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Robotic surgery in urologic oncology: gathering the evidence

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Abstract

In less than a decade, the widespread application of robotic technology to the field of urologic oncology has permanently altered the way urologists approach malignancy. The short-term benefits of minimally invasive surgery using robotic assistance (i.e., decreased blood loss, improved convalescence and ergonomic appeal), as well as a broad marketing campaign, have helped the technology gain traction in the field of urology. Although the long-term benefits of its use in urologic surgery are less clear and the costs of robotic surgery are consistently greater than those of other approaches, the numbers of prostate, kidney and bladder cancer cases continue to rise. Identifying transferable surgical processes of care that matter most for each of the robotic cases in urologic oncology (e.g., prostatectomy, cystectomy and partial nephrectomy) is a next step toward broadly improving the quality of urologic cancer care. To this end, urologic professional societies and their surgeons should aim to identify underwriters for and participate in large clinical registries and surgical quality collaboratives.

Keywords

cystectomy; nephrectomy; oncology; outcomes; prostatectomy; robotic surgery; urology

Over the past decade, robotic technology has revolutionized surgical care in the USA. Following approval of Intuitive Surgical's da Vinci robotic systemTM for general laparoscopic surgery in 2000 by the US FDA, more than 800 US hospitals have acquired the technology, accommodating over 2500 surgeons [101]. Because the benefits of robotics primarily apply to surgery in tight spaces, the technology has thrived in pelvic, head and neck, and chest surgery. In addition to the short-term benefits of minimally invasive surgery to the patient (i.e., decreased blood loss and improved convalescence), the ergonomic appeal to the surgeon [1] and a direct-to-consumer marketing campaign [102,103] have also helped the technology gain traction in surgery. However, the considerable upfront purchase price (~US\$1.4 million) and annual maintenance contracts (~US\$100,000) highlight a potential drawback of technology adoption [2]. Ultimately, the value of robotic technology rests on the balance between the cost and the extent to which it improves the quality of patient care relative to alternative surgical approaches.

Robotic-assisted surgery in urologic oncology has focused primarily on treating men with prostate cancer, with over 80% of cases performed using robotic assistance in recent reports

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[104]. The use of robotic technology in this context has empowered laparoscopically-naïve urologists with the ability to perform minimally invasive surgery, the skills of which have been subsequently parlayed to extirpative bladder and kidney surgery. Unfortunately, the bulk of the clinical evidence supporting the adoption of robotic surgery is limited to high-volume surgeons in academic centers, precluding the generalization of outcomes to most urologists practicing in the USA. By contrast, population-based studies afford better insight into what is happening in the community. For example, while not appreciated in most case series of high-volume surgeons, the initial adoption of robotic prostatectomy has been associated with a higher likelihood of genitourinary complications (e.g., ureteral injury) at the population level [3]. Reconciling differences between large case series from high-volume centers and those from population-based studies (i.e., administrative data) will inevitably identify opportunities to improve the quality of care.

In this article, we review the outcomes and costs of robotic surgery when implemented in patients with urologic malignancies. Furthermore, we propose possible future steps in order to move the field forward in terms of improving quality and minimizing costs (i.e., maximizing efficiency).

Evolution of minimally invasive surgery in urologic oncology

The benefits of minimally invasive surgery in urology (e.g., decreased pain and hospital stay) were quickly recognized with the advent of the laparoscopic nephrectomy in the early 1990s [4]. However, learning laparoscopy is largely dependent on exposure to the technique during residency training, with steep learning curves and small case volumes proving prohibitive for most practicing urologists. Owing to technical challenges, conventional laparoscopic approaches to radical prostatectomy and cystectomy have not gained traction in the USA.

When contemporary robotic technology was introduced in 2000, prostatectomy was a logical choice to facilitate adoption due to the high-volume of procedures performed by clinicians independent of their practice environment. Practicing urologists could learn a relatively intuitive approach to minimally invasive prostatectomy with the benefits of magnification, articulating instruments and 3D visualization. Importantly, the recovery benefits of minimally invasive surgery still applied to the patient, while the ergonomic technology increased surgeon comfort, adding to its attractiveness. After refining the approach to radical prostatectomy, nephrectomy, partial nephrectomy and cystectomy were next in the diffusion of robotic surgery in urology. The novelty of the procedure, short-term patient benefits and direct-to-consumer marketing campaigns [5,102,103] have ultimately fueled demand by patients, who believe, in some cases, that robotic surgery is superior to the alternate approaches.

