ORP/LRP Additional training required Limited instrumentation No tactile feedback

A BRIEF HISTORY OF SURGICAL ROBOTICS

The first surgical robot, known as Arthrobot, was developed in Canada in 1983 and designed to assist in orthopedic procedures. In 1985, the PUMA 560 (Unimate Robot Systems, Ewing Township, NJ) was used for computed tomography–guided brain biopsy. In 1988, orthopedic surgeons used a computer enhancement system called ROBODOC (Integrated Surgical Systems, Santa Monica, CA) to more precisely drill the femur during hip arthroplasty. The first surgical robot assistance seen in urology was in 1988 at Guy's and St. Thomas' Hospital in London with the use of PROBOT to perform transurethral prostate surgery. In 1993, the Automated Endoscopic System for Optimal Positioning (AESOP) (Computer Motion, Inc, Santa Barbara, CA) was released, a voice-activated robotic arm that aided in laparoscopic camera holding and positioning, allowing the surgeon to use both hands without the need of an assistant. The most significant advancements came in 1998 with the introduction of the ZEUS Robotic Surgical System by Computer Motion, Inc and the da Vinci Surgical System. The first da Vinci robot-assisted laparoscopic procedure was a cholecystectomy, performed by Drs Cadiere and Himpens in 1997. In July 2000, the da Vinci robot was given approval by the US Food and Drug Administration for use in laparoscopic procedures and the first reported robot-assisted laparoscopic prostatectomy took place in Paris. In 2003, Intuitive Surgical, Inc bought out Computer Motion, Inc and is currently the only company marketing robot-assisted surgical systems.[3,4]

THE DA VINCI SURGICAL SYSTEM

The da Vinci Surgical System has 3 components: a surgeon's console, a patient-side robotic cart with 4 robotic arms manipulated by the surgeon, and a high-definition

3-dimensional (3D) vision system. Articulating surgical instruments are mounted on the robotic arms, which are introduced into the body through cannulas.[5] Advantages of the robotic system include a stable operator-controlled camera, a magnified high-definition view, 3D stereo visualization through a 2-channel endoscope, improved dexterity with articulating EndoWrist instruments with 7° of freedom, motion scaling, and tremor filtration. These features allow for improved precision and fine dissection in a confined space, and allow for easier and more fluid control during reconstructive maneuvers such as intracorporeal suturing. Disadvantages of the robotic system include the lack of tactile feedback, the need to train additional staff, and increased cost associated with the robot, which includes an upfront purchase price of between $1.4 and $2.1 million, annual maintenance contract of $150,000, and additional disposable supply cost of at least $1500 per case. The value of robotic technology lies in balancing these costs with the improvement in patient care and outcomes relative to other surgical approaches.

ROBOTIC SURGERY OF THE KIDNEY AND URETER

Partial Nephrectomy

The incidence of renal tumors has been increasing over the past several decades with an annual incidence of approximately 61,500 cases and 14,000 deaths in the United States.[6] Due to advances in technology and increased use of cross-sectional imaging, most of these tumors are diagnosed at clinical stage T1 and are amenable to nephron-sparing surgery with partial nephrectomy. Nephron-sparing surgery (NSS) with renal preservation for small renal masses has equivalent oncologic outcomes to radical nephrectomy while lowering the risk of severe chronic kidney disease. Many studies have shown that renal insufficiency is associated with increased cardiovascular events, hospitalization, and mortality.[7] The European Organization for Research and Treatment of Cancer provided the first Level I evidence that long-term oncologic outcomes between partial nephrectomy and radical nephrectomy were equivalent, allowing partial nephrectomy to become a standard of care for small renal masses.[8] Open partial nephrectomy (OPN) was the gold standard for NSS, but it involves large abdominal or flank incisions, longer hospital stays, longer periods of convalescence, increased pain, and more perioperative morbidity.

Initially introduced by Winfield and colleagues[9] in 1993 for a patient with a calyceal diverticulum containing stone, laparoscopic partial nephrectomy (LPN) subsequently emerged as a viable alternative in the surgical management of small renal masses. Retrospective reviews and meta-analyses have shown that although OPN is associated with shorter operative time and decreased cost, minimally invasive partial nephrectomy offers decreased blood loss, lower complication rate, and shorter hospital stay.[10,11] However, many studies have discussed the prolonged learning curve associated with purely LPN, which has prevented its widespread adoption and relegated the technique to experienced laparoscopic surgeons. Furthermore, a population-based study by Abouassaly and colleagues[12] revealed that the introduction of laparoscopic renal surgery decreased the uptake and use of partial nephrectomy for renal cell carcinoma at least partially due to technical ease and decreased surgical morbidity with laparoscopic radical nephrectomy. Gettman and colleagues[13] first reported on the safety and feasibility of robot-assisted laparoscopic partial nephrectomy (RALPN) in 2004, offering the benefits of minimally invasive surgery with facilitation of the major surgical steps of the procedure (tumor dissection, renal reconstruction) and a shorter learning curve. The estimated learning curve for LPN with respect to operative time is 100 to 150 cases. On the other hand, RALPN has drastically shortened the learning curve to approximately 16 cases, with respect to operative time, and 26 cases for warm ischemia time.[10] Ellison and colleagues[14] found that ischemia, blood loss, and operative times improved after the first 33 cases. Kaouk and colleagues[15] showed that once the learning curve was overcome, there was a significant decrease in blood loss, transfusion rate, conversion rate, postoperative complication rate, mean operative time, and length of stay. Interestingly, the increased operative time associated with RALPN may pertain to the preparation and docking of the robot, with Masson-Lecomte and colleagues.[16] showing that actual “skin-to-skin” operative times demonstrated no significant difference. Additionally, when comparing pure LPN to RALPN, studies have found that RALPN offers decreased warm ischemia time, decreased blood loss, and shorter hospital stay with similar perioperative outcomes, complication rates, and oncologic control.[11,17–20]

In fact, the indications for RALPN have expanded to include more complex tumors such as lesions that are multifocal, endophytic, posterior, hilar, and bilateral, and masses larger than 7 cm, and within a solitary kidney. Studies have demonstrated the safety and feasibility of treating these challenging masses in select patients, using renal nephrometry scores to classify their complexity.[19,20] Anatomy-based nephrometry scoring systems allow for standardized academic reporting of tumor characteristics, precise patient-specific surgical planning, and can predict partial nephrectomy outcomes. These scores can inform the surgeon regarding the difficulty during partial nephrectomy for a given mass, and have been correlated with ischemia time, operative time, blood loss, complications, length of stay, and the likelihood of conversion to a radical nephrectomy. Furthermore, nephrometry scoring systems can assist in clinical decision-making on performing a radical nephrectomy versus partial nephrectomy or an open procedure versus a minimally invasive approach.[21]

