JOURNAL OF SURGICAL RESEARCH • FEBRUARY 2018 (222) 34–38

Available online at www.sciencedirect.com

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journal homepage: www.JournalofSurgicalResearch.com

Robotic-assisted single-port donor nephrectomy using the da Vinci single-site platform

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ARTICLE INFO

Article history:
Received 3 August 2017
Received in revised form 16 September 2017
Accepted 29 September 2017
Available online 31 October 2017

Keywords:
Donor nephrectomy
Surgical technique
Living donation

ABSTRACT

Background: Although single-port donor nephrectomy offers improved cosmetic outcomes, technical challenges have limited its application to selected centers. Our center has performed over 400 single-port donor nephrectomies. The da Vinci single-site robotic platform was utilized in an effort to overcome the steric, visualization, ergonomic, and other technical limitations associated with the single-port approach.

Materials and methods: Food and Drug Administration device exemption was obtained. Selection criteria for kidney donation included body mass index <35, left kidney donors, and ≤2 renal arteries. After colonic mobilization using standard single-port techniques, the robotic approach was utilized for ureteral complex and hilar dissection.

Results: Three cases were performed using the robotic single-site platform. Average total operative time was 262 ± 42 min including 82 ± 16 min of robotic use. Docking time took 20 ± 10 min. Blood loss averaged 77 ± 64 mL. No intraoperative complications occurred, and all procedures were completed with our standard laparoscopic single-port approach.

Conclusions: This is the first clinical experience of robotic-assisted donor nephrectomy utilizing the da Vinci single-site platform. Our experience supported the safety of this approach but found that the technology added cost and complexity without tangible benefit. Development of articulating instruments, energy, and stapling devices will be necessary for increased application of robotic single-site surgery for donor nephrectomy.

Introduction

The advent of laparoscopic donor nephrectomy was shown to improve living donor organ donation rates.[1] Further refinements in equipment and technique enabled our group to transition to a single-port approach as our standard of care in 2009. We have shown that this approach yields equivalent recipient outcomes and improved donor cosmesis and satisfaction in patients at our center.[2] Other groups have shown benefits in cosmesis and possible decreases in postoperative pain and complications, but also reported greater technical challenges.[3] Despite these findings, the single-port approach remains uncommon nationwide. This is likely due to the substantial learning curve, ergonomic challenges associated with the equipment, and the greater difficulty in obtaining safe visualization of the surgical field.

The da Vinci Surgical System Single-port platform addresses a number of potential limitations of present laparoscopic instruments. The binocular camera provides a much improved field of view, and the articulation of the dissecting

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0022-4804/$ – see front matter
https://doi.org/10.1016/j.jss.2017.09.049

instruments can often exceed the capabilities of standard instrumentation. In the single-site platform in particular, instruments controlled by the operating surgeon's left and right hands cross within the port, and the controls are then reversed by the software. This leads to a more intuitive control of the operating instruments (left hand controls left instrument, right hand controls right instrument) which can otherwise be challenging to surgeons learning the single-port technique. Furthermore, unintentional tremors in the surgeon's hands are filtered.

The da Vinci robot is well-established in gynecologic and urologic procedures in particular. It has been expanded to nearly all facets of chest and abdominal surgeries. However, the experience with the da Vinci single-site platform is far more limited. Initial studies reported only on laparoscopic cholecystectomy.[4] We felt that the single-port platform had the potential to ameliorate the significant technical and ergonomic challenges that currently limit more widespread application of single-port donor nephrectomies. Here, we report our initial experience utilizing the robotic single-port platform to augment our standard laparoendoscopic single-site approach.

Materials and Methods

Patients

A Food and Drug Administration investigational device exemption for the single-site platform was obtained. The study was conducted under approval of the University of Maryland Institutional Review Board (HP-00055955). Three donor nephrectomies were performed between January and April 2015. Patients underwent robotic-assisted single-site donor nephrectomy by a three surgeon team (RB, JL, and MP) utilizing existing da Vinci instrumentation and single-site platforms. Donors were limited to adults' aged 18-70 y in general good health, with altruistic motivation for donation and approval of our Living Donor Committee. Donors of incompatible blood type, with a body mass index (BMI) >35, with more than two renal arteries, or who were donating the right kidney were excluded.