Cost implications

The cost of robotic technology adoption rests neither upon patients nor payers, but upon hospitals for acquisition, maintenance and instrument replacement [2]. With approximately US\$1.4 million in upfront costs and US\$100,000 in annual maintenance fees, robotic technology represents a substantial investment that may never be recouped through surgical volume alone at many hospitals [6]. Essentially, the excess costs related to robotics reduce the hospital margin on a per case basis (relative to conventional surgery). However, adopting robotic technology offers hospitals a niche in the marketplace, especially for early adopters. The promise of market share growth through increased referrals, new patients and enhanced reputation probably drives hospitals to adopt the technology [105]. However, the degree to which adoption affects their bottom lines is unknown.

When considering direct costs, the evidence suggests that those for robotics supersede the costs associated with laparoscopy (Table 1). Despite the fact that robotics inevitably facilitate shorter hospitalizations and all related expenses (i.e., narcotic use and consultations, etc.), the costs associated with disposable instrumentation are considerable, and a primary reason for its greater expense [2]. Collectively, these sunk costs cut into the hospital payment for the procedure (reimbursed based upon the diagnosis-related group [DRG]), reducing the margin per surgical episode.

By contrast, at the physician level, robotic prostatectomy is reimbursed under the laparoscopic prostatectomy code which is similar to that of conventional radical prostatectomy (US\$1810 vs 1703) [106]. Patients likewise do not feel the economic impact of their treatment choice over that of conventional prostatectomy, as any copayments are similar. To the extent that the robotic approach improves patient outcomes, the added costs associated with the approach, which tend to come from the hospital's share, are insufficient to preclude adoption of the technology. In this context, we now examine the current state of evidence supporting robotic-assisted surgery for radical prostatectomy, partial nephrectomy and radical cystectomy.

Outcomes

Robotic radical prostatectomy

Perioperative outcomes—Relative to conventional surgery, the robotic approach to radical prostatectomy is consistently associated with reduced blood loss, decreased rates of blood transfusions and shorter hospitalizations, as illustrated in Table 2. Although these factors may vary by individual provider [7], the literature has consistently documented these benefits at both the clinical and population levels. In clinical studies, a distinct disadvantage of the robotic approach appears to be longer total operative time, which typically includes robot docking, setup and improves over time [8]. Among the comparative studies in a systematic review [9], the operative time for open prostatectomy (range: 127–214 min [10,11]) was almost always shorter than for the robotic approach (range: 160–288 min [12,13]), although this probably reflects the learning curve of the latter. At the population level, minimally invasive prostatectomy (the majority of which were robotically assisted) have been associated with an increased risk of genitourinary complications within 30 days following surgery compared with the open approach (4.7 vs 2.1%; $p = 0.001$) [3]. By contrast, minimally invasive approaches were associated with fewer anastomotic strictures than open surgery (5.8 vs 14.0%; $p < 0.001$) [3].

Postoperative outcomes: oncologic—The oncologic outcomes for radical prostatectomy are evaluated by surgical margin status, biochemical recurrence rates, and cancer-specific and overall mortality. The last two are difficult to assess given the prolonged natural history of the disease and are therefore excluded from this review. The first is perhaps best addressed in the current literature indicating surgical margin status for robotic prostatectomy (9.3–26% [13,14]) is similar to that of open (11–36% [15,16]) and laparoscopic (11–30% [15,17]) surgery [9]. Obviously, the outcomes of these clinical series reflect disease severity, pathologic specimen processing and the skills of a select few surgeons performing robotic prostatectomy. The limited scope of clinical series suggests the need to look more broadly at oncology outcomes using population-based data to better understand how the broader community of urologists are performing. For example, one study of Medicare patients demonstrated salvage therapy rates within 6 months of robotic surgery that were over three-times greater than those for the open approach [18]. Reconciling the discrepancies between clinical series and population-based data for robotic prostatectomy may inform areas of needed improvement in the urologic oncology community.