Overall, the 2 surgical principles for optimizing postoperative functional outcomes following a partial nephrectomy are to maximize volume preservation and to minimize ischemia. Historically, a 1-cm rim of healthy parenchyma was recommended to allow for optimal oncologic control[22]; however, further study demonstrated that the width of the margin does not affect local control.[23] Thus, the width of the negative margin can be kept to a thin, uniform rim of normal parenchyma.[21] RALPN has been associated with equivalent oncologic outcomes when compared with the open and laparoscopic approaches.[10,11] Novel surgical approaches have been developed that reduce ischemic time during partial nephrectomy, including early unclamping, segmental clamping, tumor-specific clamping, and unclamped techniques.[19,21] These techniques may positively impact postoperative renal function, which relies on kidney quality, remnant quality, ischemia type, and the duration of ischemia.[21] Thompson and colleagues[24] examined the importance of warm ischemia time on postoperative renal function, reviewing 362 patients with a solitary kidney who underwent partial nephrectomy. They found that longer warm ischemia time was associated with acute renal failure in the postoperative period and with new-onset stage IV chronic kidney disease during follow-up. Furthermore, when evaluating warm ischemia time in 5-minute increments, a cutoff point of 25 minutes provided the best distinction between patients with and without postoperative renal consequences, leading the authors to conclude that “every minute counts when the renal hilum is clamped.”[24] One disadvantage of LPN is the prolonged warm ischemia time and subsequent renal dysfunction, secondary to the technical complexity of intracorporeal suturing. Robotic assistance, through improved dexterity and visualization, has significantly decreased the time for tumor resection and intracorporeal suturing, thus reducing warm ischemia time and leading to improved postoperative renal function.[19] Benway and colleagues[17] performed a multi-institutional analysis of perioperative outcomes following RAPN and LPN, finding that the robotic approach was associated with less intraoperative blood loss (155 vs 196 mL, $P = .03$), decreased hospital stay (2.4 vs 2.7 days, $P < .0001$), and shorter warm ischemia times (19.7 vs 28.4 minutes, $P < .0001$). Our single-center experience, with more than 300 RAPN using the early unclamping technique, has demonstrated an average warm ischemia time of 14.7 minutes. The postoperative complication rate has been 18% with only a 1% rate of severe complications. We have had 5 cases of delayed postoperative bleeding, presumably from arteriovenous fistulas, which all occurred after LPN using the standard technique in which early unclamping was not used.

When considering the various approaches to partial nephrectomy, particularly those involving robotic assistance, cost is an important issue. Yu and colleagues[25] analyzed the Nationwide Inpatient Sample and found that, although the costs associated with robotic surgery were higher for all other procedures studied, the median cost of partial nephrectomy did not vary significantly by approach ($15,724 for RALPN, $12401 for LPN, and $11,817 for OPN [$P = .442$]). Ferguson and colleagues[26] performed a direct-cost analysis that showed no difference in total cost between RALPN and LPN ($13,560 vs $13,439, $P = .29$). Laydner and colleagues[27] reported that the increased cost of RALPN due to instrumentation and supplies can be offset by the decreased cost of postoperative hospitalization and more rapid convalescence. However, it is important to note that in addition to the variable cost per case, the cost associated with RALPN is exacerbated when factoring in the acquisition cost of the robotic platform.[10] Alemozoffar and colleagues[28] similarly compared hospital costs of these approaches, factoring in variable costs, fixed costs, and length of hospital stay. The investigators found that the variable costs (operating room [OR] supplies, time, anesthesia, inpatient care) were similar, the OR supplies contributed a greater cost for the minimally invasive approaches, and the inpatient costs were higher for the OPN. They concluded that RALPN and LPN were less costly alternatives to OPN if maintenance costs were not included, the length of stay was $\leq$2 days, and operative time was $\leq$195 and 224 minutes, respectively. As the robotic procedure becomes more efficient and the robotic platform becomes more available and affordable, the differences in cost, previously thought to be a major disadvantage, are becoming more minimal.

Radical Nephrectomy

The advantages of laparoscopic kidney surgery have been apparent for the past 20 years, with numerous centers demonstrating shorter hospital stay, less blood loss, decreased narcotic use, and quicker return to normal activity when compared with open surgery.[29–31] The current recommendation from the European Association of Urology (EAU) for patients with clinical T2 renal tumors, who are not candidates for nephron-sparing surgery, is to undergo a laparoscopic radical nephrectomy, due to the benefits of lower morbidity compared with open nephrectomy.[32] However, because a radical nephrectomy is a purely extirpative procedure, the advantages of robotics (such as the ease of intracorporeal suturing and complex reconstructive maneuvers) are not necessarily beneficial in this setting. Therefore, the general consensus is that robotic assistance is unnecessary when performing a radical nephrectomy.

Gill and colleagues[33] first reported the feasibility of robotic radical nephrectomy (RRN) in the porcine model, followed by Talamini and colleagues[34] reporting the combined human experience of 4 institutions, demonstrating its safety and efficacy. Petros and colleagues[35] described their experience with 101 consecutive cases of RRN and concluded that robotic assistance allowed for consistent outcomes regardless of procedure complexity. However, the main disadvantages to using robotic assistance for radical nephrectomy is the cost of the procedure with no clearly demonstrated improved outcome or extended indications. In 2001, Guillonneau and colleagues[36] evaluated RRN and found the approach failed to demonstrate benefits over the traditional laparoscopic nephrectomy. A literature review by Asimakopoulos and colleagues[37] showed that although RRN is a safe, feasible, and oncologically effective surgical treatment for clinically localized renal cell carcinoma, there was no advantage of the robotic approach over standard laparoscopy and, in fact, the robotic platform added significant expense and operative time to the procedure. According to a study by Yang and colleagues,[38] compared with laparoscopic nephrectomy, RRN conferred $11,267 more in total charges and $4565 in hospital stay charges without improving patient morbidity. On the other hand, a recent application of robotics in the radical nephrectomy setting involves complex cases of renal vein and vena cava tumor thrombus. There have been small series describing complete vena cava control, tumor thrombus removal, and caval reconstruction using robotic assistance.[35,39] It is likely that, in the hands of very experienced robotic surgeons, this approach may become more commonplace. Until clear evidence supporting the superiority of RRN over less expensive extirpative modalities is gathered, laparoscopic nephrectomy will remain the gold standard for uncomplicated renal masses not amenable to NSS.

Pyeloplasty

Ureteropelvic junction obstruction (UPJO) is the most common congenital anomaly of the ureter and long-term success rates greater than 90% have been reported with the open dismembered pyeloplasty. In an effort to reduce the morbidity associated with the open approach, Kavoussi and Peters[40] and Schuessler and colleagues[41] described the first techniques for laparoscopic dismembered pyeloplasty in 1993. Two years later, Peters and colleagues[42] described the first pediatric laparoscopic pyeloplasty. More recently, robotic approaches have been found to be useful for procedures with a considerable amount of intracorporeal suturing and the first robotic pyeloplasty was described by Gettman and colleagues[43] in 2002.

Multiple series and meta-analyses of minimally invasive pyeloplasty, in adults and pediatric populations, demonstrate a low perioperative morbidity and high success rate.[44] Compared with traditional laparoscopy, robotic pyeloplasty offers reduced morbidity, shorter learning curve, enhanced tissue manipulation, and improved visualization.[44,45] The first reported series by Patel[46] emphasized the procedure's minimal morbidity and easy learning process. Furthermore, small series have examined the challenging scenario of secondary redo-robotic pyeloplasty and have shown it to be a feasible operation with good outcomes and acceptable complication rates. Literature comparing adult patients who underwent open pyeloplasty versus laparoscopic pyeloplasty shows that, although associated with a longer operative time, patients undergoing laparoscopic pyeloplasty required less pain medication and had a shorter length of stay. Bansal and colleagues[47] presented a randomized controlled study of patients undergoing open and laparoscopic pyeloplasty. The investigators found that operative time was shorter for the open pyeloplasty group (122 vs 244 minutes, $P<.01$), whereas pain medication requirement and length of hospital stay were decreased in the laparoscopic group (107.14 vs 682.35 mg diclofenac, $P<.01$); (3.1 vs 8.3 days, $P<.01$). When comparing laparoscopic pyeloplasty with robotic pyeloplasty, perioperative complication rates, diuretic scintigraphy-dependent success rates, and length of stay were found to be similar, whereas the operative time in many studies favored the robotic approach.[44,45] Hemal and colleagues[48] reviewed 60 cases of minimally invasive pyeloplasty and found that robotic pyeloplasty was associated with a significantly shorter operative time (98 vs 145 minutes) and equivalent long-term success rates compared with purely laparoscopic pyeloplasty. Overall, the studies suggest that laparoscopic pyeloplasty is a safe and effective minimally invasive approach to UPJO that offers reduced perioperative morbidity. When available, the robotic platform is quickly emerging as a new standard of care in the management of UPJO in adults, offering similar outcomes to the open and laparoscopic approach with increased precision and a shorter learning curve.