Surgical technique

Donors were positioned in the right lateral decubitus position on the flexed operating table. Although the robot was draped and prepared for surgery, it was initially kept outside of the operating field. Our standard single-port technique was utilized for port insertion at the umbilicus, diagnostic laparoscopy, lysis of any adhesions, and mobilization of the left colon from the retroperitoneum. Our standard equipment included the single-incision laparoscopic surgery (SILS) port (Covidien, Dublin, Ireland), 5 mm Olympus articulating camera (Olympus, Tokyo, Japan), Maryland dissector, and laparoscopic Harmonic Scalpel (Ethicon, Somerville, NJ). Following left colonic mobilization from the splenic flexure through the pelvic brim, the robot was docked. The base of the da Vinci robot (Si model) was positioned by bringing the robotic arms into the field directly above the patient's left shoulder and angled toward the umbilicus. The base of the robot was adjacent to, but several inches away from, the base of the operating table.

The SILS port was replaced with the da Vinci single-site port and the da Vinci camera inserted via the camera port (Fig. 1). The two short curved robotic cannulas were inserted under direct vision, and the ports then docked to the robot with care to ensure that the two operating arms were in the appropriate "blue" operating zone. The 30° camera was docked first, positioned with the lens facing downward, followed by the two instrument cannulas. In cases not limited by the position of the robotic arms and the patient's size, standard laparoscopic instruments were inserted via the assistant port for suction and/or retraction.

The device was used as long as steady progress was being achieved and donor safety was maintained. The robotic single-port platform was used primarily for isolation and elevation of the ureteral and/or gonadal vein complex and renal hilar dissection. Device use was terminated per protocol when preparations were to be made for vessel stapling and organ removal or when further progress had halted. At this point, the robot was undocked and removed from the operative field. A staff surgeon was at the bedside throughout all phases of the operation. Renal mobilization, final vascular dissection and stapling, and renal extraction were performed after conversion to standardized single-port laparoscopy in all cases. The robot was neither utilized for, nor impeded, vascular stapling and kidney extraction. Thus, robot use did not affect warm ischemic times. Measured endpoints included operating time, blood loss, and ergonomics.

Data collection and analysis

Clinical data were collected during the intraoperative and perioperative periods. A nonsurgeon member of the research team attended all surgical procedures. Surgeons were immediately queried on standardized subjective variables regarding the ease of use and utility of the robotic platform.[5] Analysis was performed on ergonomic and other collected data during

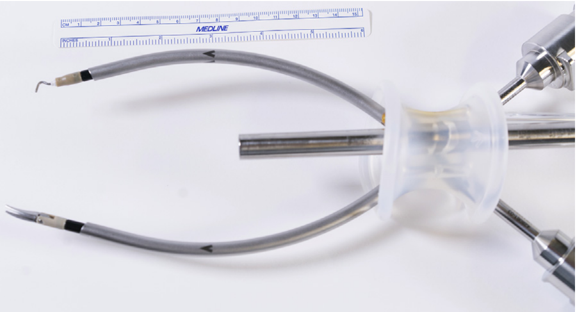

Fig. 1 – The robotic single-site port viewed from above. Dissection was primarily performed with a hook electrocautery and a Maryland dissector. Intelligent programming permits the hook electrocautery to be controlled by the surgeon's right hand, despite it being inserted through the left side of the port and being controlled by the left-sided robotic arm. (Color version of figure is available online.)

the operative procedures. No statistically significant conclusions were drawn; all analyses were descriptive.