Postoperative outcomes: functional—Functional outcome assessments for robotic prostatectomy typically evaluate the recovery of urinary control and erectile function. The use of validated instruments to assess preoperative function and postoperative recovery is not uniform among studies comparing robotic prostatectomy to other approaches. For this reason, continence and erectile function are defined by a variety of means (e.g., lack of pad use and erection sufficient for intercourse). Nevertheless, recovery of urinary continence for patients undergoing the robotic approach (84–97% [19,20]) appears similar to the other approaches at 1 year (continence at 1 year, open 87–93% [21,22], laparoscopic 82–95% [23,24]) [9]. Because of comparable long-term continence rates among the procedures, the true benefits of robotic prostatectomy in continence recovery may be in the near term, where 68–96% [19,25] of men were continent at 6 months compared with 43–80% [21,26] of men undergoing open surgery [9].

With respect to recovery of erectile function, it may be easier to perform nerve sparing given the magnification and decreased blood loss for the robotic approach. In addition, several modifications to nerve sparing techniques (e.g., prostatic fascia sparing [27–29], athermal technique [30]) have been developed using robotic assistance. Whether these translate into improved potency outcomes remains debatable. For example, one study comparing robotic to open prostatectomy demonstrated quicker recovery of erectile function for the robotic approach [12]. As shown in Table 2, results in terms of potency at 12 months after robotic surgery are at least as good, if not better, as those for the open procedure in expert hands (73% potent at 12 months) [21].

Summary

Although the decreased blood loss and transfusion rates favor the robotic approach to radical prostatectomy, no definitive evidence currently supports that choice of surgical approach results in better or worse functional and oncologic outcomes. Identifying individual surgeon outcomes probably holds the key to future results for patients considering radical prostatectomy, open, laparoscopic or robotically assisted [7]. One important tool in decreasing complications in the robotic approach, especially during the learning curve, is to implement a structured mentored training program for the surgeon and assistants [31]. This approach enables more efficient transfer of technical skills from experienced mentors to those adopting the technology [32]. However, the sheer volume of prostatectomy cases in the USA calls for identifying the processes that matter during radical prostatectomy among the best performers through large collaborative studies, and broadly implementing those processes in order to improve the care for patients with prostate cancer.

Robotic radical & partial nephrectomy

The rise of laparoscopic nephrectomy is speculated to have been, in part, at the expense of performing open partial nephrectomy [33]. Laparoscopic partial nephrectomy remained prohibitively challenging for most urologists prior to robotic technology, yet some were able to adopt the relatively straightforward skill set needed to execute laparoscopic nephrectomy. In fact, some urologists performed laparoscopic nephrectomy even in the setting of small renal masses where partial nephrectomy potentially might be indicated [34]. A growing familiarity with the robot and the relative ease of intracorporeal suturing may be responsible for recent efforts to expand the use of the technology to renal surgery.

Radical nephrectomy

The use of a robot to assist with performing radical nephrectomy probably represents an excessive application of the technology. The benefits of a relatively straightforward laparoscopic approach compared with open radical nephrectomy have been consistently

demonstrated and are considered a standard in instances where the entire kidney needs to be removed [35]. Thus, laparoscopic nephrectomy stands little to gain from robotic assistance except potentially for operating time and cost. This is evidenced by the fact that robotic-assisted nephrectomy reports are scant, with one series showing prolonged operative times with similar blood loss [36].

Partial nephrectomy

Once the approach to open partial nephrectomy was refined and validated, laparoscopic partial nephrectomy was the next step towards implementing minimally invasive surgery for renal masses. The oncologic effectiveness of the laparoscopic approach has been shown to be equivalent to that of the open approach with significantly less morbidity [37]. Due to their complexity, these cases were largely performed at high-volume centers, among surgeons specializing in laparoscopic surgery [37,38]. The surgical obstacles facing laparoscopic partial nephrectomy (tumor dissection and renal reconstruction) were primarily technical, exacerbated by the time constraints of hilar clamping and the lack of wristed instrumentation to facilitate suturing. Essentially, laparoscopic dissection and suturing techniques largely precluded most urologists from performing this procedure.

