

Robotic-assisted laparoscopic surgery: recent advances in urology

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The aim of the present review is to summarize recent developments in the field of urologic robotic surgery. A nonsystematic literature review was performed to retrieve publications related to robotic surgery in urology and evidence-based critical analysis was conducted by focusing on the literature of the past 5 years. The use of the da Vinci Surgical System, a robotic surgical system, has been implemented for the entire spectrum of extirpative and reconstructive laparoscopic kidney procedures. The robotic approach can be applied for a range of adrenal indications as well as for ureteral diseases, including benign and malignant conditions affecting the proximal, mid, and distal ureter. Current evidence suggests that robotic prostatectomy is associated with less blood loss compared with the open surgery. Besides prostate cancer, robotics has been used for simple prostatectomy in patients with symptomatic benign prostatic hyperplasia. Recent studies suggest that minimally invasive radical cystectomy provides encouraging oncologic outcomes mirroring those reported for open surgery. In recent years, the evolution of robotic surgery has enabled urologic surgeons to perform urinary diversions intracorporeally. Robotic vasectomy reversal and several other robotic andrological applications are being explored. In summary, robotic-assisted surgery is an emerging and safe technology for most urologic operations. The acceptance of robotic prostatectomy during the past decade has paved the way for urologists to explore the entire spectrum of extirpative and reconstructive urologic procedures. Cost remains a significant issue that could be solved by wider dissemination of the technology. (Fertil Steril® 2014;102:939–49. ©2014 by American Society for Reproductive Medicine.)

Key Words: Andrology, indications, robotic surgery, robot-assisted laparoscopy, urology

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Robotic-assisted laparoscopy offers unique features compared with standard laparoscopic surgery. EndoWrist instrumentation enhances surgical dexterity and facilitates intracorporeal suturing. In addition, the three-dimensional, high definition, stereoscopic-magnified vision provides an unmatched view of anatomical structures. Overall, robotic technology allows the surgeon to perform complex tasks in a minimally invasive fashion, with a much faster learning curve than laparoscopy (1).

In urology, the application of robotics was initially boosted by the exponential growth of robotic radical prostatectomy (RARP), which in the United States has largely supplanted

open surgery as main procedure for prostate cancer (2, 3). In addition, during the past decade, robotics has been increasingly used in numerous other procedures in urology (4, 5). The aim of the present review is to summarize recent developments in the field of urologic robotic surgery.

LITERATURE SEARCH

A nonsystematic literature review was performed using PubMed and Scopus to retrieve publications related to robotic surgery in urology (Fig. 1). In the free-text protocol, the following terms were applied: robotic urologic surgery; robotic kidney surgery; robotic adrenal surgery; robotic ureteral sur-

gery; robotic prostate surgery; robotic bladder surgery; robotic urology. An evidence-based critical analysis was conducted by focusing on the literature of the past 5 years.

UPPER URINARY TRACT Kidney Surgery

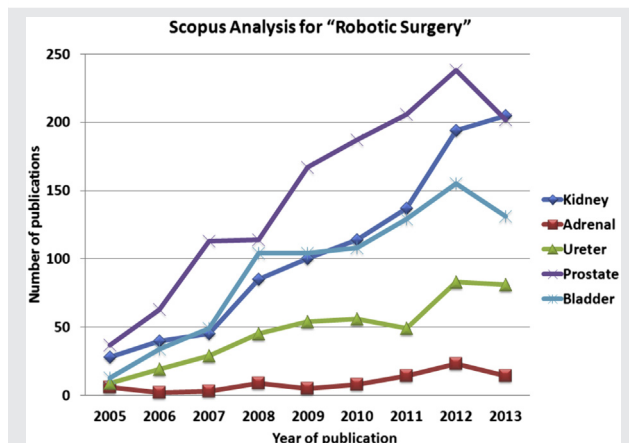
The use of the da Vinci Surgical System robot has been implemented for the entire spectrum of extirpative and reconstructive laparoscopic kidney procedures. Current clinical practice guidelines recommend partial nephrectomy as gold standard treatment for small renal masses (6, 7), given the suggested advantages of nephron-sparing surgery versus radical nephrectomy in terms of renal function preservation and, ultimately, survival (8). Nevertheless, partial nephrectomy remains an underused procedure (9), and this might be related not only to hospital and patient factors (10), but also as a result of the negative impact caused by the introduction of

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FIGURE 1



Organ-based scopus bibliometric assessment of publications related to the field of robotic-assisted urologic surgery.

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laparoscopic radical nephrectomy (11). Recent data suggest that robotic technology may enable surgeons across different practice settings to perform nephron-sparing surgery more frequently (12, 13).

The robotic approach offers the option of a minimally invasive partial nephrectomy, which is likely to recapitulate the safety and effectiveness of the open technique. The standardization of each surgical step has allowed for optimization of the procedure (14) (Fig. 2). In addition, indications for robotic partial nephrectomy have significantly expanded to include more demanding clinical scenarios, such as completely intraparenchymal tumors (15), hilar tumors (16), multiple tumors (17), and patients who have undergone a previous ipsilateral nephron-sparing procedure (18), those with pre-existing chronic kidney disease (19), as well as elderly (20) and obese (21) persons.

