Laparoscopic robotic pyeloplasty using the Zeus Telesurgical System

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We present the initial clinical experience using a robot to perform a laparoscopic dismembered pyeloplasty at a Canadian centre. Five patients were confirmed to have ureteropelvic junction obstructions through nuclear renography, cross sectional imaging and intravenous pyelography. After performing a retrograde ureteropyelography and double J stent placement, laparoscopic dismembered pyeloplasty was performed by a single surgeon at a remote workstation using the Zeus™ Telepresence Surgery System (Intuitive Surgical,). The mean total operative time was 225±48 minutes, anastomotic time was 71±16 minutes, and the mean time required to set-up the robot was 30±17 minutes. The estimated blood loss was less than 100 ml in each case. A mean total of 22±10 mg of morphine sulfate equivalents were used for analgesia, and the patients were discharged home after a mean of 58±10 hrs. There were no robotic failures, and all evaluable patients are free of pain and demonstrable obstruction. One patient developed a delayed urine leak, which resolved with percutaneous drainage. The robot provides the ability to perform complicated operations with precision through elimination of tremor, scaling of motion, and through the use of 'wristed' instruments that enhance the freedom of movement normally limited by straight-shafted laparoscopic needle drivers. The development of robotic telesurgery is still in its infancy, and the significance of its role in urologic surgery continues to be evaluated.

Key Words: renal, laparoscopic, robotic, pyeloplasty

Introduction

The impetus of modern telerobotic surgery originated from the belief that surgeons would one day be able to perform remote surgical procedures in outer space or in a battlefield by operating an on-site robot from a distant, safe location. Over the last decade, several different robotic platforms including Da Vinci (Intuitive Surgical,), Artemis and Zeus (Intuitive Surgical,) have been developed to perform telerobotic operations. However, only the Zeus platform has been developed to perform long distance telerobotic surgery.[1]

The open pyeloplasty procedure has provided durable long-term results for the treatment of ureteropelvic junction obstruction, but is associated with post-operative pain and prolonged convalescence in adult patients. Although both antegrade and retrograde endopyelotomy have been developed to decrease the invasiveness of pyeloplasty, long-term durability has recently been shown to be limited.[2] Laparoscopic repair of the ureteropelvic junction, on the other hand, has been shown to reduce the morbidity of pyeloplasty, while maintaining the excellent results of the open procedure.[3] However, this procedure is technically challenging and is associated with a steep learning curve.

Advancements in surgical robotics have provided features that enable the laparoscopic surgeon to perform complex tasks with ease. These advancements include the improvement of precision, dexterity, and reduction of fatigue through the use of motion scaling, motion filtration, and the use of 'wristed' instruments.

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Sung et al first used the Zeus^{TM} robot to perform laparoscopic pyeloplasty in a large animal model.[4] We wanted to assess the clinical feasibility of laparoscopic robotic pyeloplasty using the Zeus^{TM} telesurgical platform with a future objective of performing long-distance pyeloplasty.

Patients and methods

Between January 2003 and August 2003, five robotic laparoscopic pyeloplasties were performed on five patients with primary ureteropelvic junction obstructions (UPJOs). All procedures were performed by a single surgeon (PL) at a single site (London Health Sciences Centre). The patients had flank pain and either intravenous pyelography or ultrasound imaging was initially performed by referring physicians, prompting further urologic work-up. Three patients - 1, 3, 4 in Table 1 had recurrent episodes of pyelonephritis associated with UPJO and patient 4 had a chronic indwelling left ureteral stent placed for intractable pain. Pre-operative imaging using lasix renography, computerized tomographic angiography, and retrograde pyelography confirmed the presence of ureteropelvic junction obstruction. Additionally, nuclear renography demonstrated differential renal function of > 20% on the side of the UPJO in these five patients.

Preparation of the robot

The Zeus^{TM} robot is a surgical platform that utilizes three table mounted-robotic arms and one console station. One robot arm controls the camera through either touch pad, manual or voice control. The other two arms have the ability to move through five degrees of freedom and manipulate objects through 'wristed' instruments. Numerous instruments (i.e. scissors, needle driver tips) can be mounted on the robotic manipulator arms to facilitate dissection and suturing. Additionally, there was a surgical assistant present at the bedside to exchange instruments and make fine adjustments to the robot arms during the course of the surgery.

