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ORIGINAL ARTICLE

Robot-assisted laparoscopic pyeloplasty (RALP) in children with complex pelvi-ureteric junction obstruction (PUJO): results of a multicenter European report

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Abstract

Purpose This study aimed to report a multi-institutional retrospective case series of outcomes after robot-assisted laparoscopic pyeloplasty (RALP) in pediatric patients with complex pelvi-ureteric junction obstruction (PUJO).

Methods All patients undergoing complex RALP over the last 5 years were included. RALP was defined complex in the following cases of PUJO: anatomic variations including ectopic, malrotated, horseshoe, or duplex kidney and recurrent PUJO after failed open pyeloplasty.

Results Forty-eight patients underwent complex RALP in four European centers in the study period and included 18 girls and 30 boys with a median age of 8 years (range 5–12). The PUJO was associated with anatomic variations in 35/48 (72.9%), whereas a recurrent PUJO was present in 13/48 (27.1%). A dismembered Anderson–Hynes pyeloplasty was performed in all patients. The median operative time including docking was 178.5 min (range 117–255) and the median anastomotic time was 64.8 min (range 50–76). All patients were discharged on 2nd postoperative day (POD). The median follow-up was 18.2 months (range 14–43). The overall success rate was 95.8% (46/48). Early postoperative complications (< 30th POD) included urinary tract infections (UTIs) and stent-related irritative symptoms in 4/48 (8.3%) [II Clavien], whereas late complications (> 30th POD) included recurrence of PUJO in 2/48 (4.2%), who needed re-operation [IIIb Clavien].

Conclusions RALP was safe, feasible, and with good mid-term outcome in complex PUJO. An accurate pre-operative planning, a standardized technique, and an experienced surgical robotic team represented key points to manage successfully such complex cases.

Keywords Complex · Robot · Pyeloplasty · Children · Technique · Complications

Introduction

Pelvi-ureteric junction obstruction (PUJO) is the most common congenital obstructive anomaly of the ureter and open dismembered pyeloplasty, originally described by Anderson and Hynes, has historically been the treatment of choice with success rates higher than 90% in different series [1, 2]. Thereafter, the development of minimally invasive surgery (MIS) has introduced laparoscopic pyeloplasty as an effective and safe alternative to open repair of PUJO, with advantages of less postoperative pain, reduced hospitalization, and better cosmetic outcome [3, 4]. However, laparoscopic pyeloplasty still remains a very demanding procedure due to the technical challenges of intra-corporeal suturing that have limited its widespread diffusion in pediatric urology [2]. In the last few years, the advent of robotic platform led

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to overcome many of the technical disadvantages of laparoscopy [5–8].

A complex anatomy including complete intrarenal pelvis, high ureteral insertion or long ureteral stricture, and anatomic variations of morphology and position of the kidney including horseshoe kidney (HSK), renal malrotation, ectopic kidney, or duplex kidney with lower moiety PUJO pose a high level of technical difficulty for reconstruction, due to unfamiliar and distorted anatomy, even in experienced hands [9–11]. The vascular anatomy of the pelvi-ureteric junction (PUJ) is more complex in patients with HSK and ectopic kidney and the presence of crossing vessels in the PUJ may negatively impact the surgical outcome [2, 12]. In such cases, the dissection of the PUJ should be carefully performed to avoid any vascular lesions. Furthermore, the correct identification of any crossing vessels and the link between their presence and the etiology of PUJO is crucial, as well [13]. In cases with lower pole PUJO, the vascularity of the upper moiety ureter should be carefully preserved to avoid stenosis in the upper moiety system and this further adds to complexity [14]. Recurrent PUJO after failed open pyeloplasty represents a further difficult scenario as the normal anatomy is distorted by scar fibrotic tissues [15].

Currently, there is no consensus regarding the optimal surgical approach for treatment of difficult PUJO. In addition, only a few cases of minimally invasive pyeloplasty in such complex cases have been described in the literature, with limited numbers of robotic procedures in the pediatric population [16–22].