Results

Case#1

The first donor was a 42-year-old Caucasian female with a BMI of 27.2 donating her left kidney to her fiancé. She had no significant past medical or surgical history. Her left kidney had two arteries and a single renal vein. Our standard single-port approach was utilized for 37 min for initial laparoscopy and mobilization of the left colon. The robot was then positioned, docked, and ports placed (18 min). The robotic single-port platform was then used for 65 min (out of the total 230 min of operating time) before converting back to our standard single-port approach. Using the robotic hook electrocautery and Maryland bipolar forceps, the lower pole of the left kidney was elevated and the ureter was identified. After elevating the ureter, retroperitoneal tissue inferiormedial to it was divided with the hook cautery, elevating the ureter and periureteral tissue as a bundle. The ureter was then traced and freed cephalad toward the hilum with care taken to avoid skeletonizing it. The inferior border of the left renal vein was identified, and tissues anterior to the vein were divided using the hook electrocautery. In this particular donor, the gonadal vein was in an extremely medial location and was not elevated with the ureter. The upper pole of the kidney was then approached, and the plane between the left adrenal gland and the upper pole of the kidney was developed using the hook electrocautery and the bipolar forceps. This exposed the cephalad border of the left renal artery. The posterior attachments of the kidney were separated from the retroperitoneum, and the robot was undocked. The remaining hilar dissection, including ureter, renal artery, and renal vein stapling and/or division, and kidney extraction was performed using our standard single-port technique.

Estimated blood loss was 50 mL. The patient was discharged home after an uneventful 2-day hospital stay. On outpatient follow-up visit 2 wk later, the incision was healing well without drainage or evidence of infection.

The use of the robot led to improved self-reported surgeon ergonomics and did not contribute additional subjective mental or physical fatigue. Nonetheless, there was occasional difficulty in manipulating the instruments due to interference between robotic arms as well as an inability to perform fine dissection or precise motions during the hilar dissection.

Case #2

The second donor was a 58-year-old Caucasian female with a BMI of 28, donating her left kidney to her close friend. She had no significant past medical or surgical history. Her left kidney had standard anatomy. Our standard single-port approach was utilized for 16 min for initial laparoscopy and mobilization of the left colon. The robot was then positioned, docked, and ports placed in 11 min. The robotic single-port platform was then used for 103 min (out of the total 246 min of operating time) before converting back to our standard single-port approach. Using the robotic console, the ureter-gonadal vein complex was dissected to the renal vein. The renal vein was cleared anteriorly and the upper pole of the kidney was separated from the adrenal gland. In this particular case, the surgeon at the bedside provided active assistance with the elevation of the ureter and gonadal vein complex as well as with suctioning through the assistant port. This also enabled additional traction to be placed on the kidney, assisting during separation from the adrenal gland. The kidney was then separated from its retroperitoneal attachments and additional dissection was performed to completely free the left renal vein before the robot was undocked. The remaining dissection and kidney extraction were performed using our standard single-port technique.

Estimated blood loss was 30 mL. The patient did well and had no complications during her 2-day hospital stay or noted on follow-up.

The second use of the robot led to self-perceived improvements in efficiency of robot use and docking, as well as greater comfort with increasing degrees of hilar dissection. There was less interference between robotic arms during this case.

Case #3

The third donor was a healthy 56-year-old Caucasian female with a BMI of 24.2 donating her left kidney, which had standard anatomy. Upon entering the abdomen, the left colon was found to be markedly distended, and intraabdominal domain was quite limited despite the standard use of complete muscle relaxation by our anesthesia colleagues and an intraabdominal inflation pressure of 15 mm Hg. This required 44 min of standard single-port laparoscopy to mobilize the colon. The robot was then positioned, docked, and ports placed (30 min). It was difficult to place the trocars safely and satisfactorily given the limited intraabdominal domain, increasing our docking time. The robotic single-port platform was then used for 78 min (out of the total 310 min of operative time) before converting back to our standard single-port approach.

The robotic technique was utilized for ureter-gonadal vein complex dissection and partial separation of the adrenal gland. This proved more difficult than it is typically due to the left colonic distention and fatty mesocolon and mesentery. The kidney was freed from its retroperitoneal attachments. We then returned to the hilar dissection, and a number of small lymphatics and associated veins were divided with the bipolar forceps. Following additional dissection, we were able to visualize the anterior and inferior border of the renal vein. The robot was then undocked, and the original SILS port device was reinserted. Ultimately, we exchanged the SILS port for a GelPoint (Applied Medical, Rancho Santa Margarita, CA) as we could insert a fourth instrument for gentle traction on the colon and mesentery in order to safely complete dissection and extraction.