The surgical technique for kidney cancer most likely to benefit from a robotic approach appeared to be partial nephrectomy. For those familiar with robotic prostatectomy and open partial nephrectomy, transitioning to robotic partial nephrectomy is a logical addition to their surgical armamentarium. In addition, those classically trained in laparoscopic partial nephrectomy have also benefited from robotic assistance given the ease of intracorporeal dissection and suturing [39].

Perioperative outcomes

The perioperative outcomes of robotic-assisted partial nephrectomy series are shown in Table 3. The robotic approach appears to be comparable to the open approach with regard to warm ischemia times (19–32.1 vs 20.1 min) and superior to that of conventional laparoscopy (30.7 min) [37]. Likewise, the robotic approach appears to have improved blood loss relative to laparoscopic (300 ml) and open (376 ml) surgery [37]. Operative time is also consistent with both open (266 min) and laparoscopic (201 min) approaches, demonstrating this approach is a feasible option with respect to perioperative outcomes, while decreasing length of stay relative to open surgery [37].

Postoperative outcomes: oncologic

The primary oncologic outcome of partial nephrectomy series has been the rate of positive surgical margins because of the difficulty assessing local recurrence and metastatic spread during the short follow-up periods of current robotic studies. Although surgical margins do not necessarily lead to local recurrence in the setting of focal areas, they are considered a marker of success for partial nephrectomy [40,41]. There have been no clinical trials comparing the robotic approach to others, yet robotic case series seem to show equivalent rates of positive surgical margins (3.9%) [39] relative to open (1.3–5.5%) [37,41] and laparoscopic surgery (2.9%) (Table 3) [37]. The long term oncologic outcomes following robotic partial nephrectomy are unknown.

Complications

The complication rates for laparoscopic partial nephrectomy have traditionally exceeded those of open surgery [37]. Complications of partial nephrectomy include collecting system leaks and conversions to radical nephrectomy. As shown in Table 3, urinary leaks rarely

occurred in the reported robotic series and no partial nephrectomy attempt using robotic assistance was converted intraoperatively to a radical nephrectomy.

Summary

Robotic-assisted radical nephrectomy has not been reported in the literature to the extent of partial nephrectomy, probably owing to the limited benefits of robotics in performing relatively straightforward laparoscopy. Robotic partial nephrectomy outcomes appear to mimic the results of laparoscopy among experienced laparoscopic surgeons, with potentially decreased warm ischemia time. The feasibility of adopting robotic-assisted nephron-sparing surgery may be increasing among surgeons familiar with robotic prostatectomy. The greatest concern outside of surgical preference for excising renal masses surrounds the unnecessary resection of benign disease (16–37%) found in open, laparoscopic and robotic series [37,42]. Improving biopsy performance may preclude unnecessary surgery on benign lesions [43].

Robotic radical cystectomy

The cystectomy population represents the oldest and most infirm of urologic oncology patients, and the tremendous stress of the procedure places patients at a relatively high risk of perioperative death. As a result, advances in surgical approach and postoperative management have minimized, but not alleviated, the morbidity (~30%) and mortality (~2%) of radical cystectomy [44]. Despite being a less intricate operation than radical prostatectomy, significant risks of bleeding and bowel complications exist [44].

In an effort to expand upon minimally invasive options for bladder cancer, laparoscopic cystectomy was adopted by surgeons with advanced laparoscopic skills [45]. The procedure was primarily restricted to academic centers, owing to the technical challenges of laparoscopy in the pelvis [45,46]. Most recently, robotic approaches to cystectomy have become more popular among surgeons familiar with the technology through radical prostatectomy, although the urinary diversion continues to be performed extracorporeally in most cases [47].