Current evidence shows that robotic partial nephrectomy is able to offer a wider range of indications, better operative

FIGURE 2

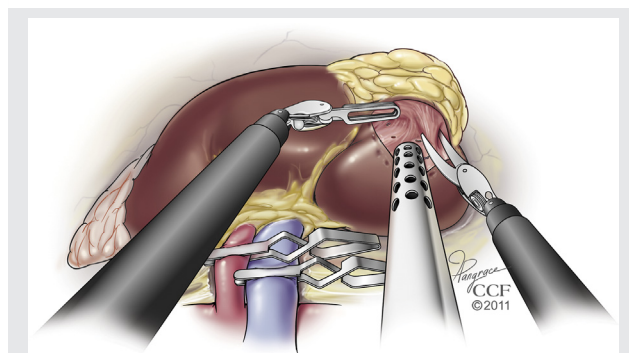


Illustration showing clamped renal hilum and tumor resection using robotic scissors. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2010–2012. All Rights Reserved.)

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outcomes, and lower perioperative morbidity than conventional laparoscopic partial nephrectomy (22, 23). In addition, robotic partial nephrectomy seems to be effective in renal function preservation and oncologic control at an intermediate follow-up interval (24). Thus, robotics is likely to supplant laparoscopy as the most common minimally invasive approach for partial nephrectomy whenever the necessary technology is available (25).

Laparoscopic radical nephrectomy (RN) is the recommended standard of care for patients with grade T2 kidney tumors and smaller renal masses not treatable by a nephron-sparing approach (26). Long-term outcome data indicate that laparoscopic RN offers equivalent cancer-free survival rates to those of open radical nephrectomy (27, 28). Since the pioneering series of five patients reported by Klingler et al. (29), data in the literature on the use of robotics for RN remain sparse, with all reports being small cases series with limited follow-up. Rogers et al. (30) reported their experience with robotic-assisted nephrectomy for benign and malignant diseases. After a mean follow-up of 15.7 months, there was no local recurrence. Conversion rate decreases with increasing experience of the surgeon. More recently, Dogra et al. (31) confirmed that robotic RN is feasible and safe, with good oncologic outcome on short-term follow-up.

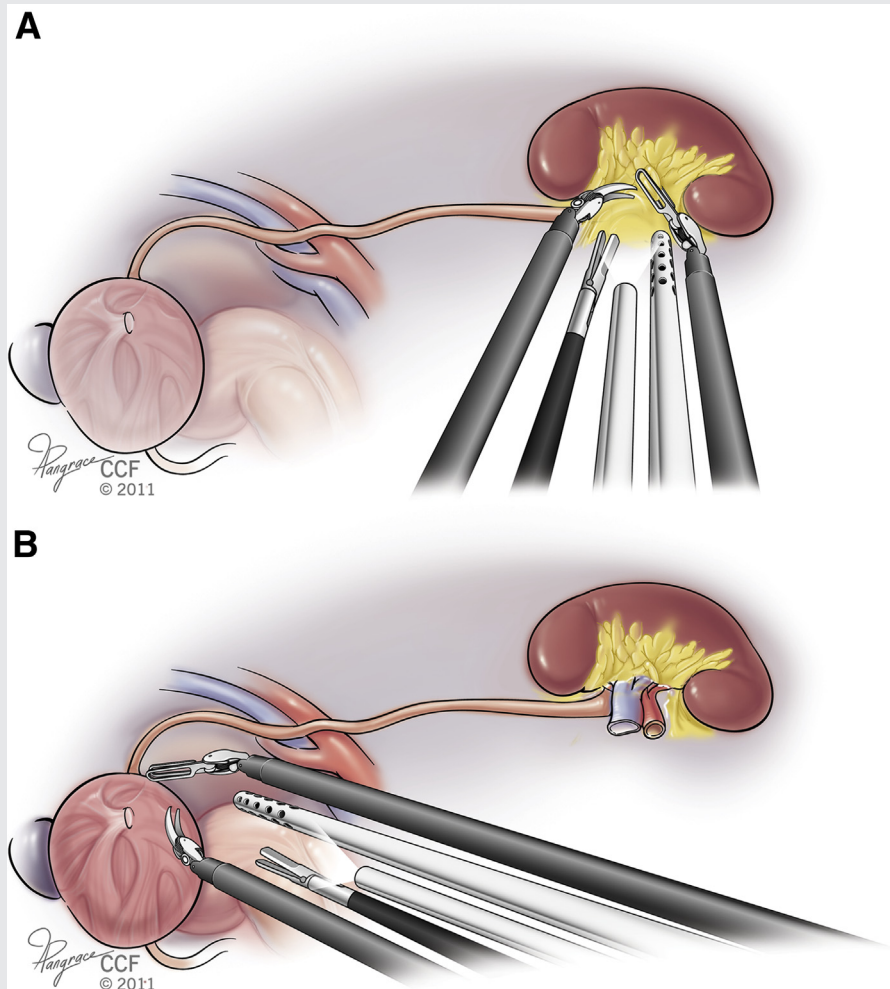
Although the open surgical approach remains the preferred approach in the management of large renal tumors presenting with a thrombus within the vena cava, robotic-assisted surgery may provide the dexterity necessary to allow for the safe application of minimally invasive techniques to such complex clinical scenarios. Abaza (32) reported the first series of robotic RN with inferior vena caval thrombectomy. The inferior vena cava was opened in all five patients, and tumor thrombi were delivered intact, followed by sutured closure. There were no complications, transfusions, or readmissions.

