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Review Article

# Current Status of Robot-Assisted Laparoscopic Surgery in Pediatric Urology

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Laparoscopic procedures for urological diseases in children have been proven to be safe and effective. However, the availability of laparoscopic procedures is still partly limited to experienced, high-volume centers because the procedures are technically demanding. The da Vinci robot system is being used for an increasing variety of reconstructive procedures because of the advantages of this approach, such as motion scaling, greater optical magnification, stereoscopic vision, increased instrument tip dexterity, and tremor filtration. Particularly in pediatric urologic surgery, where the operational field is limited owing to the small abdominal cavity of children, robotic surgical technology has its own strengths. Currently, robots are used to perform most surgeries in children that can be performed laparoscopically. In this review, we aimed to provide a comprehensive overview of the current role of robot-assisted laparoscopic surgery in Pediatric Urology by analyzing the published data in this field. A growing body of evidence supports the view that robotic technology is technically feasible and safe in pediatric urological surgery. Robotic technology provides additional benefits for performing reconstructive urologic surgery, such as in pyeloplasty, ureteral reimplantation, and enterocystoplasty procedures. The main limitations to robotic surgery are its high purchase and maintenance costs and that the cost-effectiveness of this technology remains to be validated.

***Keywords:*** *Minimal invasive surgery; Pediatrics; Robotics; Surgery*



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## INTRODUCTION

Minimally invasive surgery has advanced dramatically during the past few decades. Conventional laparoscopic surgery has significant advantages over the traditional open surgical approach in terms of cosmetic outcomes, pain medication requirements, and hospitalization length. However, its availability is still partly limited to experienced, high-volume centers because it is technically demanding [1,2].

Robot-assisted laparoscopic surgery has enabled surgeons to overcome the limitations of complex laparoscopic procedures. Particularly in pediatric urologic surgery, where the operational field is limited by the small abdominal cavity of children, robotic surgical technology has its own strengths derived from its motion scaling, greater optical magnification, stereoscopic vision, increased instrument tip dexterity, and tremor filtration [3]. Following the pioneering surgery of Meininger et al. [4], many researchers have published data on pediatric robotics. Currently, robots are used to perform most surgeries in children that can be performed laparoscopically. In this review article, we aimed to provide a comprehensive overview of the current status of robot-assisted laparoscopic surgery in pediatric urology.

## PEDIATRIC ROBOTIC SURGERY FOR URETEROPELVIC JUNCTION OBSTRUCTION AND VESICOURETERAL REFLUX

### 1. Pyeloplasty

Conventionally, the gold standard surgical method for the

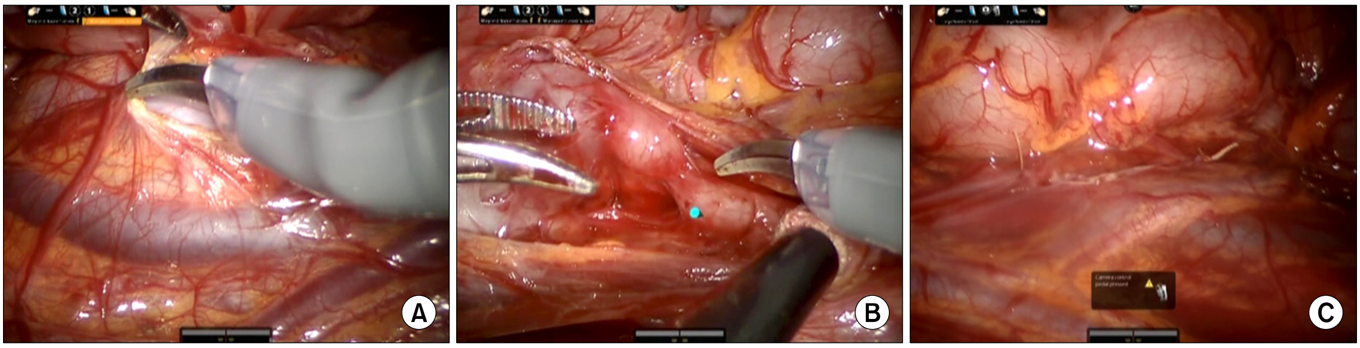


**Fig. 1.** Transperitoneoscopic, transmesenteric approach to the renal pelvis can reduce the operative time as demonstrated in this figure. (A) Incision of the mesenteric window over the dilated renal pelvis. (B) Identification of the obstructed ureteropelvic junction. (C) Final view of the operation filed after closure of the mesenteric window following pyeloplasty.