ROBOTIC SURGERY OF THE BLADDER

Radical Cystectomy

Bladder cancer is the fourth most commonly diagnosed malignancy in the United States, with an estimated 74,000 cases to be diagnosed in 2015 ultimately leading to 16,000 deaths.[6] Open radical cystectomy (ORC) with urinary diversion is the gold standard for patients with muscle-invasive bladder cancer and for those with high-risk recurrent non–muscle-invasive disease, providing effective long-term oncologic control and disease-free survival.[49] Despite a better understanding of pelvic anatomy and advances in surgical technique, radical cystectomy is still associated with a significant rate of perioperative complications (approximately 60%), with approximately half of these being high-grade complications (Clavien grade 3–5).[50] In an effort to reduce this morbidity, minimally invasive approaches, most notably laparoscopic and robotic, are being increasingly used. Parra and colleagues[51] first described a laparoscopic simple cystectomy in 1992. Using similar techniques, Sanchez de Badajoz and colleagues[52] reported the first laparoscopic radical cystectomy (LRC) the following year and several studies have supported its feasibility. However, this technically challenging procedure was not widely adopted. The first experience with robot-assisted laparoscopic radical cystectomy (RARC) was reported by Menon and colleagues[53] in 2003. More recently, several studies have demonstrated the feasibility of RARC and its use has steadily increased over the past decade.

Generally, ORC is associated with a high risk of complications and outcomes are associated with hospital and surgeon experience. Although randomized controlled trials and meta-analyses examining RARC have demonstrated decreased blood loss, transfusion rate, time to return of bowel function, and length of hospital stay, the mean operative time was increased. When compared with ORC, the postoperative complication rates, positive surgical margins (PSM), lymph node yield, and quality-of-life outcomes have been equivalent or slightly better for patients undergoing RARC. Nix and colleagues[54] compared patients undergoing ORC and RARC in a randomized controlled trial. Although the overall complication rate and mean hospital stay were not significantly different between the 2 groups, and the OR time was increased with RARC (4.2 vs 3.52 hours, $P<.0001$), the investigators found significant differences favoring the robotic group with regard to estimated blood loss (258 vs 575 mL, $P<.0001$), time to flatus (2.3 vs 3.2 days, $P = .0013$), time to bowel movement (3.2 vs 4.3 days, P .0008), and use of in-house morphine equivalent (89 vs 147 mg, $P = .0044$). Additionally, the mean number of lymph nodes removed from the RARC and ORC groups was 19 and 18, respectively, demonstrating the robotic approach to be noninferior to the open cystectomy. Parekh and colleagues[55] performed a pilot prospective randomized clinical trial comparing ORC and RARC. In their analysis, the 2 groups had no significant differences in oncologic outcomes, such as PSM or lymph node yield. The RARC group was noted to have a decreased estimated blood loss when compared with ORC (400 vs 800 mL). They also noted a trend in the RARC patients toward a decreased rate of excessive length of stay (greater than 5 days, 65% vs 90%, $P = .11$) and fewer transfusions (40% vs 50%, $P = .26$). Bochner and colleagues[56] performed the largest randomized prospective trial to date comparing patients undergoing ORC and RARC and found that RARC patients had a lower mean intraoperative blood loss (516 vs 676 mL, $P = .027$), but significantly longer operative time than the ORC group (456 vs 329 minutes, $P<.001$). Postoperative complications, mean hospital stay, quality-of-life outcomes, and pathologic variables, including PSM and lymph node yield, were similar between the groups. Furthermore, when comparing RARC and pure LRC, study has shown decreased transfusion and perioperative complication rates associated with RARC.[49,56–63] This is significant, as perioperative blood transfusion has been linked to perioperative morbidity and predictors of complications following RARC include age, ASA (American Society of Anesthesiologists score) score, Charlson comorbidity index, body mass index, and blood transfusion.[58,64,65] Although these data are encouraging, it is important to note that many studies may suffer from selection bias.

Measures of surgical quality for radical cystectomy include PSM rates and lymph node yields, both of which have implications for oncologic outcomes. A PSM affects local recurrence, increases the risk of metastatic progression, and decreases cancer-specific survival. The literature has demonstrated that rates of PSM between ORC and RARC are equivalent.[49,56,66] In addition, higher lymph node yields are associated with improved cancer-specific and overall survival. Herr and colleagues[67] described a significant increase in mortality in patients with node-positive disease if fewer than 11 lymph nodes were obtained at the time of ORC. Lymphadenectomy not only provides staging information, but is also considered potentially curative in patients with microscopic nodal metastases. Therefore, it is essential that an adequate lymph node dissection be performed at the time of cystectomy. Several studies have supported that an extended lymph node dissection is feasible with robotic assistance and with increasing experience comes improved lymph node yields, as experience is clearly a crucial factor.[49,56,63,66] Long-term study has shown that overall survival, cancer-specific survival, and recurrence-free survival rates following LRC and RARC are similar to that of ORC.[63,68]

An advantage of the robotic platform for many procedures is that it offers the benefits of minimally invasive surgery with the potential for a shortened learning curve. Whereas Pruthi and colleagues[69] failed to demonstrate a difference in perioperative outcomes among the first 50 cases of RARC with extracorporeal diversion, Hayn and colleagues[70] found significant improvements in mean operative time and lymph node yield for their first 164 cases (180 vs 136 minutes, $P<.001$); (16 vs 24 lymph nodes, $P<.001$). In addition, Richards and colleagues[60] demonstrated reduction in overall complication rate from 70% in their first 20 cases to 30% in the second and third 20 cases ($P = .013$). The International Robotic Cystectomy Consortium (IRCC) suggested that 20 operations are needed to reach a plateau operative time and 30 cases are needed to reach a lymph node count greater than 20.

Some have hypothesized that some of the postoperative complications from the procedure result from the significant amount of bowel manipulation during the reconstructive portion of the case, thus advocating for a totally intracorporeal approach. Currently, the vast majority of urinary diversions are performed extracorporeally with approximately 3% of patients undergoing a totally intracorporeal RARC.[71] High-volume centers are just beginning to accumulate data regarding this approach. However, to date, there appears to be no distinct advantage over the standard extracorporeal diversion. Results from the IRCC found similar overall complication rates, however there were significantly fewer gastrointestinal complications in the intracorporeal group (10% vs 23%).[72] Although RARC with intracorporeal diversion is a feasible operation with reasonable outcomes, it is a complex procedure that may be associated with initially increased operative times. Moreover, it really is feasible only when performed by a very experienced robotic team, often requiring multiple attending surgeons experienced in robotics and significant amount of preoperative planning. Thus, its applicability in most clinical settings is debatable. However, some investigators propose that operative time decreases with experience, and a totally intracorporeal approach enhances the benefits seen with minimally invasive techniques, further reducing perioperative morbidity.[59,63,72]

Differences observed in the cost of performing these cases continues to be an issue. Analyses show that for RARC with an ileal conduit, an additional average cost of $1740 was incurred compared with ORC, whereas RARC with an ileal neobladder adds an additional $3920. The additional costs associated with the robot were primarily related to OR costs (eg, robot, supplies, facilities) and physician costs.[56] Additionally, the difference in hospital stay did not appear to offset the additional costs of equipment and longer operative times associated with the robot. Alternatively, Martin and colleagues[73] found that when hospital costs, including length of stay, medications, transfusions, treatment of complications, and related 30-day readmissions were factored in, RARC was 60% less expensive than ORC. To truly identify the cost difference between these approaches, a well-designed randomized controlled trial is necessary comparing experienced robotic surgeons to equally experienced open surgeons.