Robotic-assisted surgery has also been adopted by vascular surgeons for procedures where dexterity is required for fine suturing and reconstruction (33). We recently described our technique and show the technical feasibility of robotic-assisted renal artery aneurysm repair (34). The use of the da Vinci Si Surgical System facilitated segmental artery dissection, allowing for selective clamping during reconstruction.

In recent years, robotic nephroureterectomy (NU) has received attention as a viable minimally invasive procedure used in the surgical treatment of upper tract urothelial cancer (35). Robotic NU is very similar to laparoscopic NU, but the extra degrees of freedom and articulation of the robotic wrists make the isolation of the distal ureter and bladder closure less technically challenging. Also, lymph node dissection may be enhanced with the magnified vision of the robotic camera, and the articulation of the wristed instruments can facilitate working in proximity to the great vessels.

Early experience with robotic NU required repositioning of the robot and/or the patient (36). Newer approaches have eliminated the need for patient repositioning or robot redocking (37–39). We recently reported our institution's simplified technique of robotic NU allowing to en bloc resection of the kidney, ureter, and the bladder cuff without patient repositioning or robot redocking (40) (Fig. 3). A key step of the procedure is the management of the bladder cuff. The

FIGURE 3



Schematic demonstration of the seamless transition of the robotic instruments from (A) the upper abdominal quadrant to (B) the pelvis during "simplified" robotic-assisted nephroureterectomy. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2010–2012. All Rights Reserved.)

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ureter is dissected into the pelvis to the bladder hiatus; then, the detrusor muscle is then dissected until the bladder mucosa is tenting. Before excising the bladder cuff, two 3-0 Vicryl sutures (Ethicon Endo-Surgery) are preplaced, one lateral and the other medial. The distal ureter along with the bladder cuff is excised en bloc circumferentially. The bladder defect is then closed by running the two preplaced Vicryl sutures toward each other and tying them together (Fig. 4).

A recent multi-institutional series of 43 robotic NU suggested that the procedure can be an alternative to other established techniques, given the promising early perioperative outcomes. However, further data are necessary for a long-term oncologic assessment (41).

The use of robotics in urologic laparoscopy has expanded exponentially in recent years, given the unique features provided by the robotic platform. Especially in the setting of reconstructive procedures where extensive suturing is needed, such as for the surgical management of ureteropelvic junction

obstruction, robotic assistance was widely implemented. The first robotic pyeloplasty series was reported by Gettman et al. (42) in 2002. Since then, this robotic procedure has been increasingly adopted, as shown by Monn et al. (43), who used data from the US Nationwide Inpatient Sample looking at 3,947 pyeloplasties done between 2005 and 2010, showing a statistically significant increase in the number of robotic pyeloplasty procedures. In a recent systematic review by Autorino et al. (44), meta-analysis of data from nine published studies on 277 robotic cases and 196 laparoscopic cases showed that the use of robotics is likely to be associated with a shorter operative time (weighted mean difference, -27.9 minutes; 95% confidence interval -52.5 to 3.3 ; $P=.03$), possibly reflecting a shorter learning curve, especially for the suturing portion of the pyeloplasty procedure. Overall, despite the two techniques being comparable in terms of indications, safety, and efficacy, the robotic approach is likely to become the preferred option whenever the technology is available.

FIGURE 4

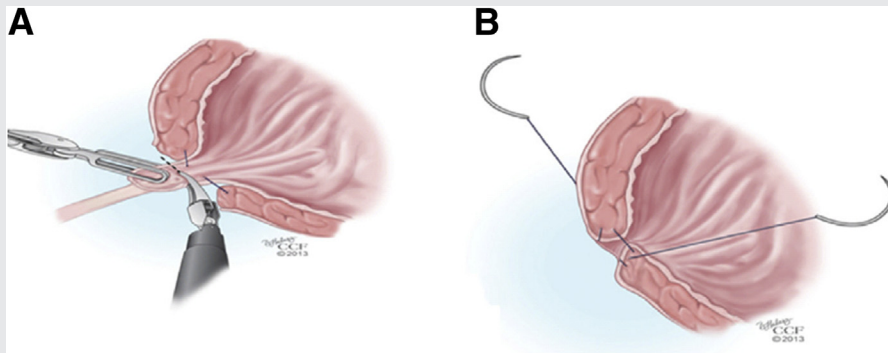


Illustration showing bladder cuff management during robotic nephroureterectomy. (A) En bloc circumferential excision of the distal ureter along with the bladder cuff. (B) The bladder defect is then closed by running the two preplaced Vicryl sutures toward each other and tying them together. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2010–2012. All Rights Reserved.)

