Robot-assisted urologic surgery in 2010 – Advancements and future outlook

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Abstract

Robotic surgery is a cutting edge and minimally invasive procedure, which has generated a great deal of excitement in the urologic community. While there has been much advancement in this emerging technology, it is safe to say that robotic urologic surgery holds tremendous potential for progress in the near future. Hence, it is paramount that urologists stay up-to-date regarding new developments in the realm of robotics with respect to novel applications, limitations and opportunities for incorporation into their practice. Robot-assisted surgery provides an enhanced 3D view, increased magnification of the surgical field, better manual dexterity, relatively bloodless field, elimination of surgeon's tremor, reduction in a surgeon's fatigue and mitigation of scattered light. All these factors translate into greater precision of surgical dissection, which is imperative in providing better intraoperative and postoperative outcomes. Pioneering work assessing the feasibility of robotic surgery in urology began in the early 2000's with robot-assisted radical prostatectomy and has since expanded to procedures such as robot-assisted radical cystectomy, robot-assisted partial nephrectomy, robot-assisted nephroureterectomy and robot-assisted pyeloplasty. A MEDLINE search was used to identify recent articles (within the last two years) and publications of specific importance, which highlighted the recent developments and future direction of robotics. This review will use the aforementioned urologic surgeries as vehicles to evaluate the current status and future role of robotics in the advancement of the field of urology.

Key Words: Bladder, cystectomy, laparoscopy, minimally invasive surgery, nephroureterectomy, nephrectomy, prostate, prostatectomy, pyeloplasty kidney, robotics

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INTRODUCTION

Urology is a dynamic surgical discipline, which has undergone many developments and refinements over the past few decades. The advent of laparoscopic surgery was a major breakthrough in the urologic landscape and provided a minimally invasive alternative to conventional open procedures.[1] The decreased intraoperative estimated blood loss (EBL), shorter hospital stay and quicker return to function makes laparoscopic urologic surgery extremely appealing to physicians and patients alike.[2] The bottleneck with respect to laparoscopic urologic surgery seems to be the relatively long learning curve that is required for a surgeon to achieve proficiency.[2]

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Robotic surgery using the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA) seems to remedy this extended learning curve[3] while offering the same, if not better, advantages as laparoscopic surgery.[2] The wristed instruments allow for improved dexterity in the confines of the pelvis and the robot is able to correct any tremor the surgeon may have.[2] In addition, optimal port placement translates into non-collision of the robotic arms and can be instrumental in performing a more precise surgery.[4] This, in conjunction with a 3D camera that can confer 15-fold magnification of the surgical field, allows for better preservation of critical anatomical structures, which translates into enhanced intraoperative and postoperative outcomes.[5] Numerous studies show that robotic surgery offers less intraoperative EBL, shorter hospital stays, less postoperative pain, decreased medical complications and quicker return to function than its open counterpart.[2,5,6] The frequently cited drawbacks of robotic surgery in the status quo relate to issues of cost, lack of tactile feedback and over-reliance on the patient side surgeon.[7] Recent advances such as the Fourth arm are beginning to provide more freedom to the robotic console surgeon,[8] while widespread adoption by more high-volume centres across the globe will help mitigate costs. The need for tactile feedback is somewhat remedied by the enhanced visual field and dexterity of robotic instrumentation, and it is important to note that the patient side surgeon has tactile feedback, which can provide insight into how to assist the console operator. New developments such as single-port and natural-orifice approaches are expanding the realm of possibility for this cutting-edge modality and, in our opinion, underscore the immense interest regarding the use of robotics in urology.[9]

This article will provide an overview of recent developments in various robotic procedures and then explore the future direction of robotic surgery in the development of the field of urology.

METHODS

A MEDLINE search was performed for keywords such as "robotics", "robot-assisted surgery", "laparoscopy", "robot-assisted radical prostatectomy", "robot-assisted radical cystectomy", "robot-assisted pyeloplasty", "robot-assisted partial nephrectomy", "robot-assisted pyelolithotomy", to name a few. Articles were selected that fit the scope of the topic with special consideration given to articles published in 2009-2010, and also landmark papers in the field and publications describing the future outlook of robot-assisted urologic surgery.