ROBOTIC SURGERY OF THE PROSTATE

Radical Prostatectomy

Adenocarcinoma of the prostate is the most commonly diagnosed solid organ malignancy and the second-most common cause of cancer death in the United States, with an estimated 220,800 new cases leading to 27,540 deaths in 2015.[6] Because of prostate cancer screening, most prostate cancers are clinically localized at diagnosis. Despite a spectrum of therapeutic options being available, radical prostatectomy has been shown to offer improved overall and disease-specific survival across all D'Amico risk groups.[74] Open radical prostatectomy (ORP) was initially considered the gold standard for the surgical treatment of localized prostate cancer. Hugh Hampton Young performed the first perineal prostatectomy in 1905.[75] Terrence Milin performed the first radical retropubic prostatectomy in 1947.[76] Anatomic studies by Walsh and Donker more clearly established the vasculature, fascial planes, urethral sphincter, and neurovascular bundles and, using this information, Walsh[77] performed the first nerve-sparing radical retropubic prostatectomy in 1982.[77] The establishment of laparoscopy and growing success of less invasive treatment alternatives for prostate cancer led to the first laparoscopic radical prostatectomy (LRP), described by Schuessler and colleagues[78] in 1992. The investigators[78] described their initial series of 9 patients in 1997, stating that although LRP was feasible, it offered no clear advantage over ORP with regard to oncologic control, urinary continence, potency, length of stay, convalescence, and cosmetic result. In addition, operative times were significantly longer, averaging 9.4 hours.[78] Although LRP was thought by many to offer the advantages of minimally invasive surgery, including decreased blood loss and shorter length of stay, it was generally considered a challenging procedure because it involved 2-dimensional visualization, a counterintuitive nature that led to a steep learning curve, and required advanced laparoscopic skills to perform complex tasks such as intracorporeal suturing. These limitations prevented widespread use of the LRP by the average urologist. A dramatic change occurred in the management of prostate cancer, as well as the evolution of robotic surgery, when the first robot-assisted laparoscopic prostatectomy (RALP) was performed in 2000. The improved 3-dimensional visualization and jointed laparoscopic instruments made laparoscopic dissection technically easier, creating widespread surgeon and patient interest in minimally invasive prostatectomy. Binder and Kramer[1] described the first 10 RALP procedures and Menon and colleagues[2] published the first large series in the United States comparing the robotic and open approaches in 2002. These series and subsequent reports led to the widespread rapid acceptance of the RALP as a safe and efficacious treatment option for clinically localized prostate cancer. In fact, it is likely that more than 80% of all radical prostatectomies will be performed robotically by 2020.[79]

Investigators have studied the perioperative outcomes associated with RALP. The goal of minimally invasive surgery is to reduce postoperative morbidity and multiple meta-analyses have demonstrated that laparoscopic, particularly robot-assisted, prostatectomies were associated with significantly less operative blood loss, fewer transfusions, shorter hospital stay, and fewer intraoperative complications.[80–82] In addition to improved visualization and control of the dorsal venous complex, an advantage of the laparoscopic approach is the positive pressure created by the pneumoperitoneum, which results in a tamponade effect, reducing venous and capillary bleeding during the operation and decreased blood loss during the case. Trinh and colleagues[79] found that men who underwent RALP had a lower transfusion rate, were less likely to experience a perioperative complication, and had a decreased rate of prolonged length of stay than patients who underwent ORP. Similarly, an analysis of the Surveillance, Epidemiology, and End Results (SEER) Medicare data comparing RALP to ORP showed a lower rate of transfusion and lesser likelihood of prolonged length of stay.[83] Studies have shown that the postoperative pain experienced by those who undergo ORP and RALP is similar. This is partially because the infraumbilical midline muscle-splitting incision used for an ORP is generally less painful than those in the upper abdomen because of the latter's involvement with respiration.[75] On the other hand, Pierorazio and colleagues[84] evaluated a single-institution experience over a 20-year period and showed that those who underwent RALP were more likely to experience a prolonged length of stay, develop an ileus, have a urine leak, and require a blood transfusion when compared with ORP. This study had some significant biases, most importantly being the comparison of early experiences with minimally invasive surgery to that of seasoned open surgeons from Johns Hopkins. Additionally, Eastham[85] analyzed the SEER Medicare database and showed that postoperative morbidity was lower in patients who underwent their operation by very high-volume surgeons at very high-volume hospitals. These studies illustrate the importance of surgeon experience, hospital experience, and surgical approach in determining outcomes following prostatectomy. In studies from centers that specialize in RALP, significantly less blood loss and lower transfusion rates have been noted, although overall complication rates are similar in many centers.[86,87]

Oncologic control is the most important outcome in the surgical treatment of cancer. In addition to cancer-specific and overall mortality, biochemical recurrence (BCR) and the rate of PSM have been used as surrogate indicators to measure primary cancer control when evaluating different surgical approaches to prostate cancer. Interestingly, there are no randomized controlled trials assessing oncologic control between RALP and ORP. Furthermore, surgeon partiality and patient preference make performing a randomized controlled trial very difficult in the United States. Retrospective reviews from high-volume centers provide us with most of the data on the subject, although these studies may be limited by selection bias, may lack adequate power, and depend on the experience of one or a few skilled surgeons, so their findings may not be generalizable. Numerous centers have compared the rates of PSM and BCR between ORP and RALP and it is important to note that most studies have shown equivalent outcomes.[74,75] This may be partially attributable to adjustments in surgical technique over the years with regard to apical dissection and nerve-sparing, tailoring the dissection to the location and degree of cancer present.

Functional outcomes are also important in evaluating the surgical approach to prostate cancer. Urinary continence and erectile function are the 2 outcomes most affected after prostatectomy. Assessment of these outcomes is often challenging, as there is no consensus for their definition or management. With regard to urinary continence, commonly defined as requiring 0 to 1 pad per day, some studies have shown that robotic assistance has led to an earlier recovery of continence with at least equivalent long-term outcomes.[74,75,86] In their analysis comparing outcomes of patients undergoing ORP, LRP, and RALP, Frota and colleagues[88] reported continence rates of 90% to 92%, 82% to 96%, and 95% to 96%, respectively. In their largest reported ORP series, including 3477 patients, the investigators[88] describe an overall 93% continence rate. Reviewing 1300 patients undergoing LRP, Stolzenburg and colleagues[89] reported a continence rate of 68% at 3 months, 84% at 6 months, and 92% at 12-month follow-up. In their robotic series, Ahlering and colleagues[90] reported a continence rate of 88% at 12-month follow-up of 670 patients. Similarly, in each of their series of more than 1100 patients, Menon and colleagues[91] and Smith and colleagues[92] reported continence rates following RALP of 96% and 97%. Di Pierro and colleagues[93] compared continence rates between those undergoing ORP and RALP. The investigators[93] found improved 3-month continence after RALP compared with ORP (95% vs 83%, P = .003), although this difference was not significant at 12 months (89 vs 80%, P = .092). Tewari and colleagues[94] also found that patients who underwent RALP recovered urinary continence more quickly than those who underwent ORP (44 vs 160 days, P<.05). Geraerts and colleagues[95] examined continence rates in ORP and RALP patients at 1, 3, 6, and 12 months, only noting a significant difference at 1 month. At 12 months, the continence rates were 96% and 97%, respectively, although the time to continence was significantly shorter in the RALP group (16 vs 46 days, P = .026). Numerous operative techniques have been developed to improve urinary control by reducing injury to the urinary sphincter mechanism and preserving urinary continence. Ramirez and colleagues[74] reviewed some of these technical adjustments, including bladder neck preservation, periurethral suspension, periurethral reconstruction, preservation of urethral length, preservation of the puboprostatic ligaments and endopelvic fascia, and use of locoregional hypothermia.