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Adrenal Surgery

With the introduction of the da Vinci Surgical System (Intuitive Surgical), several series of robotic adrenalectomy have been reported, showing the safety and feasibility of the procedure as well as potential advantages versus laparoscopy, given the unique features of the currently available robotic system (45). We performed a systematic review of the available evidence comparing the surgical outcomes of robotic-assisted adrenalectomy with those of conventional laparoscopic adrenalectomy (46). Nine studies were selected for the analysis, which included 600 patients. We found that robotic-assisted adrenalectomy can be performed safely and effectively with operative time and conversion rates similar to laparoscopic adrenalectomy. In addition, it can provide potential advantages of a shorter hospital stay, less blood loss, and lower occurrence of postoperative complications.

We recently described our contemporary step-by-step standardized technique for robotic adrenalectomy (47)

(Fig. 5). The robotic approach can be applied for a range of adrenal indications, recapitulating the safety and effectiveness of open surgery, and potentially improving the outcomes of standard laparoscopy.

Ureteral Surgery

Iatrogenic injury is the most common cause of damage to the ureters—the distal (lower) ureter being the most vulnerable site. The incidence of ureteric trauma during gynecological surgery ranges from 0.1%–1.5% for benign cases and ≤5% for oncologic procedures, whereas ureteroscopy remains the leading cause of ureteric injury in the urological setting. Noniatrogenic ureteric trauma, which most commonly affects the upper ureter, represents less than 1% of all genitourinary injuries (48).

Robotic surgery has been applied for a variety of ureteral diseases, including benign and malignant conditions affecting the proximal, mid, and distal ureter. In all patients

FIGURE 5

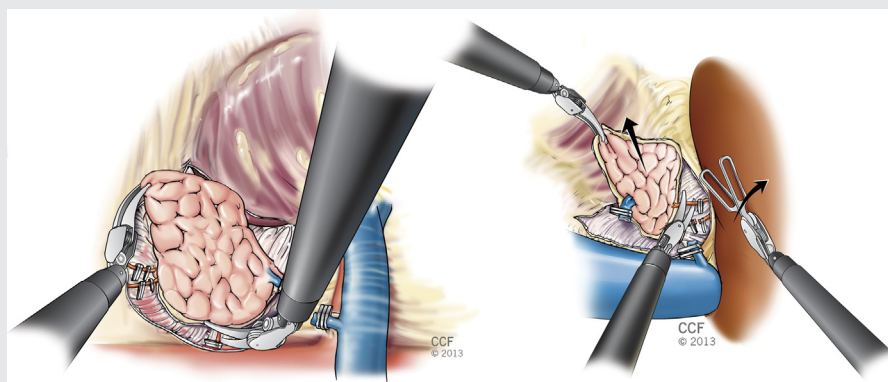


Illustration showing left and right side robotic-assisted laparoscopic adrenalectomy. Illustration shows the circumferential mobilization of the adrenal gland, taking special care with arterial blood supply. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2010–2012. All Rights Reserved.)

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appropriate ureteral reconstruction is required to restore ureteral patency and normal renal drainage (49, 50). The location and length of the potential defect to be bridged dictates the type of procedures that are required (48–50) (Table 1).

Several institutions have reported their experience with robotic ureteral reconstruction. Hemal et al. (51) reported a large series of robotic-assisted laparoscopic procedures, including distal ureterectomy with ureteroneocystostomy, ureteroneocystostomy with psoas hitch, ureteroneocystostomy with vesicovaginal fistula repair, and ureteroureterostomy. They concluded that robotic surgery can be successfully used in most ureteral pathologies at any level of the ureter, with outcomes comparable with those seen in open surgery but with the advantage of being technically less demanding than pure laparoscopy. Musch et al. (52) reported one of the largest single institution series on robotic-assisted reconstructive surgery of the distal ureter in adults. They obtained good short-term functional outcomes with a low rate of severe postoperative complications.

One of the challenging steps of robotic-assisted ureteroureterostomy is the precise intraoperative identification of the stricture site to perform a tension-free anastomosis on healthy tissue. In a report assessing primary anastomotic repair in patients with iatrogenic lumbar and iliac ureteral strictures, Buffi et al. (53) were the first to describe a precise technique to localize ureteral strictures during robotic ureteroureterostomy by using a flexible ureteroscope to transilluminate the stricture. This method was limited by the localization of only the lower margin of the stricture. More recently, Lee et al. (54) reported their experience in a small series where a novel technique incorporating intraureteral injection of indocyanine green and the use of near infrared light during robotic-assisted surgery, which allowed for real-time fluorescent visualization of the normal ureter and enhanced the ability to identify ureteral strictures. Our group reported a study comparing robotic-assisted surgery with open ureteroneocystostomy (55) (Fig. 6). Robotic surgery was found to provide excellent outcomes with shorter hospital stay, less narcotic pain requirement, and decreased blood loss.

Although the gold standard for the management of upper urinary tract transitional-cell carcinoma is nephroureterectomy, studies suggest that, in cases of low-grade, noninvasive transitional-cell carcinoma, segmental ureterectomy can provide equivalent outcomes with the added benefit of conserving renal functional mass (56). Robotic-assisted ureterectomy and ureteral reconstruction was shown to be safe

and feasible (57), and to offer excellent intermediate-term oncologic outcomes with preservation of ipsilateral renal function (58).