This report aimed to describe a multi-institutional retrospective case series of outcomes after robot-assisted laparoscopic pyeloplasty (RALP) in patients with complex PUJO due to anatomic anomalies or history of prior pyeloplasty.

Materials and methods

All patients who underwent complex RALP over the last 5 years (January 2014–January 2019) were included in the study. RALP was defined complex in the following cases of PUJO: anatomic variations including ectopic, malrotated, horseshoe or duplex kidney, and recurrent PUJO after failed open pyeloplasty. Pre-operative work-up included renal ultrasound (US) and diuretic MAG 3 renal scan in all patients. All patients underwent pre-operatively magnetic resonance urography (MRU) and/or computed tomography (CT) scan for an accurate pre-operative assessment of kidney anatomy and relationships between the kidney vasculature and the PUJ. Indications for surgery included: (1) progressive hydronephrosis on serial US; (2) loss of split renal function < 45% on initial or serial MAG3 scans; (3) worsening/persistence of the obstructed drainage on serial MAG3 scans; and (4) symptoms such as recurrent flank pain or urinary tract infections (UTIs). RALP in our series was restricted to patients older than 1 year of age and with a body weight higher than 10 Kgs, since the 8-mm robotic ports were too large to be adopted in infants and children weighing less than 10 Kgs. All surgical procedures were performed by four senior surgeons, one from each institution, who had > 20 years of experience in laparoscopy and > 3 years of experience in robotics. The surgeons performed the robotic procedures with the same robotic team, represented by assistant surgeon and nurses, in each institution. Postoperative follow-up was performed with renal US at 1, 3, 6, and 12 months after surgery and annually afterwards. An MAG3 scan was performed 1 year postoperatively in all cases. Antibiotic prophylaxis was prescribed until the removal of JJ stent.

The primary outcome of the study was the success rate of surgery. This was defined clinically by postoperative resolution of symptoms and radiologically by improvement of hydronephrosis with anterior–posterior pelvic diameter (APD) < 10 mm on US and relief of obstruction on diuretic MAG3 scan, defined by the presence of ureteric excretion at least < 15 min. Secondary outcome parameters included operative time, anastomotic time, analgesic requirement, length of hospital stay, conversions, intra- and postoperative complications, and re-operations. Operative time was defined as the total time spent into the operating room from the skin incisions to completion of skin closure. Postoperative complications were classified according to the Clavien–Dindo grading system [23] and divided in early complications if occurred within the 30th postoperative day (POD) or late if occurred after the 30th POD.

Statistical analysis was carried out using the Statistical Package for Social Sciences (SPSS Inc., Chicago, Illinois, USA), version 13.0. Demographic data were compared using the Student's *t* test. The categorical variables were compared using 2 tests. Significance was defined as $p < 0.05$.

The study received the appropriate Institute Review Board (IRB) approval at each participating center. A data user agreement (DUA) was requested and approved to share data between institutions.

Surgical technique

All procedures were performed via transperitoneal route. After the induction of general anesthesia, the patient was rolled into a semilateral decubitus position rotating the operative side up by 45 ° axially using silicone pads underneath, whereas the rotation was reduced in case of pelvic kidney (Fig. 1). A sterile Foley catheter was inserted into the bladder. Four trocars were placed in all patients, but their positioning varied accordingly to the renal anatomy. In general, the first 8-mm robotic camera port was placed infraumbilically using open Hasson technique; after induction of