Perioperative outcomes

The robotic approach to radical cystectomy is consistently associated with reduced blood loss and rates of transfusions, as shown in Table 4. The distinct disadvantage appears to be in terms of operative time compared with open surgery (ileal conduit 271 min, neobladder 312 min, mean [48]). One of the advantages of adopting robotic cystectomy has been a renewed focus on streamlining postoperative care. Recent reports of aggressive care pathways to reduce length of stay regardless of surgical approach have been successful at a high-volume academic center, drawing off practices commonplace in the general surgery literature such as foregoing nasogastric tubes and advancing diet regardless of bowel activity [49].

Postoperative outcomes: oncologic

Of the surgical cases highlighted in this article, radical cystectomy has the most to lose in terms of sacrificing oncologic principles when applying a novel surgical approach. First, negative surgical margins are more important for survival than for either partial nephrectomy or radical prostatectomy [50]. Robotic cystectomy appears to have equivalent rates of negative surgical margins compared with open series (4.2%) [50]. Second, the lymphadenectomy is more extensive, prognostic and may play a therapeutic role in oncologic outcomes [51]. Increasing the number of lymph nodes removed and the extent of lymphadenectomy dissection are arguably central to radical cystectomy outcomes [51,52]. The clinical series in Table 4 show similar lymphadenectomy outcomes for robotic surgery

compared with open series (median eight, 11 nodes for negative and positive cases, respectively) [52]. Overall, the present series are too immature to determine the long-term oncologic outcomes for robotic cystectomy.

Postoperative outcomes: functional

The functional outcomes for robotic-assisted radical cystectomy have not been reported. Although anecdotal experience suggests performing urinary diversion through a small extraction site (extracorporeal) or using robotic assistance (intracorporeal) may be more difficult compared with open surgery, the data evaluating long-term outcomes (e.g., ureteral stricture and stomal stenosis) are unknown. In addition, quality of life measures (e.g., Bladder Cancer Index) have not been reported in these patients [53].

Complications

The nonstandard approach to reporting surgical complications in the cystectomy literature makes comparing robotic outcomes difficult. Nevertheless, the rates of reported complications for the robotic approach vary from 8–16% for major to 36–49% for minor complications among the two largest series, comparable to open series (7.4% major and 38% minor complications) [48]. Long-term complication rates are not yet available.

Summary

Robotic-assisted radical cystectomy appears a safe and feasible approach with decreased blood loss and comparable initial oncologic outcomes. Most surgeons perform extracorporeal urinary diversions to minimize operative time. More importantly, renewed interest in aggressive postoperative care pathways for open and robotic approaches may streamline care for these patients, thereby minimizing their risk of hospital-acquired complications.

Expert commentary

Surgical approaches using robotic assistance in urologic oncology are increasing and offer several advantages over established techniques (i.e., laparoscopy and open surgery) including those of minimally invasive surgery, as well as increased surgeon comfort. However, the costs of robotic assistance in the operating room also exceed those of the other approaches. These excess costs are primarily borne by the hospital for acquisition, maintenance and limited use instruments. At this point, over 800 hospitals in the USA support robotic technology indicating financial barriers may not play an enormous role in preventing the spread of this approach. While the technology remains relatively new to the field of urology, especially for bladder and kidney cancer, it is especially important to capitalize on the opportunity to better understand those processes of care associated with better surgical outcomes.

Of paramount concern is the possibility that technology adoption may sacrifice, at least temporarily, the quality of care delivered to patients (i.e., consequences of the learning curve [54]). Therefore, understanding how best to identify and implement a standardized robotic approach to each of the oncology cases reviewed herein should be a top priority to ensure the optimal rollout of robotic technology to treat urologic cancers.

In this context, organizing large clinical registries and quality improvement collaboratives are two potential ways of discovering and implementing key processes of care. Identifying the overachievers, examining how they do it, and facilitating the implementation of their processes to underachieving providers has worked for other specialties. For example, a New England research consortium discovered that hospital differences in coronary bypass

mortality rates were actually related more to unrealized differences in patient care than to differences in case mix [55]. Using a combination of site visits, performance measures and anonymous feedback, cardiac surgery mortality rates declined by over 20%. Physician partnerships with Blue Cross Blue Shield in Michigan (USA) have also supported clinical outcomes registries linked to quality improvement initiatives [56].

