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Robotic-Assisted Surgery: Urological Applications and Outcomes

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Abstract

The introduction of robotic technology and minimally invasive surgical techniques has revolutionized the field of urological surgery over the last 25 years. Robotic technology has been proven to be both safe and efficacious in the management of several urological malignancies and benign urological conditions. While some robotic applications have been well established, others are still at varying stages of evolution. In comparison to conventional open approaches, the robot has been shown to enhance intraoperative visualization and precision, mitigate surgeon tremor, hasten post-operative recovery, and shorten length of hospital stay for certain indications. This technology has not yet been universally adopted, however, due to its relatively high cost, longer associated operative times, and limited outcomes data. We herein review the current applications, outcomes, and drawbacks of robotic technology within the field of urological surgery and speculate on the future directions and implications within the field.

INTRODUCTION

Minimally invasive surgery has revolutionized the field of urology more than any other surgical specialty. Driven by the expanding role of technology in the medical field, urologists have been among the first to adapt minimally invasive surgical approaches via endoscopic procedures. Shortly thereafter, robots were introduced to the surgical field. The aim of minimally invasive surgery is to decrease morbidity, hospital stay and post-operative discomfort while attempting to make procedures more precise and technically easier. Over the past 25 years, robotic platforms have been used to enhance surgical procedures, and their growing role continues to evolve.

Robot-assisted procedures were first performed in 1985, when Kwok et al. utilized a modified robot called the Programmable Universal Machine for Assembly (PUMA) 560® to aid in computer tomographic (CT)-guided stereotactic brain surgery.¹ In orthopedics, the ROBODOC® Surgical System was introduced to aid in total hip replacements.² The first urological use of the robot was pioneered in 1989 by Davis et al. with the advent of the Probot system,³ which was used to guide a rotating blade to complete a transurethral resection of the prostate. In 1993 the US Food and Drug Administration (FDA) approved the

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Automated Endoscopic System for the Optimal Positioning (AESOP) device (Computer Motion, Inc., Berkely, CA, USA).⁴ Together with EndoAssist, AESOP helps direct the robotic arm that holds the laparoscope by using voice, pedal, or infrared motion control, thereby replacing the surgical assistant during laparoscopic surgery.⁵

In 1997, the da Vinci® Surgical System, the only telerobotic system available in the market, was first used to perform cholecystectomy.⁶ This is a master-slave system in which the operating surgeon sits at a console remote from the patient and controls three or four robotic arms by hand movements and foot pedals. Since then, it took four more years before Intuitive Surgical, Inc. (Sunnyvale, CA) received FDA approval for prostatic surgery with this system.

There are several advantages of robotic-assisted surgery over conventional laparoscopy. These include 3-dimensional visualization, mitigation of surgeon tremor, up to 10× magnified images of the surgical field, and expanded range of motion. These instruments provide seven degrees of freedom as compared to the five with conventional laparoscopy, which can be particularly helpful in intracorporeal suturing. In spite of these advantages, however, this technology has not yet been universally adopted due to its high cost, longer associated operative times, and limited outcomes data. We herein review the current applications, outcomes, and drawbacks of robotic technology within the field of urological surgery and speculate on the future directions and implications within the field.

APPLICATIONS AND OUTCOMES

Robotic technology has been utilized in the management of both urological malignancies and benign urological conditions. While some robotic applications have been well established, others are still at varying stages of evolution. Common applications of the robot for malignant indications have included radical prostatectomy, radical nephrectomy, partial nephrectomy, radical cystectomy, and radical lymph node dissection. Applications for benign indications have included abdominal sacrocolpopexy, pyeloplasty, donor nephrectomy, adrenalectomy, ureteral reimplantation, vesico-vaginal fistula repair, ileal conduit and cystoplasty, ureterolysis, colposuspension, and vaso-vasostomy. We focus our ensuing discussion on the more well-established applications of the robot, while deferring less established or experimental applications beyond the scope of the current review.