The treatment of large, lower ureteral stones or impacted lower ureteral stones has always represented a challenging scenario. Robotic-assisted stone surgery has been recently explored as a possible alternative to standard therapeutic options in this setting. Dogra et al. (59) explored the feasibility of robotic-assisted laparoscopic ureterolithotomy for large (average stone size, 2.2 cm) or impacted lower ureteral stone. They outlined the ease of surgery and that shorter operative times are significant advantages compared with the laparoscopic approach.

Wagner et al. (60) first described a robotic-assisted laparoscopic approach for the use of small bowel for ureteral substitution in a patient with a solitary kidney with multiple stones procedure. Our group recently reported a case of completely intracorporeal robotic ileal ureter (Fig. 7). The unique wrist articulation provided by the robotic instrumentation facilitated the successful completion of this complex reconstructive procedure (61).

Retroperitoneal fibrosis is an uncommon disorder, with an incompletely understood etiology, often causing ureteral obstruction. Robotic ureterolysis can be performed with minimal morbidity and durable success rates for relief of symptoms in the management of retroperitoneal fibrosis (62).

PELVIC SURGERY

Prostate Surgery

From the initial descriptions of case in 2000 (63, 64), RARP has become widely adopted by urologists (2, 3) despite an absence of high quality randomized controlled clinical trials comparing it with traditional open radical prostatectomy. In addition, the procedure has continuously evolved in terms of procedural step by steps, technical modifications, and outcomes data from various institutions.

Current evidence suggest that RARP is associated with less blood loss and transfusion rates compared with open surgery, and there appear to be minimal differences between the two approaches in terms of overall postoperative complications (65). Positive surgical margin rates are at least equivalent with RARP, but firm conclusions about biochemical recurrence and other oncologic end points are difficult to draw because the follow-up in existing studies is relatively short (66). Robotic radical prostatectomy may offer advantages in postoperative recovery of urinary continence and erectile function (67, 68). Surgeon experience and institutional volume of procedures strongly predict better outcomes in all relevant domains (69). In addition, total hospitalization costs seem to remain higher for patients treated with RARP (70).

More recently, RARP was shown to be a safe and effective option for selected patients with a high risk prostate cancer, either alone or as the initial step in a multimodal treatment plan. In this setting, staging extended lymphadenectomy can be done safely and thoroughly robotically (71).

Besides prostate cancer, robotics has been used for simple prostatectomy in patients with symptomatic benign prostatic

TABLE 1

Robotic-assisted ureteral reconstruction: criteria for surgical planning.

Location of ureteral defect	Procedure	Alternative option
Upper third	Ureteroureterostomy	Ureterocalycostomy
Middle third	Ureteroureterostomy	Boari flap
Lower third	Ureteroneocystostomy	Vesicopsoas hitch
Complete ureter	Ileal interposition	Autotransplantation