The console station is a remote telesurgical unit that utilizes two video screens to provide external (operating room) and magnified three dimensional endoscopic visual feed-back to the surgeon. Robotic arms that wrap around the surgeon's own arms and hand-held spheres provided the means to manipulate the two robotic 'manipulator' arms at the bed-side Figure 1. Scaling of jaw-width, wrist and instrument rotation and movement was set according to surgeon preference prior to the operation. The console-based computer filtered out hand tremors to improve precision. A foot clutch was used to enable and disable the robot arms to allow adjustments of the console arms according to the location of the arms at the bedside in order to improve surgical ergonomics and reduce surgical fatigue. The Zeus^{TM} robot was used to perform the entire pyeloplasty procedure in one case ('skin to skin') and used to perform only the anastomosis in the other four cases. In one procedure, case 4, a urologist located at a remote site (over 200 km away) used Socrates^{TM} to manipulate the Aesop^{TM} camera arm.

TABLE 1. **Operative and early post-operative results from robotic pyeloplasty**

	Case 1	Case 2	Case 3	Case 4	Case 5	Mean ± std
Age (years/sex)	42F	24M	27M	23M	76M	
Diagnosis	crossing vessel	crossing vessel	intrinsic UPJ	intrinsic UPJ	crossing vessel	
Lap time (minutes)	245	140	240	260	240	225±48
Robot set-up (minutes)	60	30	20	15	25	30±17
Anastomotic time (minutes)	95	55	60	80	65	71±16
EBL (ml)	100	50	100	40	50	68±30
MSO_4 (mg)	32	18	34	12	16	22±10
Hospital stay (hours)	60	48	72	48	60	58±10

Socrates™ is a tele-communications platform which utilizes integrated services digital network (ISDN)-based video and audio communication to allow a remote surgeon to communicate with the operating surgeon. In addition, it allows the remote operator to manipulate the on site camera with Aesop™ (a voice-controlled, robotic endoscope positioning system designed for minimally invasive surgical procedures).

Surgical technique

Briefly, under general anaesthesia, the patient undergoing robotic pyeloplasty was positioned in the cystolithotomy position, and cystoscopy with retrograde pyelography was performed. Using fluorscopic guidance, the approximate 'latitude' of the UPJ was marked on the patient's abdominal wall 4 cm lateral to the lateral rectus fascia on the side of the obstructed kidney. The patient was then stented with a 30 cm 6 French double J stent under fluoroscopic guidance, and a 3 way foley catheter was inserted. The patient was then placed in direct flank position without bed flexion with the obstructed kidney facing upwards. The three Zeus™ arms were then secured to the operating table with the camera arm mounted on the rails along the posterior aspect of the patient and the two 'manipulator' arms mounted towards the anterior aspect of the patient Figure 1. The initial laparoscopic port was placed using a 10 mm Hasson insertion device directly over the previously 'marked' UPJ site. This provided direct alignment and triangulation of the 4 mm 'manipulator' arms 8 cm cephalad and caudal to the original port along the lateral rectus fascia Figure 2. This port alignment was derived from our prior experience in pre-clinical surgical sessions. Using either ultrasound energy or a modifed monopolar electrosurgical device attached to the manipulator arm, the colon was dissected free of its lateral peritoneal attachments, exposing the obstructed kidney and ureter. The ureter was dissected to the UPJ, leaving a generous amount of periureteral fat to maintain its vascular supply. If a crossing vessel was encountered, the UPJ and renal pelvis were dissected free, transected and transposed anterior to the crossing vessel. After a 1-2 cm spatulation of the 'normal' ureter, the redundant renal pelvis along with the UPJ was sharply excised. In cases without a crossing vessel, the same procedure was performed without transposition of the UPJ around the obstructing vessel. A fourth 5 mm port was placed lateral to the established ports and well away from the path of the robot arms. The surgical assistant at the side of the operating table used this port for suction/irrigation and retraction. Using the Anderson-Hynes approach to the repair of the UPJ, a 4.0 15 cm absorbable suture on an RB-1 needle was used to secure the 'heel' of the ureter to the dependent portion of the renal pelvis. With the stent retracted

Figure 1. Position of surgeon at the console. The robotic arms wrap around the surgeon's own arms and hand-held spheres provide the means to manipulate the robotic arms at the bed-side. Visualization of the telesurgical pyeloplasty procedure is provided by a three-dimensional image projected on to the central monitor.