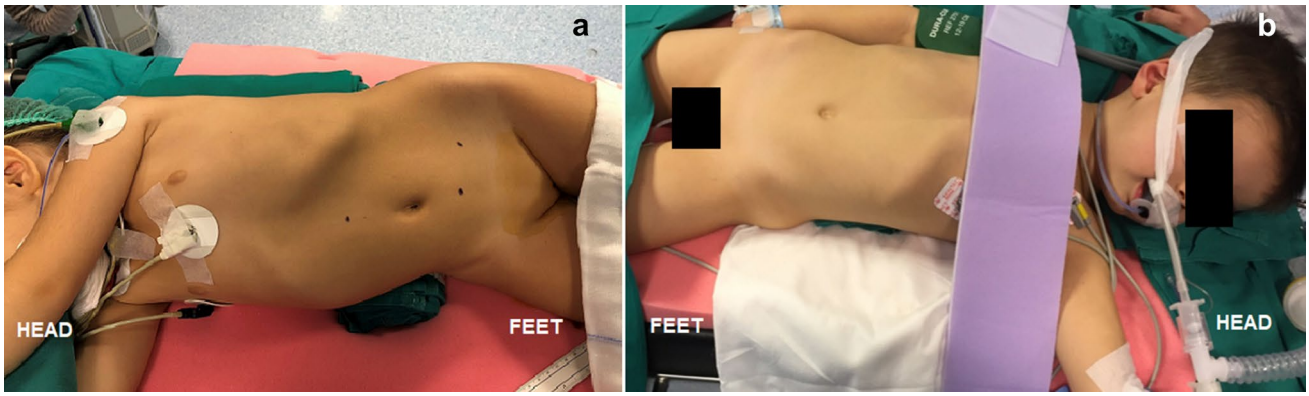

Fig. 1 Patient's positioning in standard case (**a**) and in pelvic kidney (**b**)

pneumoperitoneum, the two operative 8-mm robotic ports were placed under vision in the upper and lower quadrants. Finally, the fourth 5-mm assistant port was positioned on the pararectal line, mean 7-cm caudal to the robotic camera port, and the da Vinci Xi robot was docked, using a three-arm configuration. Unlike the standard ports' position for RALP, the ports for HSK and pelvic kidney were placed more caudally than usual, due to the low-lying position of the kidney (Fig. 2).

Regarding the operative technique, after incision of the Toldt's line and the lowering of the colon, the dilated renal pelvis was detected and isolated, together with the PUJ and the cranial portion of the ureter, preserving the gonadal veins. The PUJ was fully exposed, ensuring that any further anterior crossing vessels were preserved. The PUJ was then transected and excised. A dismembered Anderson–Hynes pyeloplasty was then performed, with transposition of any identified crossing vessels to avoid any compression of the reconstructed PUJ. The isthmus was preserved in all patients with HSK. A double-J stent was placed into the ureter in an anterograde fashion through the assistant port in all cases. The pyeloplasty was carried out with 5–0 monofilament interrupted or running sutures, according to the surgeon's preference. The Toldt's fascia was reconstructed with separate stitches and a 15 F abdominal drain was placed through the 5-mm assistant port. Trocars' orifices were closed using resorbable sutures.

Video 1 reproduces all steps of RALP in an ectopic pelvic and malrotated kidney.

Results

A total of 232 RALP were performed in four European centers of pediatric urology in the study period (January 2014–January 2019). Forty-eight out of 232 patients (20.7%) underwent complex RALP and included 18 girls and 30 boys with a median age of 8 years (range 5–12) and a median weight of 30 Kgs (range 19–35). The PUJO was associated with anatomic variations in 35/48 (72.9%),