PROSTATE

Robot-assisted radical prostatectomy

Robot-assisted radical prostatectomy (RARP) is rapidly gaining acceptance in the urologic community as a safe and efficacious treatment option for localised prostatic adenocarcinoma with comparable oncological outcomes as open and laparoscopic counterparts.[10] RARP seems to have overtaken retropubic radical prostatectomy (RRP) as the treatment of choice due to patient preference for minimally invasive surgical options.[5] Patient intrigue coupled with aggressive marketing of robotic surgery means that the majority of prostatectomies performed in the status quo utilises the da Vinci platform.[5] RARP has come a long way since the first large series appeared in the literature,[11] and a recent analysis by Menon *et al*. found that RARP provided acceptable rates of biochemical recurrence at 5 years for clinically localised prostate cancer.[12] This study was especially promising as it included a large cohort of patients for analysis and demonstrated that when an experienced and well-trained surgeon performs RARP, adequate long-term oncologic efficacy is obtained.[12] Newly emerging evidence reinforces this point, with RARP having lower rates of positive surgical margins than RRP and laparoscopic radical prostatectomy (LRP).[10]

In one of the largest studies to date, Menon *et al*. found that their Vattikuti Institute prostatectomy (VIP) technique achieved comparable oncological outcomes to conventional nerve-sparing modalities but offered 84% of patients total urinary control at a mean 12-month follow-up, with a further 8% using liners for reassurance purposes.[13] Furthermore, the VIP technique utilised the increased dexterity of the robot's wristed instruments and high-magnification 3D view to ensure preservation of the lateral prostatic fascia, which conferred better erectile function postoperatively as compared to conventional open surgery.[11,13] The aforementioned results were corroborated in a meta-analysis from various high-volume centres, which revealed that RARP had better return of urinary continence and improved sexual function postoperatively than after open and laparoscopic modalities.[10] Patel *et al*. recently reported that the age of the patient had a significant effect on potency after RARP, with younger men having quicker return to sexual function at 6 weeks, 3, 6 and 12 months postoperatively.[14] Complication rates after RARP in a recent study of 2,500 patients were found to be 5.08%, with the vast majority of complications being either Clavien grade I or II.[15] RARP also seemed to have decreased intraoperative EBL, risk of intraoperative transfusion and anastomotic strictures[5] in comparison with RRP.[10] Coupled with the fact that RARP seems to have a shorter learning curve than LP,[16] it appears that the use of robotic surgery in the realm of localised prostatic adenocarcinoma will reach ever greater heights.

BLADDER

Robot-assisted radical cystectomy

In 2010, there are estimated to be over 70,000 new cases of cancer of urinary bladder in the US, which account for over 14,000 deaths.[17] The probability of developing carcinoma of the bladder increases as an individual gets older; moreover, in patients over the age of 80, bladder cancer becomes the fourth highest killer.[17] Therefore, in older patients who are acceptable surgical candidates, it is imperative that we utilise surgical techniques that will minimise stress inflicted to the body and allow for a smoother return to function. Robot-assisted radical cystectomy (RARC) offers an attractive minimally invasive alternative to the current gold standard of open radical cystectomy (ORC) for muscle-invasive bladder cancer and high-risk non-muscle–invasive disease.[18] The interest generated since the initial description of RARC[19-21] has been immense and larger case series are now appearing in the literature. Pruthi *et al*. reported their initial experience with 100 patients who underwent RARC and found that there were no positive surgical margins and that the mean hospital stay was 4.9 days, with mean bowel movement being at 2.8 days.[22] The complication rate appeared to be 36%, with 8% of these being Clavien grade III or higher.[22] In a mean follow-up of 21 months, the authors reported that 15 patients manifest recurrent malignancy with 6 individuals succumbing to their disease.[22] The same group reported the first prospective randomised trial of ORC versus RARC in 41 patients and found that there was no significant difference in postoperative complication rate (33% RARC vs. 50% ORC; $P = 0.279$) and mean hospital stay (5.1 days RARC vs. 6.0 days ORC; $P = 0.239$).[23] The investigators reported that RARC had a longer operative time than ORC (4.2 vs. 3.5 hr; $P < 0.001$), but that there was less intraoperative EBL associated with RARC (258 vs. 575 ml; $P < 0.001$).[23] RARC also appeared to confer quicker time-to-bowel movement and time to flatus with less use of narcotic analgesics for pain relief.[23] This landmark study used a prospective randomised clinical trial to demonstrate that RARC was not inferior in comparison to ORC and matched up favourably with respect to various intraoperative and postoperative outcomes.[23] While there is still much work that needs to be done to assess long-term oncological outcomes, RARC is an evolving technique that affords patients and physicians alike an efficacious minimally invasive treatment option in the treatment of bladder cancer.