So far, collaboratives to improve surgical quality have been limited in urologic oncology (e.g., COLD registry sponsored by Endocare™) [57]. Perhaps the success of the clinical care pathways at the University of North Carolina (NC, USA) for robotic cystectomy could be a nidus for a cystectomy registry [49]. Although it is arguable whether Intuitive Surgical is obligated to participate in sponsoring such a registry, it is probably necessary to make the broadest improvements in robotic surgical care. Establishing robotic surgery registries should be a priority for our professional societies and their memberships while the technology is dispersing.

One of the important unanswered questions in robotic surgery in urologic oncology is how to reconcile the differences in outcomes among high-volume providers and those who have less optimal outcomes. The primary data collection and analysis from the aforementioned surgical registries will detail important processes of care and outcomes, but only for those who participate. The expensive and resource intensive nature of registries may preclude some practices from participating. A central registry of hospitals who have acquired robotic technology and when would also allow investigators to evaluate population-based trends in the marketplace where the technology has dispersed.

Five-year view

The future of robotic surgery in urologic oncology, at least in the short term, will continue to flourish as overall outcomes appear to be no worse than those of open or laparoscopic surgery. The benefits to the patient are primarily those of minimally invasive surgery (i.e., decreased blood loss and length of stay), while their functional outcomes remain similar to those of experienced open surgeons. As residents are trained in robotic surgical approaches in urologic oncology, they will become more familiar with these approaches than with open surgery. However, for the practicing urologist, training in robotic surgery may take significantly more effort, at least in some cases, to attain competency. Because there are no current standardized credentialing systems for robotic surgery, identifying measures of surgeon competency and safety with the robotic surgical approach is needed [58,59]. In order to fully take advantage of the technology and use the collective experience of thousands of surgeons who care for urologic oncology patients, large-scale clinical registries and quality collaboratives are also needed to provide the evidence informing the best quality surgical care for the most patients.

Key issues

- Robotic surgery has exponentially increased in urologic oncology, specifically for radical prostatectomy, with increasing reports of radical cystectomy and partial nephrectomy.
- Outcomes for robotic-assisted radical prostatectomy in clinical series demonstrate decreased blood loss and length of hospital stay, with similar oncologic and functional outcomes to open and laparoscopic surgery. Population-based studies concur for the most part, although indicate increased rates of incontinence and erectile dysfunction diagnoses following minimally invasive prostatectomy.

- Robotic-assisted radical cystectomy has shown the expected benefits of minimally invasive surgery (i.e., decreased blood loss) with similar short-term oncologic outcomes and complication rates compared with open surgery. Long-term oncologic and functional outcomes are also needed.
- Partial nephrectomy, prohibitively complex laparoscopically for most urologists, is feasible with the robotic approach, especially after gaining familiarity with robotic prostatectomy. Robotic technology may allow urologists previously inexperienced with laparoscopy to conduct minimally invasive nephron-sparing surgery.
- The costs of robotic surgery are consistently greater than either laparoscopy or open surgery and are primarily covered by the hospital. Approximately US\$1.4 million for purchase, US\$100,000 for annual maintenance and US\$1000 for limited use instruments per case exacerbate the cost discrepancy. On the other hand, over 800 hospitals have acquired over 1200 robots in the USA, indicating the desire to adopt the technology.
- Robotic-assisted surgery is billed and reimbursed under a laparoscopic billing code making the use of administrative data difficult to evaluate population-based outcomes. Separate billing codes would make future comparative effectiveness studies more feasible.
- An important unanswered question in robotic surgery in urologic oncology is how to reconcile the differences in outcomes among overachievers and providers with less optimal outcomes. Establishing robotic surgery registries to better understand these differences should be a priority for our professional societies and their memberships to broadly improve the quality of future robotic surgery in urologic oncology.

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Table 1

Cost of robotic surgery in urologic oncology.