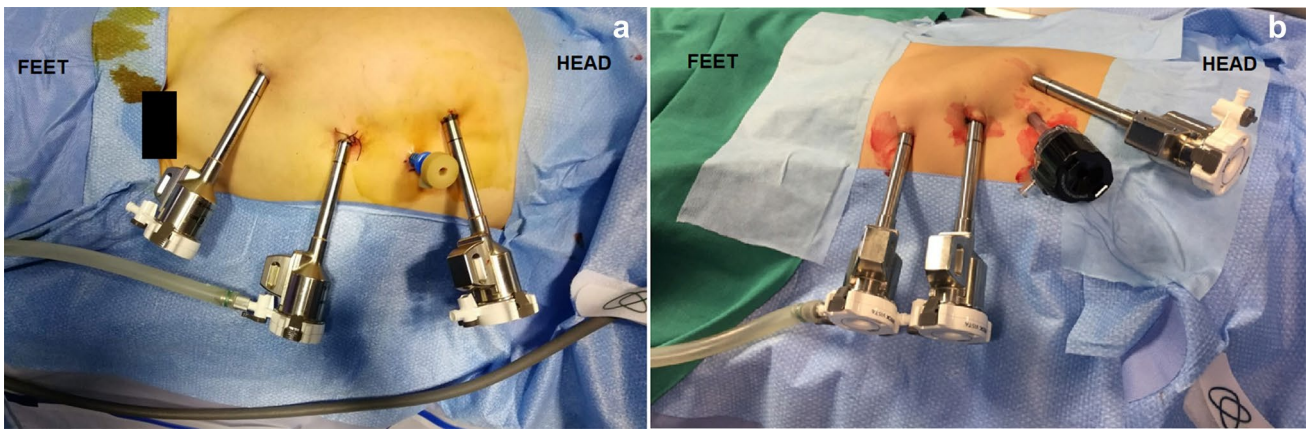

Fig. 2 Trocar placement in standard case (**a**) and in pelvic kidney (**b**)

including HSK ($n = 11$), ectopic pelvic kidney ($n = 9$), renal malrotation ($n = 13$), and duplex kidney with lower pole PUJO ($n = 2$). A recurrent PUJO after failed open pyeloplasty was present in 13/48 (27.1%). Most patients (33/48, 68.7%) were symptomatic, with mainly colicky flank pain (27/48, 56.2%) followed by urinary tract infections (UTIs) (5/48, 10.4%) and hematuria (1/48, 2.2%). The PUJO was right-sided in 23/48 (47.9%) and left-sided in 25/48 (52.1%). Dismembered Anderson–Hynes pyeloplasty was performed in all patients. Crossing vessels were identified and de-crossed in 9/48 (18.7%). The median operative time including docking was 178.5 min (range 117–255) and the median anastomotic time was 64.8 min (range 50–76). No intra-operative complications occurred. Full oral diet was resumed the same day of surgery. The median analgesic requirement (paracetamol 15 mg/kg/8 h) was 21.2 h (range 7–43). Patients were discharged on POD 2 following catheter and drain removal. The JJ stent was removed at median 22.4 days postoperatively (range 6–30).

The median follow-up length was 18.2 months (range 14–43). The overall success rate was 95.8% (46/48). The success rate in children who had recurrent PUJO after prior failed open pyeloplasty was 100% (13/13). At follow-up, all patients reported complete resolution of clinical symptoms and improvement of hydronephrosis on ultrasound (median pre-operative APD 32.5 mm vs. median postoperative APD 8.6 mm) [$p < 0.001$] and no residual obstruction on diuretic renogram (median pre-operative renal drainage 48 min vs. median postoperative renal drainage 9.5 min) [$p < 0.001$]. Early postoperative complications (< 30th POD) included urinary tract infections (UTIs) and stent-related irritative symptoms in 4/48 (8.3%) patients, who were managed with medical therapy (II Clavien). Late postoperative complications (> 30th POD) included recurrence of PUJO in 2/48 (4.2%) patients, who needed re-operation [IIIb Clavien]. Both patients (one 6-year-old girl and one 4-year-old boy) who failed RALP were asymptomatic and the late recurrent PUJO was diagnosed at follow-up imaging as progressive increase of hydronephrosis, with APD > 30 mm on US and persistence of obstruction, with ureteric excretion at > 20 min on diuretic MAG3 scan. Endoscopic balloon dilatation of the PUJO and ureteral stenting was successfully performed in one patient, 8 months following the initial RALP. A salvage attempt with ureteral stenting failed in the second patient, who underwent redo dismembered pyeloplasty using robot-assisted approach, 6 months following the initial RALP. After stent removal, imaging reported improvement of hydronephrosis (APD < 10 mm on US) and relief of obstruction (excretion at < 15 min on MAG3 scan) in both patients.

All patients' demographics and outcome parameters are reported in Tables 1 and 2.