Robot-assisted partial cystectomy

Robot-assisted partial cystectomy (RAPC) for the treatment of malignant bladder lesions was recently performed in three patients and found to be technically feasible with acceptable intraoperative and postoperative outcomes.[24] We have had similar experience at our institution with RAPC in three patients and found that mean operative time, mean EBL and average hospital stay were all within satisfactory limits.[25] The procedure also seems to confer satisfactory short-term oncological outcomes and provides a bladder sparing surgical option in select patients.

KIDNEY

Robot-assisted partial nephrectomy

Robot-assisted partial nephrectomy (RAPN) was first described in 2004 by Gettman *et al*.[26] It has since enjoyed widespread adoption at many high-volume centres. Recent evidence suggests that RAPN offers equivalent oncological control to open partial nephrectomy (OPN) and laparoscopic partial nephrectomy (LPN) while providing the additional benefit of shorter hospital stay, less intraoperative EBL and shorter warm ischaemia time (WIT).[27] In an analysis of over 100 RAPN and LPN cases, no significant difference was found in the rate of focal positive margins between the two modalities.[28] While it may be too early to assess long-term oncological control in this relatively new surgical technique, early results from a series of 100 RAPN showed no tumour recurrence at 12 months.[29] Intraoperative EBL during partial nephrectomy has been shown to be an accurate predictor of early and late recovery of kidney function,[30] and considering that 26% of patients undergoing partial or radical nephrectomy have some degree of renal impairment preoperatively,[31] RAPN holds the promise of better long-term nephron preservation. Studies also show that RAPN generally provides shorter WIT as compared to LPN.[27] This seems to hold true even in cases that require calyceal repair, have complex renal tumours or have multiple tumours.[27] New evidence reveals that RAPN has a relatively short learning curve with regard to parameters such as acceptable WIT and total operative time.[3] All the aforementioned advantages suggest, in our opinion, that RAPN will garner widespread acceptance as the minimally invasive treatment of choice for small renal masses. Figure 1 shows a stepwise demonstration of RAPN.

Early results from trials of selective renal artery clamping in efforts to further decrease renal ischaemic damage have been promising and are especially attractive in patients with already compromised kidney function.[32] We recently compared the efficacy of clamping the renal artery alone versus both the renal artery and vein in 95 patients and found that clamping only the renal artery was associated with decreased EBL, decreased WIT, decreased operative time and less increase in serum creatinine (unpublished data). The feasibility of natural orifice translumenal endoscopic surgery (NOTES) for RAPN was recently assessed in a porcine model and while WIT was within acceptable standards, the great technical and surgical difficulty conferred with existing robotic instrumentation made the procedure especially laborious.[33] We believe that significant modifications in robotic design are necessary before such techniques are ready to enter the mainstream.