Study (year)	Institution	Costs assessed	Cost (US\$)		Ref.
			Open	Laparoscopic	
Radical prostatectomy					
Bolenz <i>et al.</i> (2010)	UT Southwestern	Direct hospital costs	\$4437	\$5687	[60]
Mouraviev <i>et al.</i> (2007)	Duke University	Direct hospital costs	\$5259		[61]
Burgess <i>et al.</i> (2006)	Tulane University	Total hospital charges	\$31,518		[62]
Radical cystectomy					
Smith <i>et al.</i> (2010)	University of North Carolina	Hospital costs	\$14,608		[63]

Robotic radical prostatectomy series^{†‡}.

Table 2

Study (year)	Institution	Cases			Perioperative			Oncologic			Functional		Ref.
		OR time (min)	Blood loss (ml)	Length of stay	Transfusion (%)	Complication (%)	Anastomotic stricture (%)	Overall PSM (%)	Urinary continence at 12 months (%)	Potency at 12 months (%)			
Lasser <i>et al.</i> (2010)	Brown University	239	232	2.4	3.8	17.1		18.8				[64]	
Krambeck <i>et al.</i> (2009)	Mayo Clinic	294	236	≤2 days 89.2%	5.1	8		15.6	91.8		70	[65]	
Murphy <i>et al.</i> (2009)	Epworth Hospital – Australia	400	186	3.1	2.5	15.8		19.2	91.4		62	[66]	
Patel <i>et al.</i> (2008)	Global Robotics Institute	1500	105	1 day 97%	0.5	4.3		9.3				[14]	
Zorn <i>et al.</i> (2007)	University of Illinois, Chicago	300	282	1.4	1.7	2.3		20.9	90		80	[25]	
Patel <i>et al.</i> (2007)	Ohio State University	500	130	POD 1 in 97%	0.4	0.4		9.4	97		78	[19]	
Mottrie <i>et al.</i> (2007)	Onze-Lieve-Vrouw Hospital, Belgium	184	171		0.5	n = 22 (percentage not available)		15.7	95% at 6 months			[67]	
Menon <i>et al.</i> (2007)	Henry Ford	2652	154	1.14	0 intraoperative	2.3		13	84		70	[20]	
Hu <i>et al.</i> (2006)	Brigham and Women's	322	186		1.6	14.6	0.6					[68]	
Van Appeldorn <i>et al.</i> (2006)	Melbourne	150	191–292	3.4	n = 4 (percentage not available)	3.3		17.3				[69]	
Joseph <i>et al.</i> (2006)	University of Rochester	325	180	POD 1 in 96%	1.3	n = 32	2.2	13	96% at 6 months		70	[70]	

[†]The series in this table are not the findings of a systematic review or a meta-analysis of the literature.

[‡]Some references have been adapted from a systematic review by Ficarra *et al.* [11].

OR: Operating room; POD: Postoperative day; PSM: Positive surgical margin.

Robotic partial nephrectomy series^{†‡}.

Table 3

Study (year)	Institution	Cases (n)	Tumor size (cm)	Malignant (%)	Perioperative				Ref.			
					OR time (min)	Warm ischemia time (min)	Blood loss (ml)	LOS (days)		Conversion (n)	Urine leaks (n)	Positive surgical margin
Scoll <i>et al.</i> (2010)	Fox Chase Cancer Center	100	2.8	81.3	206	25.5	50	3.2	2	2	5 (5.7%)	[71]
Gong <i>et al.</i> (2010)	City of Hope Hospital	29	3.0	96.6 [§]	197	25	220	2.5	0	0	0	[72]
Benway <i>et al.</i> (2009)	Three academic centers [¶]	129	2.8	67.2	189	19.7	155	2.4	2 OPNx	3	5 (3.9%)	[39]
Michli <i>et al.</i> (2009)	Cooper University Hospital	20	2.7	70	142	28.1	263	2.8	1 to find needle, 1 delayed RN for abscess	0	0	[73]
Wang <i>et al.</i> (2009)	Washington University	40	2.5	62.5	140	19	136	2.5	1 to robotic cryotherapy, 1 to OPNx	1	1	[42]
Ho <i>et al.</i> (2009)	Medical University of Innsbruck	20	3.5	65.0	83	21.7	189	4.8	0	0	0 [#]	[74]
Deane <i>et al.</i> (2008)	UC Irvine	11	3.1	100	229	32.1	115	2.0	0	0	0	[75]
Aron <i>et al.</i> (2008)	Cleveland Clinic	12	2.4	83.3	242	23	329	4.7	2 laparoscopic PNx	–	0	[76]
Rogers <i>et al.</i> (2008)	National Institutes of Health	8 (14 tumors)	3.6	87.5 ^{††}	192	31	230	2.6	0	0	0	[77]
Kaul <i>et al.</i> (2007)	Henry Ford	10	2.3	80	155	21	92	1.5	1 exploration for bleeding	1	0	[78]
Caruso <i>et al.</i> (2006)	New York University	10	1.95	80	279	26.4	240	2.6	1 to hand assist, 1 to open procedure	0	0	[79]
Gettman <i>et al.</i> (2004)	Mayo Clinic	13	3.5	76.9	215	22	170	4.3	0	0	1	[80]