Estimated blood loss was 150 mL and an uneventful recovery was made.

The third use of the robot proved technically challenging even when converted to our standard approach, although the case proceeded safely.

Case summary (Table 1)

Each of the three cases was technically successful, and the donors were discharged within 2 d of operation. The average total operative time was 262 ± 42 min which included 82 ± 16 min of robotic use and 20 ± 10 min of docking time. Patient blood loss averaged 77 ± 64 mL. No intraoperative complications occurred, and all procedures were completed with a laparoscopic single-port approach. Ergonomic survey data indicated little surgeon stiffness or tiredness, mental fatigue, or exhaustion. Surgeons reported occasional difficulty visualizing the field, inability to perform precise motions, and awkward manipulation of robotic instruments which improved in subsequent cases. Fascial incision length was less than 40 mm.

Routine follow-ups at 14 d, 1 mo, 3 mo, 6 mo and 1 y have revealed no donor complications or hernia formation.

Discussion

Laparoscopic donor nephrectomy has become a standardized technique with outstanding donor and recipient outcomes throughout the United States. We have shown that our standard single-port donor nephrectomy outcomes mirror these results. Nonetheless, the single-port approach offers slightly more challenging visualization of the target anatomy and has clear ergonomic limitations in terms of surgeon comfort. These factors, together with a rather steep learning curve, have likely contributed to the lack of widespread acceptance of the single-port donor nephrectomy technique.

As current results in donor nephrectomy are excellent, the introduction of new techniques and equipment must be applied prudently, with a paramount focus on donor safety. We found that the robotic camera does provide a greater degree of depth perception for the operating surgeon, and the console design provides ergonomic improvements over currently available standard laparoscopic equipment utilized via a single-port.

Nonetheless, the application of the single-port robotic platform, in its present iteration, will likely have limited impact on single-port donor nephrectomies. The surgical team participating in this trial has performed more than 400 single-port donor nephrectomies utilizing standard laparoscopic instrumentation and has high volume experience with complex hepatobiliary and urologic surgeries using the standard da Vinci robotic platform. Prior to the trial, surgeons practiced extensively in a dedicated on-site robotic laboratory, performed live animal single-port surgery at purpose-built facilities, and performed the donor nephrectomy procedure on a human cadaver at the corporate headquarters of Intuitive Surgical, Inc with the design engineers in attendance. This enabled our team to quite rapidly conclude that there was minimal benefit of the robotic technology in its present form after our brief clinical trial in this complex case.

The greatest critique of the robotic single-port platform, as applied to donor nephrectomy, is that it added steps to the surgical procedure, while decreasing the available instrumentation. Any potential increase in surgeon comfort or visualization seems to have been greatly overshadowed by these limitations. In terms of increasing operative steps and overall time, the robotic platform, by definition, introduces steps, such as docking, undocking, arm positioning, etc, that will increase operative time even when performed by an experienced surgical team (as compared to a standard single-port technique that omits these steps.) Robotic set-up and docking was time-consuming and did not seem to improve over the course of three cases. The lack of articulating dissectors and energy devices further limited the single-port platform to cases with relatively facile dissection, which is not typically the case with donor nephrectomies.

As a single-port approach is the standard of care at our center, and because no patients are offered more traditional hand-assist or purely laparoscopic multiple-port approaches, our group is not in a position to assess the value of robotic technology in advancing traditional, multiple-port donor nephrectomies. Several groups have demonstrated the ability of the daVinci system to augment multiple-port donor nephrectomies.[6] This is not inconsistent with our experience, as our primary critique of the platform and its utility for donor nephrectomy is the lack of available energy devices and the relatively limited scope of instruments that are compatible with the single-port platform. The instrumentation and the availability of energy devices for the multiport robotic platform certainly increase its utility and the ability to use it in operations of higher complexity.