Robot-assisted pyeloplasty

Robot-assisted pyeloplasty (RAP) provides a viable alternative to the current gold standard open approach for the treatment of ureteropelvic junction (UPJ) obstruction.[34] Gettman *et al*. reported one of the earlier comparisons of RAP with the laparoscopic approach and found that the robotic method was

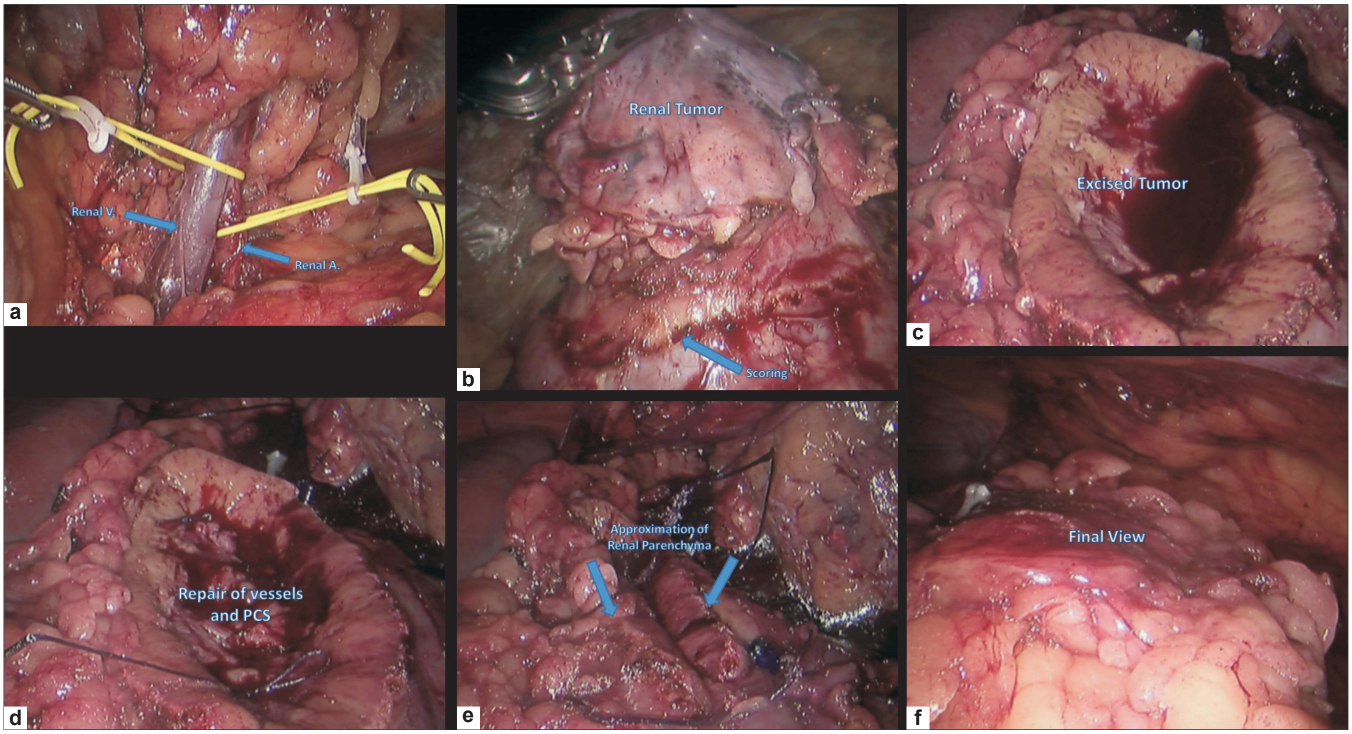

Figure 1: Stepwise demonstration of robot assisted partial nephrectomy; (a) Dissected renal hilum demonstrating renal artery (RA) and renal vein (RV); (b) Dissected renal tumor and renal scoring performed prior to clamping the RA; (c) View showing the renal parenchyma after tumor excision; (d) Repair of pelvicalyceal system (PCS) and small renal vessels; (e) Renal parenchyma reconstruction (renorrhaphy); and (f) final view showing closure of Gerota's fascia