[†]The series in this table are not the findings of a systematic review or a meta-analysis of the literature.

[‡]Some references have been adapted from Scoll *et al.* [66].

[§]Of 29 patients, one had oncocytoma, and two had hybrid oncocytic tumors of unknown malignant potential.

[¶]Academic centers included Henry Ford Health System, NYU Langone Medical Center and previously reported cases from Washington University.

[#]Only reported for malignancy.

^{†‡}Of eight patients, one had oncocytoma, two had hybrid oncocytic tumors of unknown malignant potential.

LOS: Length of stay; OPNx: Open partial nephrectomy; OR: Operating room; PNx: Partial nephrectomy; RN: Radical nephrectomy.

Robotic radical cystectomy series^{†‡}.

Table 4

Study (year)	Institution	Cases (n)	Conduit	Perioperative					Oncologic		Ref.		
				OR time (min)	Blood loss (ml)	Transfusion (n)	LOS (days)	Conversion (n)	Complications			Positive surgical margin (n)	
									Major	Minor			
Pruthi <i>et al.</i> (2010)	University of North Carolina	100	61 38	276	271	0	4.9	0	8%	36% (overall)	0	19	[47]
Kauffman <i>et al.</i> (2009)	Cornell University	79	46 25	330 450	300 370	2	5.0	0	49% of patients 16 events	 62 events	6 [‡]	18.4	[81]
Schumacher <i>et al.</i> (2009)	Karolinska Institute	18	5 13	501	525		12	3			1–T4	20	[82]
Lee <i>et al.</i> (2009)	Columbia University	6	5 1	296	325 150		12	0	3 of 6 patients – ileus, infection		0	23	[83]
Woods <i>et al.</i> (2008)	Tulane, Mayo Arizona	27		400	277	3		0	33%		2–T4	12.3	[84]
Murphy <i>et al.</i> (2008)	Guy's & St Thomas' NHS Foundation Trust	23	19 4	368 517	278	1	11.6	0	26%		0	16	[85]
Yuh <i>et al.</i> (2008)	SUNY Buffalo/Roswell Park	54	Flat disease Bulky disease	294 334	450 615	0 7		0 2	0 0		0 0	20 15	[86]
Rhee <i>et al.</i> (2006)	University of Virginia	7	Ileal conduit	638	479	4	11	0			0		[87]
Galich <i>et al.</i> (2006)	University of Nebraska	13	6 5	697	500	7	8	0	15.4%		0		[88]
Menon <i>et al.</i> (2003)	Henry Ford	17	3 14	260 308	150			1			0	4–27	[89]
Beecken <i>et al.</i> (2003)	J.W. Goethe Univ. Frankfurt	1	Neobladder intracorporeal	510	200			0	0	0	0		[90]

[†]The series in this table are not the findings of a systematic review or a meta-analysis of the literature.

[‡]No data on disease stage for positive surgical margins, although 41% of patients had pT3/T4 disease.

LOS: Length of stay; OR: Operating room.