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FIGURE 6

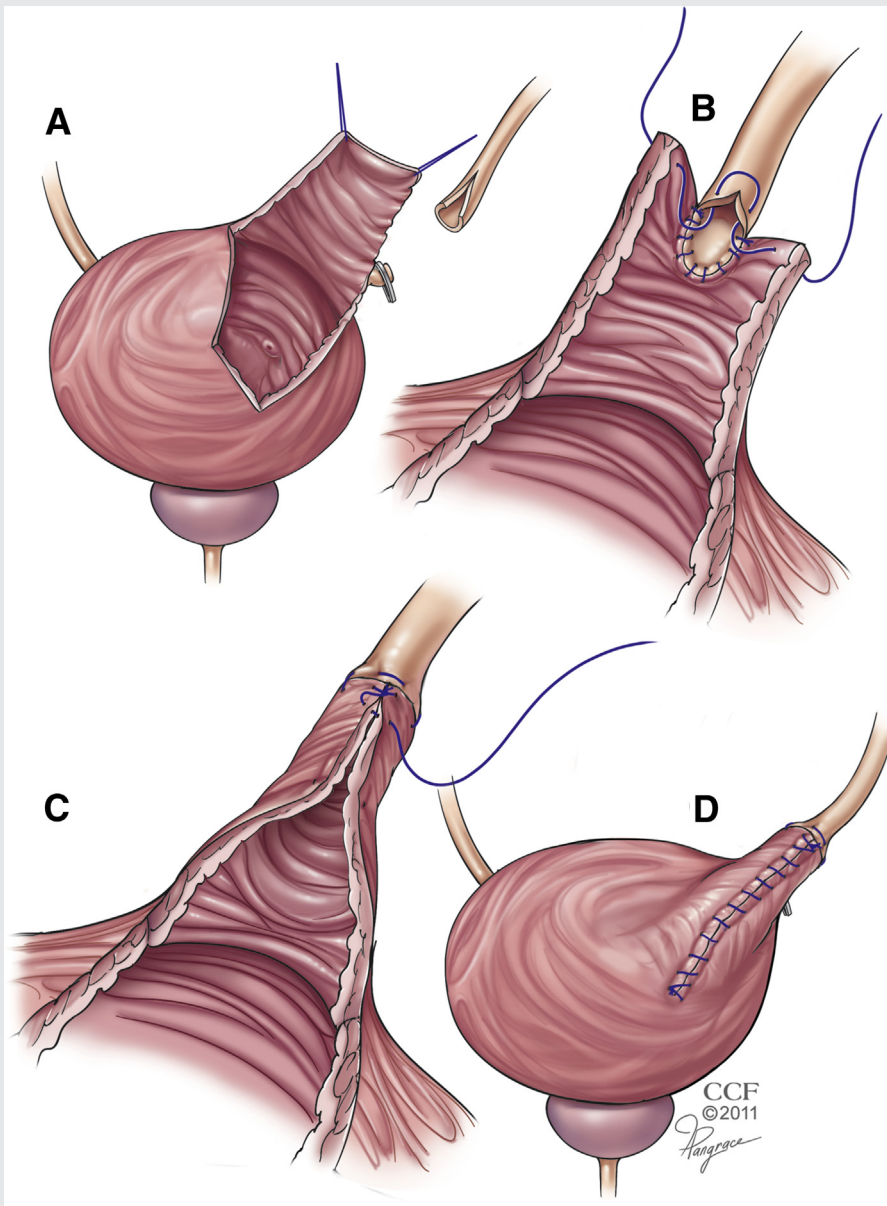


Illustration showing the creation of a Boari flap. (A) Bladder flap is developed; (B) ureter is anastomosed to the tip of the flap; (C) tubularization of the Boari flap; (D) completion of the procedure. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2010–2012. All Rights Reserved.)

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hyperplasia. Data suggest that robotic simple prostatectomy represents a safe and efficacious treatment in selected patients with larger prostates, with potential advantage in terms of hospital stay and transfusion rate when compared with open surgery (72).

Bladder Surgery

The gold standard treatment for nonmetastatic muscle invasive and selected high-risk nonmuscle invasive bladder cancer remains open radical cystectomy with pelvic lymph

node dissection (73). Since the first report by Menon et al. (74) in 2003, robotic-assisted radical cystectomy has been adopted in several large institutions. A recent systematic review and meta-analysis, which included 962 patients from one randomized controlled trial, eight prospective studies, and four retrospective studies, showed that robotic-assisted radical cystectomy was associated with longer operative time, that patients might benefit from less overall perioperative complications, more lymph node yield, less estimated blood loss, a lower need for perioperative transfusion, and shorter length of hospital stay (75). Recent studies suggest

FIGURE 7

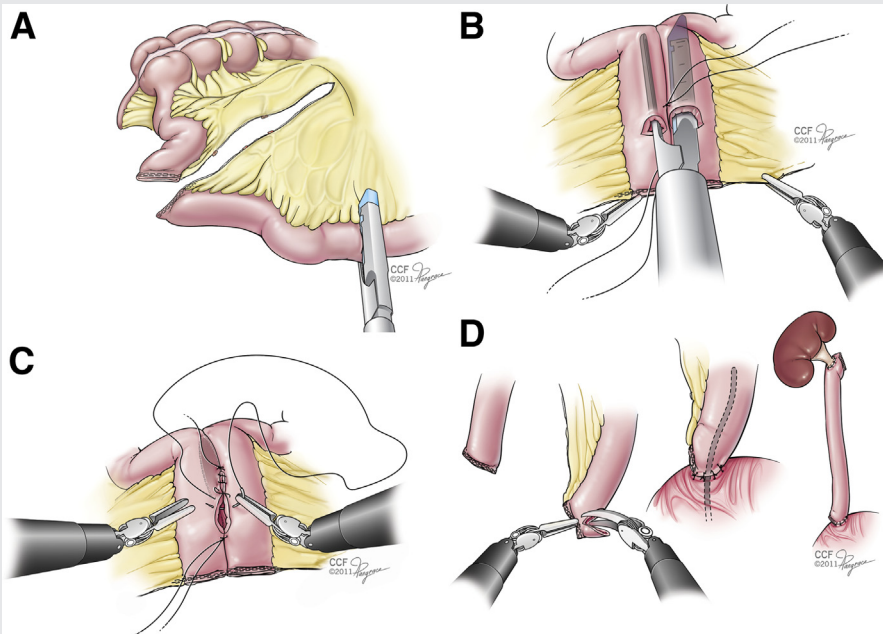


Illustration showing (A) intracorporeal ileal segment isolation using an Endo-GIA stapler; (B) intracorporeal re-establishment of bowel continuity; (C) sutured closure of the butt end of the repair; (D) resection of a portion of the distal ileal stapleline and creation of the ileovesical and pyeloileal anastomoses. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2010–2012. All Rights Reserved.)

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that minimally invasive radical cystectomy provides encouraging oncologic outcomes mirroring those reported for open radical cystectomy (76–78).

Traditionally, after completion of robotic-assisted radical cystectomy, an extracorporeal urinary diversion was preferred because of the complexity of the procedure. In recent years, the evolution of robotic surgery has enabled urologic surgeons to perform urinary diversions intracorporeally (79). Intracorporeal urinary diversion has the potential benefits of a smaller incision, reduced pain, decreased bowel exposure, and reduced risk of fluid imbalance. A study by The International Robotic Cystectomy Consortium compared the outcomes of 167 patients who underwent intracorporeal urinary diversion with the outcomes of 768 patients who had an extracorporeal diversion. Patients with intracorporeal urinary diversion were at a lower risk of experiencing a postoperative complication during the first postoperative 90 days (80).