Table 1 Patients' demographics in our series

Patients' demographics	
Case number, *n*	48
Sex	
Male, *n* (%)	30 (62.5%)
Female, *n* (%)	18 (37.5%)
Median age, years (range)	8 (5–12)
Median weight, Kgs (range)	30 (19–35)
Associated Anomalies	
Horseshoe Kidney (HSK), *n* (%)	11 (22.9%)
Ectopic Pelvic Kidney, *n* (%)	9 (18.7%)
Renal malrotation, *n* (%)	13 (27.1%)
Duplex kidney with lower pole PUJO, n (%)	2 (4.2%)
Recurrent PUJO after failed open repair, *n* (%)	13 (27.1%)
Side of PUJO	
Right, *n* (%)	23 (47.9%)
Left, *n* (%)	25 (52.1%)
Symptoms	
Colicky flank pain, *n* (%)	27 (56.2%)
Urinary tract infections (UTIs), *n* (%)	5 (10.4%)
Hematuria, *n* (%)	1 (2.2%)
Asymptomatic, *n* (%)	15 (31.2%)
Pre-operative work-up	
Ultrasound (US), *n* (%)	48 (100%)
Mag 3 renogram, *n* (%)	48 (100%)
Magnetic Resonance Urography (MRU), *n* (%)	35 (72.9%)
Computed tomography (CT), *n* (%)	13 (27.1%)

Discussion

The current evidence about the optimal surgical approach for minimally invasive treatment of difficult PUJO is very poor, with limited numbers of robotic procedures in the pediatric population [16–22]. To our knowledge, this report represents the largest multi-institutional experience with pediatric RALP in complex PUJO. Based on this multicenter large experience, we would underline some key points in the surgical management of such challenging cases to achieve high success rates, as reported in our series.

First, an accurate pre-operative imaging study is crucial to identify anatomic variations and vascular anomalies that are often associated with obstructed kidneys to plan the best surgical approach [11, 24]. All patients of our series underwent pre-operatively magnetic resonance urography (MRU) and/or CT angiography.

A technical key step of RALP in complex cases is the adequate port placement; in fact, the ports for HSK and pelvic kidney should be placed about 5 cm more caudally than usual, due to the low-lying position of these kidneys, to improve the access to the PUJ [25]. Moreover, considering that the ureter is shorter in ectopic pelvic kidney compared

Table 2 Outcome parameters in our series

Outcome parameters	
Median operative time, minutes (range)	178.5 (117–255)
Median anastomotic time, minutes (range)	64.8 (50–76)
Median analgesic requirement, hours (range)	21.2 (7–43)
Median hospital stay, days (range)	2.0 (2–5)
Median resumption of oral intake, hours (range)	8 (4–12)
JJ stent removal, days (range)	22.4 (6–30)
Intra-operative complications, *n* (%)	0
Early postoperative complications (< 30th POD)	
Urinary tract infections (UTIs), *n* (%)	3/48 (6.2%)-II grade Clavien
Stent-related irritative symptoms, *n* (%)	1/48 (2.1%)-II grade Clavien
Late postoperative complications (> 30th POD)	
Stricture of anastomosis, *n* (%)	2/48 (4.2%)-IIIb grade Clavien
Other, *n* (%)	0
Re-operations, *n* (%)	2/48 (4.2%)
Overall success rate, *n* (%)	46/48 (95.8%)
Median follow-up, months (range)	18.2 (14–43)
Symptoms	
Before surgery, *n* (%)	33/48 (68.7%)
After surgery, *n* (%)	0
Degree of hydronephrosis at US	
Median pre-operative APD, mm (range)	32.5 (25–80)
Median postoperative APD, mm (range)	8.6 (0–13.2)
Renal drainage on Mag 3 renogram	
Median pre-operative excretion time, minutes (range)	48 (27–78)
Median postoperative excretion time, minutes (range)	9.5 (8–18)

POD postoperative day, *APD* anterior–posterior pelvic diameter, *US* ultrasound

with orthotopic kidney, a shorter double-J stent should be placed in such cases to avoid its accidental dislodgement through the urethra. After stent positioning, the urethral meatus should be always inspected to check the presence of a dislodged stent. Although some authors prefer the retroperitoneal approach, since it accesses the urinary tract directly and the potential risk of intra-abdominal organs injury is avoided [26], the transperitoneal route was our preferred approach in such cases, since it allowed for better assessment and surgical control of crossing vessels and vascular abnormalities frequent in complex PUJO and made ureteral transposition and anastomosis easier.