Robotic Surgery in Urological Malignancies

Prostatectomy—The most common application of the robot has been seen in the treatment of localized prostate cancer. Robotically assisted laparoscopic radical prostatectomy (RALP) has been gaining widespread acceptance as the gold standard surgical approach for localized prostate cancer, replacing the traditional open retropubic approach to radical prostatectomy. The number of RALP performed annually in the US increased from 1% of all prostatectomies in 2001 to 40% in 2006–2007.⁷ Currently, an estimated 80% of prostatectomies in the US are performed using robotic assistance.⁸ Since the first RALP procedure described by Binder et al.⁹ in 2000, Menon et al. developed the most commonly used technique, the VattiKuti Institute Prostatectomy (VIP).¹⁰ A number of modifications in the VIP technique have been developed to preserve the neurovascular bundle in an attempt to

improve potency rates.^{11, 12} Higher continence rates have also been observed at 12 months with RALP techniques.^{13, 14}

Data comparing the efficacy and outcomes of RALP to traditional open radical prostatectomy have been published. In a systematic review by Ficarra et al. both laparoscopic prostatectomy and RALP had significantly lower blood loss, shorter hospital stay and lower complication rates when compared to the open approach.¹³ However, they both involved longer operative times than the open prostatectomy. The rate of positive surgical margins was similar between all three techniques. The continence and potency rates were also similar between all three modalities. The surgical outcomes and complication rates vary by operator experience.¹⁵ Based on the data available, RALP is a safe and effective option for the surgical treatment of localized prostate cancer. Although no single study has yet proven superiority of RALP over the traditional open prostatectomy, longer follow-up data are still awaited.

Nephrectomy for Malignant Indications—The second most common application of robotic technology to urologic surgery is the robotic nephrectomy, particularly partial nephrectomies for small renal tumors. Small renal lesions are conducive to nephron-sparing surgery. Partial nephrectomy for lesions < 4 cm has become the standard of care, which provides better long-term results and preservation of renal function in comparison to radical nephrectomy.¹⁶ The robotic-assisted partial nephrectomy was first reported in 2004 and has since gained acceptance as a viable alternative to the open approach.¹⁷ Several reports have shown that robotic-assisted partial nephrectomy is safe, with acceptable pathological and functional outcomes.^{18, 19} These results are very promising and show comparable outcomes to open and laparoscopic approaches.

Cystectomy—The use of the da Vinci robotic system has been extended to radical cystectomy for the treatment of muscle-invasive bladder cancer. Menon et al. and Beecken et al.^{20, 21} published the first series on robotic cystectomies. Initially entailing an average of eight to nine hours per case in earlier series, these technically complex procedures have been reduced to an average operative time of four to six hours per case at experienced centers.^{22, 23} The most important aspect of this procedure is the type of urinary diversion, which can be performed either intra- or extracorporeally. While most centers perform extracorporeal diversion, only a few centers have reported total intracorporeal neobladder reconstruction.^{24, 25} The intracorporeal approach is challenging technically and may take up to an average of nine to thirteen hours, limiting its widespread acceptance and confining the approach to high volume centers only.²⁶

Pruthi et al. published their experience with robotic cystectomies in 100 consecutive patients demonstrating low complication rates without compromising surgical outcomes (0% positive margin rates).²⁷ Others have compared open radical cystectomies with robotic cystectomies in prospective studies on 187 patients.^{22, 28} They report similar operative time between the two groups, but significantly lower blood loss, blood transfusion rates, and length of hospital stay in the robotic group. Robotic cystectomy for muscle invasive bladder cancer remains in its infancy, and the long-term outcomes are still awaited to justify its widespread use.

Robotic Surgery in Benign Urological Conditions

Nephrectomy—Use of the conventional laparoscope for removing a kidney for benign indications has gained widespread acceptance and is considered the standard of care. Robotic manipulators to facilitate laparoscopic nephrectomies such as AESOP have been described,²⁹ but the first robotic-assisted laparoscopic nephrectomy was reported in 2001.³⁰ Since then multiple reports describing robotic-assisted nephrectomy have been published, but none of them has shown a clear advantage of the robot over the laparoscope; nonetheless, robotic technology maintains intraoperative dexterity, precision and ergonomics.