Figure 2. Port and robotic arm positions used for left pyeloplasty. The patient's head is oriented to the left of the photograph. The 'manipulator' rail-mounted robot arms were placed to the anterior side of the patient. The 'endoscopic' rail mounted arm was placed towards the posterior aspect of the patient. The initial 'endoscopic' port marked '1' was oriented directly over the ureteropelvic junction, 4 cm lateral to the left lateral rectus fascia. The left 'manipulator' port marked '2' was placed 8 cm cephalad to '1' and placed along the lateral rectus border. The right 'manipulator' port marked '3' was placed 8 cm caudal to '1' and placed along the lateral rectus border. The positioning of the arms and ports in this manner minimized collisions and limits of motion.

posteriorly and caudally by the assistant through the fourth port, the 'wristed' needle drivers powered by the robotic manipulator arms ran the suture smoothly through the posterior wall of the anastomosis using a running continuous stitch. Upon completion of the posterior wall, the stent was placed back into the renal pelvis and a 15 cm running continuous 4.0 suture was used to close the anterior wall of the anastomosis. In cases that required reduction of the renal pelvis, a similar suture was used to close the anterior and posterior walls of the renal pelvis in a running continuous fashion. Two ml of fibrin glue (Tisseel™, Baxter) sealant was applied over the entire anastomosis using a Duplocath™ (Baxter) application catheter through an assistant port. A 7 mm close-suction drain was placed through the lateral-most port. The port sites and skin incisions were closed and the robot arms were dismounted from the OR table. The foley catheter was left for 24 hours and removed. If drain output was minimal 12 hours later, the close-suction catheter was removed on post-operative day 2 and the patient discharged home. Clinical follow-up was scheduled at 3-6 weeks for stent removal, 12-16 weeks for lasix renography and clinical reassessment was made 6 months post-operatively.

Results

The results of the study are presented in Table 1. The mean time to complete the entire laparoscopic procedure was 225±48 minutes, and is consistent with other laparoscopic pyeloplasty series. The long operative times are reflective upon the extra time taken to set-up the robotic arms during the laparoscopic case. For the first case, an additional 60 minutes was required to mount and position the robotic arms on the operating table. The set-up time was used to adjust the arms with respect to angulation, positioning and to set 'upper' and 'lower' limits in order to prevent collisions and protect the patient against the travel of the external robotic arms during surgical procedure. By the last case, the mean time required to set-up the robot was reduced to half of the time required to perform the first case Figure 3.

Accordingly, the anastomotic time required to perform the initial pyeloplasty was lengthy at 95 minutes, but was reduced to 55 minutes by the second case. Failure to further reduce the anastomotic time in subsequent cases may indicate technical limitations of the device, or alternatively, an early plateau of the learning curve. Subjectively, the five degrees of motion and tremor filtration facilitated the suturing and knot tying motions compared with standard laparoscopic surgery. Tremor was essentially eliminated using computerized motion filtration provided by the Zeus™ platform.

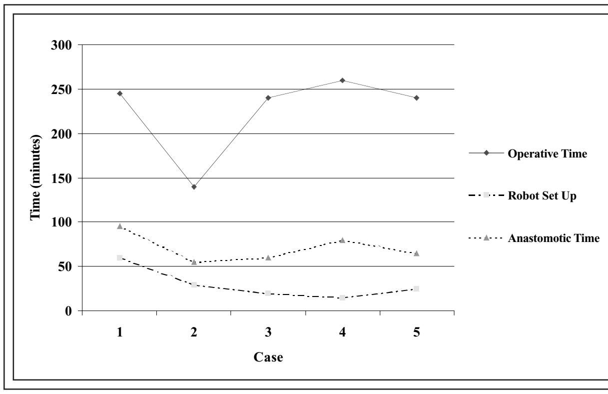

Figure 3. Comparison of sequential operative times for the five robotic pyeloplasty procedures.

There were no robotic failures and the telementored case, case 4 was performed without any difficulty using to the Socrates™ system and Aesop™ arm. As with other laparoscopic cases, mean estimated blood loss was low (68±30 ml), narcotic use was minimal (22±10 mg of morphine equivalents) and mean hospital stay was 58±10 hr.