In 1983, Walsh and Mostwin[77] described the nerve-sparing technique during ORP to improve erectile function postoperatively. They demonstrated that erectile dysfunction following a prostatectomy was secondary to injury of the neurovascular bundles on the posterolateral aspect of the prostate. The robotic platform, as well as improvement in our understanding of pelvic neuroanatomy, has allowed for many adjustments in prostatic dissection with the goal of improving postoperative potency rates. Robotic nerve-sparing using the Vattikuti Institute technique with preservation of the "veil of Aphrodite" and lateral prostatic fascia was first described by Menon and colleagues[2] in 2002. Tewari and colleagues[96] developed a grading system to assess the degree of nerve-sparing and performed retrospective validation of the technique. Additionally, use of athermal dissection and traction-free techniques avoids destruction of the nerve and nerve sheath, improving recovery and functional outcomes. Maximal nerve-sparing can be achieved by following the plane between the prostatic capsule and the multilayer tissue of the prostatic fascia, which is recommended for sexually active and functional men without comorbidities and limited-risk disease. Partial nerve-sparing, obtained by following the planes within the multilayer tissue of the prostatic fascia, is recommended for preoperatively potent men without comorbidities and localized intermediate or high-risk disease. Finally, those patients with significant erectile dysfunction, no interest in sexual activity, or a high suspicion of extraprostatic disease should undergo a non–nerve-sparing operation.[97] It is important to keep in mind that one must balance improvement in postoperative erectile function with maintaining oncologic control. A review by Ficarra and colleagues[98] showed that for patients undergoing an RALP, the predictors of postoperative potency were age, baseline erectile function, and the presence of comorbidities. Some studies examining erectile function after prostatectomy have found a higher potency rate at 12 months for patients who underwent an RALP when compared with those who underwent ORP. In a cumulative analysis of multiple single-institution studies comparing potency rates following radical prostatectomy, the 12-month potency was 52.2% after ORP and 75.8% after RALP (P = .02).[86] Furthermore, Tewari and colleagues[94] found a shorter time to potency recovery after RALP than after ORP (180 vs 440 days, P<.05); however, it is important to note that these are retrospective studies at single tertiary institutions, using definitions of potency that are often not agreed on, and evaluated patients who underwent an ideal, bilateral nerve-sparing procedure, making comparison with ORP challenging. Therefore, when comparing the outcomes of RALP experts to ORP experts, the sexual function outcomes are likely comparable and largely dependent on the expertise of the surgeon.[85]

The learning curve for RALP has been studied extensively. Continued experience and technical refinements of the procedure lead to improved operative parameters and outcomes. Menon and colleagues[2] and Ahlering and colleagues[99] demonstrated the successful transfer of open surgical skills to the robotic platform, and were able to accomplish comparable surgical times in 18 cases and 12 cases, respectively. Similarly, Patel and colleagues,[100] with fellowship training in laparoscopy, reported comparable surgical times and a learning curve of approximately 20 to 25 cases. In addition, Badani and colleagues[101] examined their experience with RALP over a 6-year period (2766 cases), comparing their first 200 cases to the most recent 200 cases. The investigators[101] noted that the mean console time decreased by 19% (121 vs 97 minutes, P<.05), despite a 100% increase in previous abdominal surgery history that frequently required adhesiolysis and an increase in the proportion of patients with intermediate-risk and high-risk disease. The investigators[101] also showed a decline in the PSM rates in the more recent cohort, attributed to increased experience of the technical aspects of the robotic surgery, growing familiarity of the laparoscopic anatomy, and developments in the pathologic reporting and processing. On the other hand, the learning curve for LRP is significantly longer, requiring 40 to 60 cases for an experienced laparoscopist and 80 to 100 cases for a laparoscopically naïve surgeon, clearly demonstrating that the robotic platform significantly shortens the learning curve for the minimally invasive prostatectomy.[102–104]

Cost is considered one of the main disadvantages to the robot-assisted approach to prostatectomy. Even when considering the possible shorter hospital stay, RALP is still more expensive than ORP. Lotan and colleagues[105] reported that the ORP had a cost advantage of approximately $487 over the LRP, and $1726 over the RALP. However, recent cost-effective analyses of RALP have indicated that cost equivalence may be achieved between ORP and RALP at high-volume centers where 10 or more cases are performed per week.[103]

Simple Prostatectomy

Benign prostatic hyperplasia (BPH) is a highly prevalent condition among older men, affecting nearly 6.5 million white men aged 50 to 79 years in the United States and 1.1 billion men worldwide.[106,107] Although the most common forms of treatment for symptomatic BPH include watchful waiting, oral medications, and minimally invasive endoscopic surgery such as the transurethral resection of prostate (TURP), open simple prostatectomy (OSP) is considered a standard for patients with larger glands (>80 mL). The operation involves surgical enucleation of the BPH adenoma and has demonstrated improved outcomes with respect to International Prostate Symptom Score (IPSS), urinary flow, quality of life, and postvoid residual (PVR).[108] However, although the open operation may be more effective than medical therapy or a TURP, it can be associated with substantial risks of bleeding, transfusion, prolonged hospital stay, and other complications. Over the past decade, studies have shown that a minimally invasive approach to simple prostatectomy, particularly robot-assisted simple prostatectomy (RASP), may be a viable alternative for these patients.[109–111]

In 1900, Peter Freyer described the first open simple transvesical prostatectomy for BPH.[112] Several decades later, Terrence Millin introduced an effective transcapsular technique.[113] Medical therapy has since refined the indications for surgery and advances in surgical technique have reduced the incidence of perioperative complications and improved long-term functional outcomes.[109] Mariano and colleagues[114] reported the first laparoscopic simple prostatectomy in 2002. With advancements in robotic technology and growing experience with the RALP, Sotelo and colleagues[115] reported the first RASP in 2008, demonstrating that it was a feasible and reproducible procedure with an acceptable complication rate.

There have been several published series on RASP, which have shown it to be consistently associated with improved cosmesis, longer operative times, lower rates of complications, fewer transfusions, and decreased hospital stay when compared with OSP.[111,116] Serretta and colleagues[117] examined 1804 patients who underwent OSP and reported severe bleeding in 11.6%, blood transfusions in 8.2%, sepsis in 8.6%, median hospital stay of 7 days, and reintervention within 2 years (mainly from bladder neck stenosis) in 3.6% of patients. Similarly, Varkarakis and colleagues[118] reported a transfusion rate of 6.8% in the 232 cases of OSP they reviewed. Gratzke and colleagues[119] analyzed the perioperative outcomes of 902 patients undergoing OSP, reporting a mean operative time of 80.8 minutes, overall complication rate of 17.3%, bleeding requiring transfusion in 7.5%, urinary tract infection in 5.1%, and surgical revision due to severe bleeding in 3.7% of patients. The same benefits of the robotic platform observed in RALP (improved visualization, ergonomics, dexterity, and learning curve) also apply to the RASP, resulting in improved outcomes. In 2015, Autorino and colleagues[120] reviewed the outcomes of 1330 consecutive minimally invasive simple prostatectomy cases, including 843 laparoscopic simple prostatectomies and 487 RASP cases. For patients undergoing a RASP, the investigators[120] reported a median operative time of 154.5 minutes, median estimated blood loss of 200 mL, transfusion requirement in 3.5%, median length of stay of 2 days, and overall postoperative complication rate of 16.6% (mostly low-grade, Clavien 1–2). In addition, cost analysis by Matei and colleagues[121] revealed that charges incurred for RASP were 30% less than those for OSP, largely owing to the decreased hospital stay. Although long-term comparative studies to alternative treatment modalities have yet to be published, short-term efficacy outcomes, including IPSS, urinary flow, and resolution of urinary retention and infections have been comparable to published series of OSP.[111,116] RASP has been shown to be a safe and effective treatment option, with improved perioperative outcomes and cost, for the management of symptomatic BPH in patients who are otherwise candidates for OSP.