In our planning phases, we expected that the introduction of robotic technology would inevitably increase the operative time despite obtaining robotic experience in a purpose-built robotics lab, performing animal and cadaver procedures, and hosting numerous clinical reviews with the operative team. Despite these measures, we found that the cases (on average) took nearly twice as long as our standard cases. This was perhaps inevitable.

Table 1 – Case summary.

Patient	Age (y)	BMI (kg/m^2)	Initial SILS (min)	Docking/port placement (min)	Robotic dissection (min)	Case duration (min)	EBL (mL)	Length of stay (d)
1	42	27	37	18	65	230	50	2
2	58	28	16	11	103	246	30	2
3	56	24	44	30	78	310	150	2
Mean (±SD)	52 ± 9	26 ± 2	32 ± 15	20 ± 10	82 ± 16	262 ± 42	77 ± 64	2

SD = Standard deviation; EBL = estimated blood loss.

Due to the outstanding recipient results achieved with living donor kidney transplantation at most US centers, the "bar" is set quite high in regard to immediate graft function and 1-year outcomes. Given this, we elected to transition to our standard single-port technique for the latter aspects of vessel dissection, division of the ureter-gonadal vein complex and renal vasculature, and kidney extraction. Prior to these steps, the robot was undocked, and it presented no impediment nor required no variation in our standard renal stapling and removal technique. There was therefore no impact on warm ischemia time. As all grafts experienced immediate graft function, there appeared to be no evident negative impact on the donor kidney during the robotic portion of the nephrectomy. At most recent follow-up (>1 y) all recipients are enjoying excellent graft function.

The robotic technique is widely criticized for adding cost and complexity to other fields of surgery, and this not necessarily unjustified. The da Vinci Surgical System (Intuitive Inc, Sunnyvale, CA) can cost as much as $2.5 million dollars, a price which does not include related recurring expenses such as the replacement of disposable instruments (which may cost from $700 to $3200 per procedure) or the maintenance of the robot.

This report is quite limited in its scope, design, and impact on donor nephrectomy. We recognize that the significance of three sequential donor nephrectomies might be perceived to be of minimal interest, but nonetheless feel this work is important. Prior to embarking on further studies using the device and expending the significant time and effort required to obtain Food and Drug Administration device exemption, we suggest that further technologic improvements will be necessary. Furthermore, here we report on only subjective, and limited, metrics. Although we discussed this extensively in our trial planning, as this was primarily a safety investigation, we sought to assess surgical time, blood loss, and donor outcomes. Even in retrospect, we find it difficult to develop additional metrics to better assess the surgical safety of this device in this procedure.

Conclusions

We have demonstrated that the single-port platform can be utilized safely in a high-volume program, without compromise of the health and well-being of the donor.

Our group has accumulated a substantial experience with living kidney donation via a single-port approach, and this approach has been standard at our center for more than 5 y. As the donor and recipient outcomes have been excellent with this technique, the introduction of new technology must confer a readily apparent benefit. This is particularly true of complex and expensive technology. We did not feel that the robotic single-port platform, at least in its present iteration, provided such a benefit.

After our initial experience seemed to add cost, complexity, and time to an operation that is fairly streamlined in our center, we elected to terminate further investigations despite initial approval for 20 procedures. We are hopeful that future technology, including articulating instruments and energy devices that are presently undergoing development, will provide a greater advantage for robotic technology in complex abdominal surgeries.

Acknowledgment

Author contributions: J.C.L., R.N.B. contributed to concept, design, data analysis and interpretation, drafting of the article, critical revision of the article, and approval of the article. J.A-C., I.L., J.M.P. contributed to data analysis and interpretation, drafting of the article, and approval of the article. S.S. contributed to data analysis and interpretation, critical revision of the article, and approval of the article. M.W.P. contributed to concept and design, critical revision of the article, and approval of the article.

Disclosure

The single-port platform, surgical instruments, and ports were generously provided by Intuitive Surgical Inc. on a trial basis.

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