Indications for surgical treatment of bladder diverticula include tumor, lower urinary tract symptoms refractory to medical treatment, renal dysfunction or recurrent urinary tract infections. Robotic-assisted laparoscopic bladder diverticulectomy has been also increasingly reported in recent years (81). Based on our experience, robotic surgery represents a reasonable minimally invasive treatment option in this setting (82) (Fig. 8).

ANDROLOGICAL SURGERY

Numerous technical innovations have been described for vasectomy reversal since the basic principles of this technically

demanding procedure were established in the late 1970s (83). Robotic vasectomy reversal is an emerging field in selected urologic centers. Parekattil et al. (84) recently published a prospective cohort study comparing robotic reversal to pure microscopic reversals. Pregnancy rates (PRs) did not differ significantly for the two groups. Median operative time for the robotic technique was significantly lesser. As vasectomy reversal by experienced microsurgers has reached a high level of efficiency, it remains to be determined whether new robotic systems can actually improve surgical quality (83). Besides vasectomy reversal, several other robotic applications in andrological surgery have been explored (85). The use of robotic assistance was advocated for targeted microsurgical denervation of the spermatic cord in patients with chronic testicular pain (86), for subinguinal microsurgical varicocelectomy (87), and for testicular sperm extraction (TESE) technique in patients with nonobstructive azoospermia (85).

Overall, these novel applications of robotic surgery remain experimental, and a sound assessment of their outcomes is needed to determine their role in the field. The inferior magnification available and the lack of specialized microsurgical instruments represent two major drawbacks of the current robotic system. In addition, the da Vinci robot is associated with substantial costs, and setting it up can be time consuming, and a specialized surgical team is required.

COSTS

With the dramatic increase in the use of robotic surgery in urology significant costs in terms of acquisition,

FIGURE 8

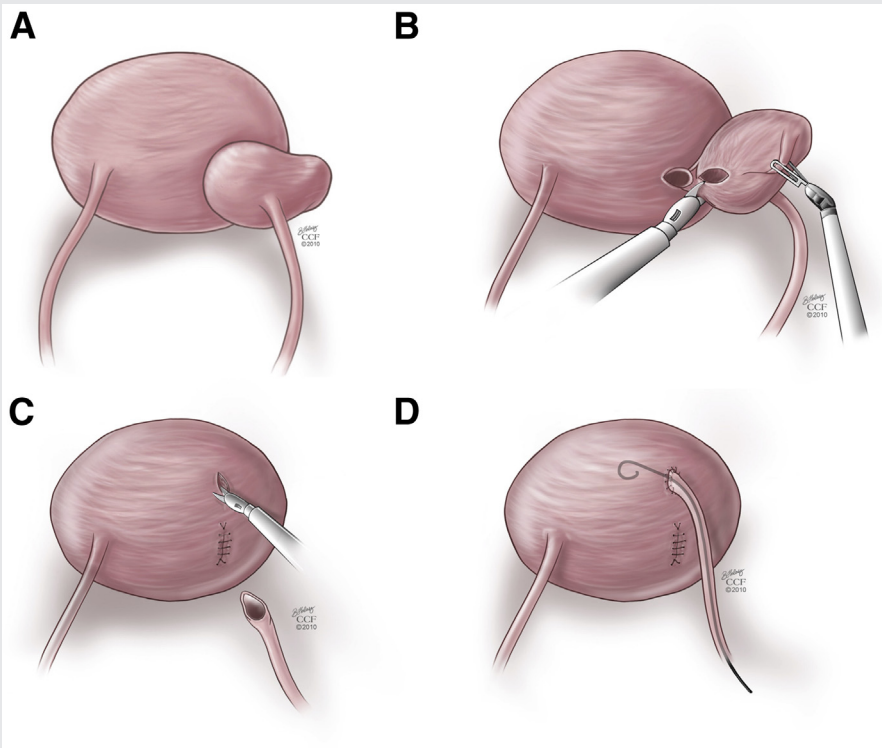


Illustration showing robotic-assisted bladder diverticulectomy. (A) Ureter ending directly into diverticulum. (B) Dissection of the diverticulum. (C) Opening the bladder to reimplant the ureter. (D) Primary ureteroneocystostomy with refluxing anastomosis. (Reprinted with permission, Cleveland Clinic Center for Medical Art & Photography © 2010–2012. All Rights Reserved.)

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maintenance, and daily instrument costs have been added. This has generated an ongoing debate on the impact of robotic surgery on current health care systems and ways of rendering robotic surgery cost-effective as much as possible.

Some investigators pointed out that there needs to be an improvement in efficacy versus alternative approaches and a decrease in costs of the robot or instrumentation (88). Other investigators pointed out that the benefits of robotics, including decreased length of hospital stay and return to work are considerable and must be measured when evaluating its cost effectiveness. In addition, robotic-assisted laparoscopic surgery can become cost-effective in mostly high-volume centers with high-volume surgeons (89).