Another important key point to reach high success rates, as reported in our series, is that these complex procedures should be performed by senior surgeons with a strong experience in MIS and a robust urological background. Based on our experience, it is crucial that not only the surgeon but also the bedside assistant and the entire robotic team should be experienced to help streamline the operation, especially at beginning of the learning curve [27].

The overall success rate of complex RALP was 95.8% (46/48) in our experience, with a recurrence rate of 4.2% (2/48). Recurrences were discovered late at follow-up imaging as patients were asymptomatic. Endoscopic balloon dilatation of the PUJO and ureteral stenting was successfully performed in one patient, whereas a redo-RALP was needed in the second case, after failed salvage attempt with ureteral stenting.

RALP revealed very effective as salvage procedure, reporting a 100% success rate in recurrent PUJO after prior failed pyeloplasty [16–20]. In such cases, the surgical technique involved the resection of the old scars in the connecting area of upper ureter and pelvis with the dissection extending deep beyond the parenchyma almost to the neck of the lower calyx. The advantages of robotic assistance in redo pyeloplasty included meticulous dissection, better delineation of the previous scarred tissue, preservation of the periureteral sheath containing vascular supply to the ureter, clean fashioning of ureteral pelvic flaps, and, finally, the possibility to perform a watertight anastomosis with fine sutures.

Although failure of open pyeloplasty is more commonly attributed to extramural fibrosis, excessive scarring due to urinary extravasation or excessive use of thermal energy leading to intramural fibrosis, another important cause of recurrent PUJO after open repair is represented by crossing vessels not identified in the initial surgery [20]. As

already reported, open pyeloplasty may require mobilization of the entire kidney and may modify the relationships of the PUJ to lower pole vessels, reducing the chance to identify crossing vessels as a potential cause of obstruction [10]. In the present report, crossing vessels were intra-operatively identified as the cause of recurrence in more than 50% of patients (7/13) with recurrent PUJO after prior failed open pyeloplasty. Based on this finding, we would suggest to search during the dissection phase any crossing vessels and to transpose them behind to the reconstructed PUJ to avoid any extrinsic compression following pyeloplasty. The robot-assisted approach usually requires a minimal mobilization of the kidney to access the PUJ and provides a higher rate of identification of aberrant lower pole vessels compared to open approach [18–20].

Currently, the major limitation to wide-scale application of robotics to the pediatric population remains the lack of specific pediatric robotic tools. The 8-mm robotic ports are too large for infants and children weighing less than 10 Kgs. Moreover, the mechanical force created by the robot is not negligible. RALP in our series was restricted to patients older than 1 year of age and with a body weight higher than 10 Kgs. Smaller sized instruments with high endowrist dexterity and multidegrees of freedom would resolve the problems encountered in pediatric robotic-assisted surgery using 8-mm instruments and allow to adopt robot-assisted approach also in infants and small children [28].

Limitations of the present study include its retrospective and non-randomized nature and the heterogeneous patients' cohort. However, considering the rarity of such complex cases, we involved different centers to collect a high number of cases.

In conclusion, our experience demonstrated that RALP was safe, feasible, and with good mid-term outcome in complex PUJO. An accurate pre-operative planning, a standardized technique, and an experienced surgical robotic team represented key points to manage successfully such complex cases. The da Vinci robot demonstrated to easily adapt to patient's anatomy and provided several technical advantages, overcoming the potential challenges involved in the minimally invasive management of such difficult cases.

Author contributions CE: project development, data analysis, and manuscript writing/editing. LM: data collection, data analysis, and manuscript editing. TB: data collection, data analysis, and manuscript editing. LM: data collection, data analysis, and manuscript editing. QB: data collection, data analysis, and manuscript editing. LF: data collection, data analysis, and manuscript editing. ME: project development, data analysis, and manuscript writing/editing.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest or financial ties to disclose.

Informed consent "Informed consent was obtained from all individual participants included in the study."

Research involving human participants and/or animals This article does not contain any studies with human participants or animals performed by any of the authors".

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