SUMMARY

As robotic technology continues to evolve, there is likely to be a continued shift in the management of urologic diseases. Innovation has led to improved outcomes while maintaining well-established surgical principles. The robotic platform offers the advantages of minimally invasive surgery with a decreased learning curve compared with the purely laparoscopic approach. Because much of the data we have today are based on retrospective reviews and meta-analyses with inherent limitations, there is a need for further prospective, multicenter, long-term randomized controlled trials. With increased surgeon experience and improved cost-effectiveness, the robot will be increasingly used for complex procedures. It is important to note that although the benefits seen with this technology are very encouraging, long-term surgical outcomes result from a combination of surgeon experience, technique, and operative approach.

REFERENCES

1. Binder J, Kramer W. Robotically-assisted laparoscopic radical prostatectomy. BJU Int 2001;87:408–10.
2. Menon M, Shrivastava A, Tewari A, et al. Laparoscopic and robot assisted radical prostatectomy: establishment of a structured program and preliminary analysis of outcomes. J Urol 2002;168:945–9.
3. Ng AT, Tam PC. Current status of robot-assisted surgery. Hong Kong Med J 2014;20:241–50.
4. Jain S, Gautam G. Robotics in urologic oncology. J Minim Access Surg 2015; 11:40–4.
5. Intuitive Surgical. da Vinci Surgical System. Intuitive Surgical, Inc. 2015. Available at: www.intuitivesurgical.com/products/davinci_surgical_system/. Accessed March 22, 2016.
6. Siegel RL, Miller KD, Jemal A. Cancer statistics. CA Cancer J Clin 2015; 2015(65):5–29.
7. Go AS, Chertow GM, Fan D, et al. Chronic kidney disease and the risks of death, cardiovascular events, and hospitalization. N Engl J Med 2004;351:1296–305.
8. Van Poppel H, Becker F, Cadeddu JA, et al. Treatment of localised renal cell carcinoma. Eur Urol 2011;60:662–72.
9. Winfield HN, Donovan JF, Godet AS, et al. Laparoscopic partial nephrectomy: initial case report for benign disease. J Endourol 1993;7:521–6.
10. Laviana AA, Hu JC. Current controversies and challenges in robotic-assisted, laparoscopic, and open partial nephrectomies. World J Urol 2014;32:591–6.
11. Wu Z, Li M, Liu B, et al. Robotic versus open partial nephrectomy: a systematic review and meta-analysis. PLoS One 2014;9:e94878.
12. Abouassaly R, Alibhai SM, Tomlinson G, et al. Unintended consequences of laparoscopic surgery on partial nephrectomy for kidney cancer. J Urol 2010; 183:467–72.
13. Gettman MT, Blute ML, Chow GK, et al. Robotic-assisted laparoscopic partial nephrectomy: technique and initial clinical experience with DaVinci robotic system. Urology 2004;64:914–8.
14. Ellison JS, Montgomery JS, Wolf JS Jr, et al. A matched comparison of perioperative outcomes of a single laparoscopic surgeon versus a multisurgeon robot-assisted cohort for partial nephrectomy. J Urol 2012;188:45–50.

15. Kaouk JH, Hillyer SP, Autorino R, et al. 252 robotic partial nephrectomies: evolving renorrhaphy technique and surgical outcomes at a single institution. Urology 2011;78:1338–44.
16. Masson-Lecomte A, Yates DR, Hupertan V, et al. A prospective comparison of the pathologic and surgical outcomes obtained after elective treatment of renal cell carcinoma by open or robot-assisted partial nephrectomy. Urol Oncol 2013;31:924–9.
17. Benway BM, Bhayani SB, Rogers CG, et al. Robot assisted partial nephrectomy versus laparoscopic partial nephrectomy for renal tumors: a multi-institutional analysis of perioperative outcomes. J Urol 2009;182:866–72.
18. Wang AJ, Bhayani SB. Robotic partial nephrectomy versus laparoscopic partial nephrectomy for renal cell carcinoma: single-surgeon analysis of >100 consecutive procedures. Urology 2009;73:306–10.
19. Wang L, Lee BR. Robotic partial nephrectomy: current technique and outcomes. Int J Urol 2013;20:848–59.
20. Bi L, Zhang C, Li K, et al. Robotic partial nephrectomy for renal tumors larger than 4 cm: a systematic review and meta-analysis. PLoS One 2013;8:e75050.
21. Klatte T, Ficarra V, Gratzke C, et al. A literature review of renal surgical anatomy and surgical strategies for partial nephrectomy. Eur Urol 2015;68:980–92.
22. Uzzo RG, Novick AC. Nephron sparing surgery for renal tumors: indications, techniques and outcomes. J Urol 2001;166:6–18.
23. Sutherland SE, Resnick MI, Maclennan GT, et al. Does the size of the surgical margin in partial nephrectomy for renal cell cancer really matter? J Urol 2002;167:61–4.
24. Thompson RH, Lane BR, Lohse CM, et al. Every minute counts when the renal hilum is clamped during partial nephrectomy. Eur Urol 2010;58:340–5.
25. Yu HY, Hevelone ND, Lipsitz SR, et al. Use, costs and comparative effectiveness of robotic assisted, laparoscopic and open urological surgery. J Urol 2012;187:1392–8.
26. Ferguson JE 3rd, Goyal RK, Raynor MC, et al. Cost analysis of robot-assisted laparoscopic versus hand-assisted laparoscopic partial nephrectomy. J Endourol 2012;26:1030–7.
27. Laydner H, Isac W, Autorino R, et al. Single institutional cost analysis of 325 robotic, laparoscopic, and open partial nephrectomies. Urology 2013;81:533–8.
28. Alemozaffar M, Chang SL, Kacker R, et al. Comparing costs of robotic, laparoscopic, and open partial nephrectomy. J Endourol 2013;27:560–5.
29. Kavoussi LR, Kerbl K, Capelouto CC, et al. Laparoscopic nephrectomy for renal neoplasms. Urology 1993;42:603–9.
30. Clayman RV, Kavoussi LR, Soper NJ, et al. Laparoscopic nephrectomy: initial case report. J Urol 1991;146:278–82.
31. Dunn MD, Portis AJ, Shalhav AL, et al. Laparoscopic versus open radical nephrectomy: a 9-year experience. J Urol 2000;164:1153–9.
32. Ljungberg B, Bensalah K, Canfield S, et al. EAU guidelines on renal cell carcinoma: 2014 update. Eur Urol 2015;67:913–24.
33. Gill IS, Sung GT, Hsu TH, et al. Robotic remote laparoscopic nephrectomy and adrenalectomy: the initial experience. J Urol 2000;164:2082–5.
34. Talamini MA, Chapman S, Horgan S, et al. A prospective analysis of 211 robotic-assisted surgical procedures. Surg Endosc 2003;17:1521–4.
35. Petros FG, Angell JE, Abaza R. Outcomes of robotic nephrectomy including highest-complexity cases: largest series to date and literature review. Urology 2015;85:1352–8.