Yu et al. (90) used the US Nationwide Inpatient Sample to assess use, costs, and outcomes of robotic-assisted laparoscopic surgery versus laparoscopic surgery and open surgery for common robotic-assisted urological procedures (radical prostatectomy, nephrectomy, partial nephrectomy, and pyeloplasty). Robotic-assisted laparoscopic surgery and laparoscopic surgery versus open surgery were associated with shorter length of hospital stay for all procedures, with robotic-assisted laparoscopic surgery being the shortest for radical prostatectomy and partial nephrectomy. In addition, robotic-assisted and laparoscopic surgery are associated with fewer deaths, complications, transfusions, and shorter length of hospital stay compared with open surgery. However,

robotic-assisted laparoscopic surgery was more costly than laparoscopic and open surgery for most procedures. The same group looked at robotic-assisted laparoscopic radical prostatectomy only using the same dataset and found that higher volume hospitals showed fewer complications and lower costs than low volume hospitals on a national basis (91). Kim et al. (92) described the total hospitalization costs attributable to robotic and open surgery for radical prostatectomy using a population-based cohort by merging the US Nationwide Inpatient Sample and the American Hospital Association survey. Compared with open surgery, patients undergoing robotic radical prostatectomy had shorter median length of hospital stay and were less likely to experience any postoperative complications. However, they had higher median hospitalization costs. After adjusting for patient and hospital features, robotic surgery was associated with higher total hospitalization costs compared with open surgery (\$11,932 vs. \$9,390; $P < .001$). The investigators concluded that total hospitalization costs are higher for patients with prostate cancer treated with robotic surgery compared with those treated with open surgery. Similar findings were reported in a systematic review by Ahmed et al. (93), who reported that, despite reduced hospital stay and blood loss, robotic-assisted radical prostatectomy remains more expensive (total cost range, US \$2,000–\$39,215) than both laparoscopic (range, US \$740–\$29,771) and open radical

TABLE 2

Current role of robotics for different urologic indications.

Procedure	Advantages	Drawbacks
PN	Expanding indications for minimally invasive NSS; short-term and mid-term outcomes comparable with open NSS	Increased cost compared with open surgery
RN	None clinically; training platform toward PN	Very limited data available; increased cost compared with current standard (i.e., laparoscopy)
NU	Promising early perioperative outcomes; better lymph node dissection	Long-term outcomes still lacking; increased cost compared with open surgery and laparoscopy
PYELO	Shorter operative time and comparable outcomes compared with laparoscopy	Increased cost compared with laparoscopy
ADREN	Same outcomes as open surgery; potential advantages of a shorter hospital stay, less blood loss, and lower occurrence of postoperative complications compared with laparoscopy	Not indicated for adrenocortical carcinoma
RP	Less blood loss and transfusion rates compared with open surgery	Increased hospital cost compared with open surgery
RC	Less perioperative complications, more lymph node yield, less estimated blood loss, and shorter length of hospital stay compared with open surgery	Longer operative time compared with open surgery; long-term oncologic data still very limited
VV	Possible shorter learning curve compared with microsurgery	Very limited data available; increased cost

Note: ADREN = adrenalectomy; NU = nephroureterectomy; PN = partial nephrectomy; PYELO = pyeloplasty; RC = radical cystectomy; RN = radical nephrectomy; RP = radical prostatectomy; VV = vasovasostomy.

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prostatectomy (range, US \$1,870–\$31,518). They discussed that this difference is due to the cost of robot purchase, maintenance, and instruments, and that reduced length of hospital stay for surgery are unable to compensate for the excess costs.

Yu et al. (94) also used the US Nationwide Inpatient Sample to compare robotic with open radical cystectomy. In adjusted analyses, subjects undergoing robotic experienced fewer inpatient complications and deaths and lower parental nutrition use. However, there was no difference in length of hospital stay and robotic-assisted surgery was more costly. In another population-based study on radical cystectomy, Leow et al. (95) found robotics associated with decreased odds of minor complications and with increased expenditures attributed primarily to higher supply costs.

Mir et al. (96) compared direct costs associated with open, laparoscopic, and robotic-assisted partial nephrectomy by performing a meta-analysis of nonoverlapping studies. They found that, because of lower instrumentation costs, laparoscopy is the most cost-effective, despite a longer length of hospital stay than robotics. Our group recently reported an analysis of costs associated with different partial nephrectomy techniques (97). Robotics had higher operating room costs, primarily due to instrumentation and supplies. But this higher cost was offset by decreased cost of hospitalization.

In conclusion, robotic-assisted surgery is an emerging technology that can be safely applied for most urologic operations, offering significant technical advantages versus conventional laparoscopic surgery, given the unique features of the robotic platform. The acceptance of RARP during the past decade has paved the way for urologists to explore the entire spectrum of complex extirpative and reconstructive urologic procedures. However, advantages and drawback of robotics need to be scrutinized depending on the procedure (Table 2).

Cost remains a significant issue that could be solved by increased competition from manufacturers and wider dissemination of the technology. Further documentation including

long-term oncologic and functional outcomes is deemed necessary before definite conclusions can be drawn regarding the superiority of robotic assistance versus other established approaches.

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