Pyeloplasty—Robotic pyeloplasties have been reported in both adult and pediatric populations for the treatment of ureteropelvic junction obstruction. The benefits of minimally invasive surgery are apparent in this challenging benign condition as open repair requires a larger incision, longer hospital stay and higher morbidity. A number of studies have reported comparable success rates to open and standard laparoscopic approaches.³¹ In a nonrandomized study, Gettman et al. reported shorter operative and anastomotic times with robotic-assisted pyeloplasty as compared to conventional laparoscopic pyeloplasty.³² Bantas et al. reported an average operating time of 197 minutes in a cohort of 11 patients undergoing robotic pyeloplasty with 100% success rate at 12 months follow up.³³ With added experience operative times as short as 122 minutes have even been described in larger series.³⁴

Ureteral Reimplantation and Ureteral Reconstruction—After the advent of robotic pyeloplasties, the use of robot technology was extended to other ureteral reconstructive surgeries including uretero-ureteral anastomosis and ureteral reimplantation. Robotic-assisted procedures have also been expanded to the pediatric population, though much of the surrounding literature remains in evolution. The challenges of pediatric robotic surgery include the limited working space in children and the size of the instruments of the da Vinci platform. Satisfactory outcomes have been described in small series of extravesical ureteral reimplantation using the da Vinci system.³⁵

Urinary Diversion and Bladder Reconstruction—Limited data with few case reports are available from large volume centers describing total intracorporeal ileal conduit diversion and bladder augmentation or reconstruction.^{21, 36} As in the case for malignant indications, the main drawback cited in these reports is the relatively long operating time (over eight hours) associated with these procedures. Most surgeons prefer extracorporeal bladder reconstruction or diversion when performed in conjunction with radical cystectomy to reduce the total operating time.

Abdominal Sacrocolpopexy—Since the FDA approval for gynecological surgeries using the da Vinci system in 2005, the number of robotic gynecological procedures both for benign and oncological indications has increased, most commonly abdominal hysterectomy. The most common urogynecologic procedure of interest to urologists that has gained widespread acceptance is abdominal sacrocolpopexy for the treatment of apical or vaginal vault prolapse. Traditional open abdominal sacrocolpopexy is considered gold standard in

the management of apical vaginal prolapse with excellent long term success rates even up to 100%.³⁷ This procedure, however, involves a large incision, lengthy recovery with long hospital stay, and increased morbidity and risk of complications seen with any major open surgery. The introduction of robotic technology has minimized invasiveness and shortened recovery time and hospital length of stay when compared to the open abdominal sacrocolpopexy.³⁸ Both approaches were found to be equivalent with regard to short-term efficacy.

Adrenalectomy—While the laparoscopic adrenalectomy has been a widely accepted modality since 1992,³⁹ the use of the robot in performing adrenalectomies was first reported by Horgan and Vanuno in 2001.⁴⁰ Current literature supports the feasibility, efficacy and safety of robotic adrenalectomies. The short-term outcomes of robotic adrenalectomies have been shown to be similar to those of the laparoscopic approach, but the operative times are notably longer in robotic cases.^{41, 42} The robot carries the advantage of enhanced visualization and magnification, enabling more meticulous dissection in manipulating adrenal tumors. In light of the added expense, however, it remains unclear whether robotic technology is superior from a cost-benefit perspective in comparison to the conventional laparoscopic approach for performing adrenalectomies.

Other Benign Urological Applications—The robot has been used in the management of other benign urologic conditions as well, including vesicovaginal fistula repair, colposuspension, and vasovasostomy. However, the literature is limited to case reports, and the robot has not yet gained widespread acceptance for these indications.^{43, 44}

CONCLUSION

The introduction of robotic technology has revolutionized the field of urological surgery over the last 25 years. Current literature supports the use of the robot for certain benign and malignant urologic indications based on proven efficacy and safety. The robot has been shown to hasten recovery and shorten hospital stay in comparison to the open approach for several conditions. However, high cost remains the main drawback. While short-term surgical outcomes are promising and comparable to those of traditional open or laparoscopic procedures, long-term data is still lacking and necessary to prove superiority of robotic technology over conventional approaches. Until then, the robot will continue to play a monumental role in urological surgery.

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