One patient, case 4 developed a delayed urinary leak 2 weeks post-operatively and was treated conservatively with a percutaneous drain with resolution of the urinoma within 2 weeks despite minimal post-operative drain output within the first 48 hours and no operative technical difficulties. Five patients are currently pain free and are obstruction-free according to lasix renography at 3 and 6 months post stent removal. One patient was lost to follow up at 6 months but was pain free and are obstruction-free according to lasix renography at 3 months.

Discussion

To our knowledge, this is the first clinical series of laparoscopic robotic pyeloplasty using the Zeus telerobotic platform. Gettman et al had previously demonstrated the feasibility of pyeloplasty using the Da Vinci system.[5] This system had been shown to be superior to the Zeus sytem in terms of subjective "surgical immersion" and objective efficiency.[6] This is reflected in Gettman's short anastomotic and operative times, but unlike the Zeus system, Da Vinci has not been developed for long-distance telesurgery. Therefore, it was important to demonstrate that both telesurgical systems can be used for laparoscopic pyeloplasty prior to long distance telesurgical application.

The operative times fell dramatically between the first (240 min) and second case (140 min), which may be attributed to the ability of the robot to reduce the steep learning curve for pyeloplasty. Subsequent operative times were prolonged as a consequence of the introduction of trainees to the robotic pyeloplasty operation. Anastomotic times also stabilized rapidly due to the ability of the robot to eliminate tremor, scale movements and provide an additional degree of freedom. The 'wristed' instruments, which enhance the operative degree of freedom to five, dramatically improves the ease and accuracy of needle placement over the standard laparoscopic procedure and although not objectively demonstrated in our results, this translates into a more 'fluid' and precise anastomosis compared with standard laparoscopic surgery.

As with other laparoscopic procedures and Gettman's results using the Da Vinci robot, the blood loss, narcotic use and recovery time were very low compared with conventional open pyeloplasty procedures.[3,5] Although, the anastomosis appeared to be satisfactory at the time of pyeloplasty, one patient developed a delayed urinary leak several weeks after pyeloplasty. There were no technical issues during this case and the stent was demonstrated to have been in a proper position post-operatively. Gettman also had one delayed urine leak with his series and one potential explanation may be related with the lack of tactile feedback with the graspers. Theoretically, the robotic graspers may exert excessive pressure on the tissue, leading to damage and delayed necrosis. However, we normally use a 'minimal-touch' technique in which tissue manipulation with the grasping forceps is minimized, and therefore challenges the validity of the tissue damage argument. Irrespectively, this complication led to the standard practice of instilling 300 ml of methylene blue into the bladder in order to test the integrity of the repair upon completion of the anastomosis.

A distinction between the Da Vinci and Zeus platforms must be noted. The Da Vinci robot used by Gettman and colleagues is similar to the Zeus robot in many ways. Both units utilize remote consoles, tremor filtration, instrument scaling, and three-dimensional optics. However, the Da Vinci arms have one additional degree of freedom over the Zeus unit, further enhancing dexterity, which is especially apparent during knot tying exercises. Sung had shown that Da Vinci is more efficient at the pyeloplasty procedure compared with a previous Zeus model that lacked articulating wrists. Having performed pyeloplasty with both platforms, the authors agree that Da Vinci provides a superior surgical 'immersion' experience compared with the Zeus platform. The Da Vinci platform provides better visualization with superior three-dimensional optics, and is far easier to use through superior ergonomics and translation of movements. Additionally, after the acquisition of Computer Motion Inc., Intuitive Surgical has decided to limit research and development of the Zeus platform, and concentrate on the development of the Da Vinci robot.

Despite the obvious advantages of Da Vinci over the Zeus robot, the Zeus robot is currently the only commercially available robotic system that has been developed to manipulate surgical instruments over ISDN or internet protocol (IP) lines to a remote site. We had also performed remote tele-navigation with the Aesop arm and telementoring with Socrates during one of our procedures. Since the achievement of reproducible long distance telesurgery has been a goal of our clinical group, we have found it to be important to assess the feasibility of the Zeus platform to perform complex surgical procedures such as pyeloplasty prior to initiation of complex long-distance telesurgical procedures using IP lines or satellite connections. Currently, our group has been assessing the variables that confound long-distance telesurgery using a long-distance telesurgery Zeus unit in the animal dry labs. Although Zeus may not ultimately be the platform used to connect operating rooms of the future with long-distance telementoring and telesurgery, we have shown that it will be more than adequate to provide a vehicle to perform complex reconstructive procedures for pioneering long distance telesurgical studies and procedures. ☐

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