36. Guillonneau B, Jayet C, Tewari A, et al. Robot assisted laparoscopic nephrectomy. J Urol 2001;166:200–1.
37. Asimakopoulos AD, Miano R, Annino F, et al. Robotic radical nephrectomy for renal cell carcinoma: a systematic review. BMC Urol 2014;14:75.
38. Yang DY, Monn MF, Bahler CD, et al. Does robotic assistance confer an economic benefit during laparoscopic radical nephrectomy? J Urol 2014;192:671–6.
39. Abaza R. Robotic surgery and minimally invasive management of renal tumors with vena caval extension. Curr Opin Urol 2011;21:104–9.
40. Kavoussi LR, Peters CA. Laparoscopic pyeloplasty. J Urol 1993;150:1891–4.
41. Schuessler WW, Grune MT, Tecuanhuey LV, et al. Laparoscopic dismembered pyeloplasty. J Urol 1993;150:1795–9.
42. Peters CA, Schlussel RN, Retik AB. Pediatric laparoscopic dismembered pyeloplasty. J Urol 1995;153:1962–5.
43. Gettman MT, Neururer R, Bartsch G, et al. Anderson-Hynes dismembered pyeloplasty performed using the da Vinci robotic system. Urology 2002;60:509–13.
44. Autorino R, Eden C, El-Ghoneimi A, et al. Robot-assisted and laparoscopic repair of ureteropelvic junction obstruction: a systematic review and meta-analysis. Eur Urol 2014;65:430–52.
45. Ekin RG, Celik O, Ilbey YO. An up-to-date overview of minimally invasive treatment methods in ureteropelvic junction obstruction. Cent European J Urol 2015;68:245–51.
46. Patel V. Robotic-assisted laparoscopic dismembered pyeloplasty. Urology 2005;66:45–9.
47. Bansal P, Gupta A, Mongha R, et al. Laparoscopic versus open pyeloplasty: comparison of two surgical approaches—a single centre experience of three years. Indian J Surg 2011;73:264–7.
48. Hemal AK, Mukherjee S, Singh K. Laparoscopic pyeloplasty versus robotic pyeloplasty for ureteropelvic junction obstruction: a series of 60 cases performed by a single surgeon. Can J Urol 2010;17:5012–6.
49. Tang K, Xia D, Li H, et al. Robotic vs. open radical cystectomy in bladder cancer: a systematic review and meta-analysis. Eur J Surg Oncol 2014;40:1399–411.
50. Shabsigh A, Korets R, Vora KC, et al. Defining early morbidity of radical cystectomy for patients with bladder cancer using a standardized reporting methodology. Eur Urol 2009;55:164–74.
51. Parra RO, Andrus CH, Jones JP, et al. Laparoscopic cystectomy: initial report on a new treatment for the retained bladder. J Urol 1992;148:1140–4.
52. Sanchez de Badajoz E, Gallego Perales JL, Reche Rosado A, et al. Radical cystectomy and laparoscopic ileal conduit. Arch Esp Urol 1993;46:621–4 [in Spanish].
53. Menon M, Hemal AK, Tewari A, et al. Nerve-sparing robot-assisted radical cystoprostatectomy and urinary diversion. BJU Int 2003;92:232–6.
54. Nix J, Smith A, Kurpad R, et al. Prospective randomized controlled trial of robotic versus open radical cystectomy for bladder cancer: perioperative and pathologic results. Eur Urol 2010;57:196–201.
55. Parekh DJ, Messer J, Fitzgerald J, et al. Perioperative outcomes and oncologic efficacy from a pilot prospective randomized clinical trial of open versus robotic assisted radical cystectomy. J Urol 2013;189:474–9.

56. Bochner BH, Dalbagni G, Sjoberg DD, et al. Comparing open radical cystectomy and robot-assisted laparoscopic radical cystectomy: a randomized clinical trial. Eur Urol 2015;67:1042–50.
57. Orvieto MA, DeCastro GJ, Trinh QD, et al. Oncological and functional outcomes after robot-assisted radical cystectomy: critical review of current status. Urology 2011;78:977–84.
58. Novara G, Catto JW, Wilson T, et al. Systematic review and cumulative analysis of perioperative outcomes and complications after robot-assisted radical cystectomy. Eur Urol 2015;67:376–401.
59. Collins JW, Wiklund NP. Totally intracorporeal robot-assisted radical cystectomy: optimizing total outcomes. BJU Int 2014;114:326–33.
60. Richards KA, Kader K, Hemal AK. Robotic radical cystectomy: where are we today, where will we be tomorrow? ScientificWorldJournal 2010;10:2215–27.
61. Aboumohamed AA, Raza SJ, Al-Daghmin A, et al. Health-related quality of life outcomes after robot-assisted and open radical cystectomy using a validated bladder-specific instrument: a multi-institutional study. Urology 2014;83:1300–8.
62. Ishii H, Rai BP, Stolzenburg JU, et al. Robotic or open radical cystectomy, which is safer? A systematic review and meta-analysis of comparative studies. J Endourol 2014;28:1215–23.
63. Patel R, Szymaniak J, Radadia K, et al. Controversies in robotics: open versus robotic radical cystectomy. Clin Genitourin Cancer 2015;13:421–7.
64. Bostrom PJ, Kossi J, Laato M, et al. Risk factors for mortality and morbidity related to radical cystectomy. BJU Int 2009;103:191–6.
65. Lowrance WT, Rumohr JA, Chang SS, et al. Contemporary open radical cystectomy: analysis of perioperative outcomes. J Urol 2008;179:1313–8 [discussion: 1318].
66. Liss MA, Kader AK. Robotic-assisted laparoscopic radical cystectomy: history, techniques and outcomes. World J Urol 2013;31:489–97.
67. Herr HW, Bochner BH, Dalbagni G, et al. Impact of the number of lymph nodes retrieved on outcome in patients with muscle invasive bladder cancer. J Urol 2002;167:1295–8.
68. Snow-Lisy DC, Campbell SC, Gill IS, et al. Robotic and laparoscopic radical cystectomy for bladder cancer: long-term oncologic outcomes. Eur Urol 2014;65:193–200.
69. Pruthi RS, Smith A, Wallen EM. Evaluating the learning curve for robot-assisted laparoscopic radical cystectomy. J Endourol 2008;22:2469–74.
70. Hayn MH, Hellenthal NJ, Seixas-Mikelus SA, et al. Is patient outcome compromised during the initial experience with robot-assisted radical cystectomy? Results of 164 consecutive cases. BJU Int 2011;108:882–7.
71. Smith AB, Raynor M, Amling CL, et al. Multi-institutional analysis of robotic radical cystectomy for bladder cancer: perioperative outcomes and complications in 227 patients. J Laparoendosc Adv Surg Tech A 2012;22:17–21.
72. Ahmed K, Khan SA, Hayn MH, et al. Analysis of intracorporeal compared with extracorporeal urinary diversion after robot-assisted radical cystectomy: results from the International Robotic Cystectomy Consortium. Eur Urol 2014;65:340–7.
73. Martin AD, Nunez RN, Castle EP. Robot-assisted radical cystectomy versus open radical cystectomy: a complete cost analysis. Urology 2011;77:621–5.
74. Ramirez D, Zargar H, Caputo P, et al. Robotic-assisted laparoscopic prostatectomy: an update on functional and oncologic outcomes, techniques, and advancements in technology. J Surg Oncol 2015;112(7):746–52.