associated with less operating time.[35] Gupta and colleagues reported their initial experience with 86 patients and found that RAP was associated with a mean operative time of 121 minutes (mean anastomosis time of 47 minutes), mean EBL of 45 ml and mean hospital stay of 2.5 days.[34] Most importantly, the success rate was found to be 97% at a mean follow-up of 13.6 months.[34] A nonrandomised comparison of 30 patients who underwent RAP versus 30 patients who had laparoscopic pyeloplasty showed that RAP had decreased average operating time (98.54 vs. 142.25 min; $P < 0.001$), shorter suturing and antegrade stenting time (33.21 vs. 57.11 min; $P < 0.001$) and less dissection time (33.11 vs. 51 min; $P < 0.001$).[36] RAP also provided less average EBL (40.36 vs. 101 ml; $P = 0.035$) and shorter mean hospital stay (2.5 vs. 5.5 days; $P = 0.036$).[36] It is important to note that all 60 procedures in the above study were performed by a single surgeon who was an expert in both robotic and laparoscopic modalities and had passed the learning curve for both procedures. The authors thought that the robotic approach correlated more than laparoscopy with ease of dissection, efficiency in the tailoring of pelvic flaps and elegance of suturing.[36] Recent reports have shown that RAP can be employed efficaciously in cases of complicated UPJ obstruction, which include horseshoe kidney, malrotated kidney, ectopic kidney and giant hydronephrosis, to name a few.[37] Gupta *et al.* also described a transmesocolic approach to RAP for left UPJ obstruction in 24 patients, which had a perfect success rate at a mean 1-year follow-up with no repeat obstructions.[38] We have experience of over 100 cases of RAP and believe that it is an effective surgical technique for correction of UPJ obstruction.

Robot-assisted nephroureterectomy with excision of the bladder cuff

Upper tract transitional cell carcinoma (TCC) is treated in the status quo with open nephroureterectomy with excision of the bladder cuff. Early feasibility studies show that robot-assisted nephroureterectomy with excision of the bladder cuff (RANUT) provides a viable treatment option for this long and technically challenging procedure.[39] Eandi and colleagues reported their initial experience with 11 patients who underwent RANUT for upper tract TCC and showed promising short-term intraoperative and postoperative outcomes with regard to oncological efficacy, hospital stay, EBL and operative time.[40] This was the first case series to utilise a completely robotic approach but required undocking and redocking of the da Vinci system during the procedure to allow for better surgical access. As can be inferred, this increased total operative time by 10-15 minutes.[40] We have recently assessed the feasibility of a new technique for RANUT with excision of the bladder cuff that does not require undocking of the robot.[41] In what comprised the largest series of RANUT till date, 15 patients underwent RANUT with excision of the bladder cuff for upper tract TCC.[41] The mean operative time was 184 minutes, average EBL was 103 ml and mean hospital stay was 2.7 days.[41] More importantly, there were no complications, no positive surgical margins and no cancer recurrence on short-term follow-up.[41] Compared to other series of RANUT, Hemal and colleagues reported that their technique was associated with less EBL, shorter operative time and less hospital stay.[41] They attribute this to the strategic placement of ports, which allowed for a seamless transition between the nephrectomy portion and excision of bladder cuff part of the case.[41] Additionally, the careful handling of the ureter and tactical bladder reconstruction were also instrumental in improved intraoperative and postoperative outcomes.[41]

Robotic management of urolithiasis

Percutaneous nephrolithotomy is the current treatment of choice for large renal stones but robot-assisted extended pyelolithotomy (REP) provides an appealing option in cases of staghorn calculi and in patients undergoing concurrent RAP.[42-43] Hemal and coworkers found that in six patients who underwent REP or robot assisted pyelolithotomy, the mean operative time was 106 minutes and EBL was less than 50 ml in all cases.[44] One patient required conversion to an open procedure because the renal calculus could not be localised. The study also assessed 29 cases of RAP with concomitant pyelolithotomy for UPJ obstruction with a secondary stone, and deemed the procedure to have a 97% symptomatic efficacy rate.[44]