75. Finkelstein J, Eckersberger E, Sadri H, et al. Open versus laparoscopic versus robot-assisted laparoscopic prostatectomy: the European and US experience. Rev Urol 2010;12:35–43.
76. Perrier C. Mes premières prostatectomies rétropubiennes (opération de Millin). Praxis 1947;36:315.
77. Walsh PC, Mostwin JL. Radical prostatectomy and cystoprostatectomy with preservation of potency. Results using a new nerve-sparing technique. Br J Urol 1984;56:694–7.
78. Schuessler WW, Schulam PG, Clayman RV, et al. Laparoscopic radical prostatectomy: initial short-term experience. Urology 1997;50:854–7.
79. Trinh QD, Sammon J, Sun M, et al. Perioperative outcomes of robot-assisted radical prostatectomy compared with open radical prostatectomy: results from the nationwide inpatient sample. Eur Urol 2012;61:679–85.
80. Parsons JK, Bennett JL. Outcomes of retropubic, laparoscopic, and robotic-assisted prostatectomy. Urology 2008;72:412–6.
81. Coelho RF, Rocco B, Patel MB, et al. Retropubic, laparoscopic, and robot-assisted radical prostatectomy: a critical review of outcomes reported by high-volume centers. J Endourol 2010;24:2003–15.
82. Tewari A, Sooriakumaran P, Bloch DA, et al. Positive surgical margin and perioperative complication rates of primary surgical treatments for prostate cancer: a systematic review and meta-analysis comparing retropubic, laparoscopic, and robotic prostatectomy. Eur Urol 2012;62:1–15.
83. Gandaglia G, Sammon JD, Chang SL, et al. Comparative effectiveness of robot-assisted and open radical prostatectomy in the postdissemination era. J Clin Oncol 2014;32:1419–26.
84. Pierorazio PM, Mullins JK, Ross AE, et al. Trends in immediate perioperative morbidity and delay in discharge after open and minimally invasive radical prostatectomy (RP): a 20-year institutional experience. BJU Int 2013;112:45–53.
85. Eastham JA. Do high-volume hospitals and surgeons provide better care in urologic oncology? Urol Oncol 2009;27:417–21.
86. Eifler JB, Cookson MS. Best evidence regarding the superiority or inferiority of robot-assisted radical prostatectomy. Urol Clin North Am 2014;41:493–502.
87. Raynor MC, Pruthi RS. Robot-assisted surgery: applications in urology. Open Access J Urol 2010;2:85–9.
88. Frota R, Turna B, Barros R, et al. Comparison of radical prostatectomy techniques: open, laparoscopic and robotic assisted. Int Braz J Urol 2008;34:259–68 [discussion: 268–9].
89. Stolzenburg JU, Rabenalt R, Do M, et al. Endoscopic extraperitoneal radical prostatectomy: the University of Leipzig experience of 1,300 cases. World J Urol 2007;25:45–51.
90. Ahlering TE, Gordon A, Morales B, et al. Preserving continence during robotic prostatectomy. Curr Urol Rep 2013;14(1):52–8.
91. Menon M, Shrivastava A, Kaul S, et al. Vattikuti Institute prostatectomy: contemporary technique and analysis of results. Eur Urol 2007;51:648–57 [discussion: 657–8].
92. Smith JA Jr, Chan RC, Chang SS, et al. A comparison of the incidence and location of positive surgical margins in robotic assisted laparoscopic radical prostatectomy and open retropubic radical prostatectomy. J Urol 2007;178:2385–9 [discussion: 2389–90].

93. Di Pierro GB, Baumeister P, Stucki P, et al. A prospective trial comparing consecutive series of open retropubic and robot-assisted laparoscopic radical prostatectomy in a centre with a limited caseload. Eur Urol 2011;59:1–6.
94. Tewari A, Srivasatava A, Menon M. Members of the VIPT. A prospective comparison of radical retropubic and robot-assisted prostatectomy: experience in one institution. BJU Int 2003;92:205–10.
95. Geraerts I, Van Poppel H, Devoogdt N, et al. Prospective evaluation of urinary incontinence, voiding symptoms and quality of life after open and robot-assisted radical prostatectomy. BJU Int 2013;112:936–43.
96. Tewari AK, Srivastava A, Huang MW, et al. Anatomical grades of nerve sparing: a risk-stratified approach to neural-hammock sparing during robot-assisted radical prostatectomy (RARP). BJU Int 2011;108:984–92.
97. Montorsi F, Wilson TG, Rosen RC, et al. Best practices in robot-assisted radical prostatectomy: recommendations of the Pasadena Consensus Panel. Eur Urol 2012;62:368–81.
98. Ficarra V, Novara G, Ahlering TE, et al. Systematic review and meta-analysis of studies reporting potency rates after robot-assisted radical prostatectomy. Eur Urol 2012;62:418–30.
99. Ahlering TE, Skarecky D, Lee D, et al. 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.
100. Patel VR, Tully AS, Holmes R, et al. Robotic radical prostatectomy in the community setting–the learning curve and beyond: initial 200 cases. J Urol 2005;174:269–72.
101. Badani KK, Kaul S, Menon M. Evolution of robotic radical prostatectomy: assessment after 2766 procedures. Cancer 2007;110:1951–8.
102. Ahlering TE. Robotic versus laparoscopic radical prostatectomy. Nat Clin Pract Urol 2004;1:58–9.
103. Patel HR, Linares A, Joseph JV. Robotic and laparoscopic surgery: cost and training. Surg Oncol 2009;18:242–6.
104. Guillonneau B, el-Fettouh H, Baumert H, et al. Laparoscopic radical prostatectomy: oncological evaluation after 1,000 cases at Montsouris Institute. J Urol 2003;169:1261–6.
105. Lotan Y, Cadeddu JA, Gettman MT. The new economics of radical prostatectomy: cost comparison of open, laparoscopic and robot assisted techniques. J Urol 2004;172:1431–5.
106. Wei JT, Calhoun E, Jacobsen SJ. Urologic diseases in America project: benign prostatic hyperplasia. J Urol 2008;179:S75–80.
107. Irwin DE, Kopp ZS, Agatep B, et al. Worldwide prevalence estimates of lower urinary tract symptoms, overactive bladder, urinary incontinence and bladder outlet obstruction. BJU Int 2011;108:1132–8.
108. Ou R, You M, Tang P, et al. A randomized trial of transvesical prostatectomy versus transurethral resection of the prostate for prostate greater than 80 mL. Urology 2010;76:958–61.
109. Lucca I, Shariat SF, Hofbauer SL, et al. Outcomes of minimally invasive simple prostatectomy for benign prostatic hyperplasia: a systematic review and meta-analysis. World J Urol 2015;33:563–70.
110. Banapour P, Patel N, Kane CJ, et al. Robotic-assisted simple prostatectomy: a systematic review and report of a single institution case series. Prostate Cancer Prostatic Dis 2014;17:1–5.

111. Patel ND, Parsons JK. Robotic-assisted simple prostatectomy: is there evidence to go beyond the experimental stage? Curr Urol Rep 2014;15:443.
112. Freyer PJ. A new method of performing perineal prostatectomy. Br Med J 1900; 1:698–9.
113. Millin T. The surgery of prostatic obstructions. Ir J Med Sci 1947;(257):185–9.
114. Mariano MB, Graziottin TM, Tefilli MV. Laparoscopic prostatectomy with vascular control for benign prostatic hyperplasia. J Urol 2002;167:2528–9.
115. Sotelo R, Clavijo R, Carmona O, et al. Robotic simple prostatectomy. J Urol 2008;179:513–5.
116. Sosnowski R, Borkowski T, Chlosta P, et al. Endoscopic simple prostatectomy. Cent European J Urol 2014;67:377–84.
117. Serretta V, Morgia G, Fondacaro L, et al. Open prostatectomy for benign prostatic enlargement in southern Europe in the late 1990s: a contemporary series of 1800 interventions. Urology 2002;60:623–7.
118. Varkarakis I, Kyriakakis Z, Delis A, et al. Long-term results of open transvesical prostatectomy from a contemporary series of patients. Urology 2004;64:306–10.
119. Gratzke C, Schlenker B, Seitz M, et al. Complications and early postoperative outcome after open prostatectomy in patients with benign prostatic enlargement: results of a prospective multicenter study. J Urol 2007;177:1419–22.
120. Autorino R, Zargar H, Mariano MB, et al. Perioperative outcomes of robotic and laparoscopic simple prostatectomy: a European-American multi-institutional analysis. Eur Urol 2015;68:86–94.
121. Matei DV, Brescia A, Mazzoleni F, et al. Robot-assisted simple prostatectomy (RASP): does it make sense? BJU Int 2012;110:E972–9.