FEMALE UROLOGY

Robotic management of urinary fistula

The robotic repair of primary vesicovaginal fistula was first described in five patients by Sundaram *et al*. in 2006 and was associated with acceptable postoperative outcomes.[45] In a matched comparative analysis of open versus robotic repair of recurrent vesicovaginal fistula, robot-assisted techniques were found to be more effective in regard to better morbidity related outcomes while providing similar postoperative success rates.[46] Hemal and coworkers presented the first report of robotic repair of complex vesicouterine fistula in three patients and established the procedure to be efficacious with or without concurrent robotic hysterectomy.[47] Feasibility studies have found complex ureterovaginal fistulas to be amenable to robotic ureteroneocystostomy with the robot conferring enhanced identification of relevant anatomical structures.[48]

URETER

Robot-assisted ureteral surgery

Robotic assistance is increasingly being utilised in a variety of urologic procedures and is furthering the applicability of this exciting technology. Hemal and colleagues recently reported the feasibility of robotic intracorporeal or extracorporeal ureteric tapering with ureteroneocystostomy for primary symptomatic obstructive megaureter.[49] Various ureteral pathologies seem to be especially amenable to robotic repair in the hands of an experienced surgeon with Hemal *et al*. demonstrating the feasibility of robotic ureteroneocystostomy, ureteroureterostomy, ureteral stump excision and ureterosciatic hernia repair.[50] Table 1 shows a variety of ureteral pathologies that have been managed with robotic assistance. While long-term data is obviously crucial in assessing the extended viability of all the procedures mentioned above, it seems that the dissemination of robotics into all aspects of urology has well and truly begun.

CONCLUSION

Robotics has modernised the field of urology and has been crucial in providing patients and physicians with another

Table 1: Current status of robot-assisted urologic surgery

Prostate	Kidney	Ureter
Robot-assisted radical prostatectomy[5,11-16]	**Robot-assisted partial nephrectomy** (malignant or benign disease)[26-29,32]	Robot-assisted ureteroneocystostomy[49-50]
Robot-assisted simple prostatectomy	Robot-assisted radical nephrectomy (malignant or benign disease)	Robot-assisted ureteroureterostomy[50]
Bladder	**Robot-assisted pyeloplasty**[34-38]	Robot-assisted ureterectomy[50]
Robot-assisted radical cystectomy[18-23]	Robot-assisted nephroureterectomy with or without excision of bladder cuff (malignant or benign disease)[39-41]	Robot-assisted distal ureterectomy with re-implantation[50]
Robot-assisted partial cystectomy[24-25]	Robot-assisted heminephroureterectomy	Robot-assisted ureterolithotomy[50]
Robot-assisted diverticulotomy	Robot-assisted extended pyelolithotomy (staghorn calculi or multiple stones)[42-44]	Robot-assisted ureterolysis[50]
Robot-assisted anterior pelvic exenteration	Robot-assisted pyeloplasty and pyelolithotomy[44]	Robot-assisted ureterolympholysis[50]
Female urology	Robot-assisted pyelo-pyeloplasty and pyelolithotomy[44]	Robot-assisted ureteral stump excision[50]
Robot-assisted vesicovaginal fistula repair[45-46]	Robot-assisted renal cyst decortication/ excision	Robot-assisted ureterosciatic hernia repair[50]
Robot-assisted vesicouterine fistula repair[47]	Robot-assisted donor nephrectomy	Robot-assisted ureteropyelostomy
Robot-assisted ureterovaginal fistula repair[48]	Robot-assisted nephropexy	Robot-assisted ureterocalicostomy
Robot-assisted sacrocolpopexy	Robot-assisted management of chyluria	Adrenal
Robot-assisted bladder neck suspension		Robot-assisted adrenalectomy

Bold = Commonly used procedures at present surgical modality in the management of a vast array of urologic afflictions. The relatively short learning curve of robotic surgery is providing a comparative advantage over laparoscopic techniques and slowly making robotics the minimally invasive modality of choice. RARP signaled the commencement of the robotic revolution, and the past decade has been marked by tremendous progress in the use of minimally invasive surgery. Long-term data have recently started trickling down about the oncological outcomes provided by RARP and results indeed seem promising. While we await long-term follow-up of procedures such as RAPN and RARC, it appears that the short and intermediate term parameters of efficacy compare favourably to accepted standards and foreshadow the increased dissemination and utilisation of robot-assisted surgery in urology.

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