treatment of ureteropelvic junction obstruction is open dismembered pyeloplasty (Anderson-Hynes), which is known to be successful in 90% to 100% of cases. Few experiences with laparoscopic pyeloplasty have been reported since the first pediatric laparoscopic application by Peters et al. [5], and the approach remains to be widely adopted owing to its technical difficulty and the long learning curve. Robotic pyeloplasty is the most commonly reported robotic procedure in children to date [6]. Monn et al. [7] studied trends in robot-assisted laparoscopic pyeloplasty in pediatric patients in the United States, reporting that among 5,557 cases identified between the final quarters of 2008 and 2010, 750 cases (13.4%) were performed robotically. The first and only robotic pyeloplasty series reported in Korea was from Kim et al. [8], which included patients aged 18 years. Recently, Song et al. retrospectively reviewed the results of a consecutive robotic pyeloplasty experience in six (mean age, 10.8 years) pediatric patients and presented the safety and feasibility of this technique at the 65th Annual Meeting of the Korean Urological Association [unpublished data] (Fig. 1).

A trans- or retroperitoneal approach can be used depending on the surgeon's preference. The first series of robot-assisted retroperitoneoscopic pyeloplasties was reported by Olsen and Jorgensen [9] in 2004. In 13 children with a median age of 6.7 years (range, 3.5–16.2 years), 15 pyeloplasties were performed with the da Vinci Surgical System. During the follow-up period of 1 to 7 months, five patients (seven pyeloplasties) were evaluated with ultrasound and MAG3 scans at a 3-month follow-up and no obstruction was demonstrated. The authors concluded that the method is feasible with a shorter operative time and similar complications compared with conventional retroperitoneoscopic procedures. This same group reported a larger series involving 67 pyeloplasties in 65 children with a 5-year follow-up in 2007 [10]. The complication rate was 17.9%. One case was converted to open surgery, and four patients (6%) underwent reoperation because of ureteral kinking (two patients), an overlooked aberrant vessel (one patient), or decreased renal function necessitating balloon dilation (one patient). The authors concluded that their retroperitoneoscopic approach involved a shorter operative time and produced results and complication rates comparable with those of transperitoneal robotic pyeloplasty in children. Minnillo et al. [11] also demonstrated that robotic pyeloplasty can be safely and efficiently performed at an academic training institution through a Pediatric Urology Training Program with collaboration between robotic surgeons, surgical nurses, and anesthesiologists, and with long-term results similar to those of the gold standard, open pyeloplasty.

Several researchers have now compared the outcomes of robotic and open pyeloplasty (Table 1). Robotic pyeloplasty showed a decreased length of hospital stay and use of pain medication but had a longer operative time [12,13]. Sorensen at al. [14] found no significant differences between robotic and open surgery in terms of hospital stay, pain score, or surgical success at a median follow-up of 16 months. Recently, Barbosa et al. [15] assessed long-term postoperative outcomes of robotic and open pyeloplasty in a matched cohort of pediatric patients with ureteropelvic junction obstruction. The patients showed a higher complete resolution rate and shorter median time before improvement for robotic than open pyeloplasty. Dangle et al. [16] compared the outcomes of robotic and open pyeloplasty in infants. The mean patient age was 3.31 months in the open group and 7.3 months in the robotic group. The robotic group had a significantly longer total operating time (199 minutes vs. 242 minutes). However, there was no significant difference in hydronephrosis improvement between the two groups.

Few studies have compared robotic and laparoscopic pyeloplasty in children. Franco et al. [17] compared 15 robotic-assisted procedures and 12 laparoscopic procedures. The intraoperative time ranged from 150 to 290 minutes (mean, 223.1 minutes) for robotic pyeloplasty and from 200 to 285 minutes (mean, 236.5 minutes) for laparoscopic pyeloplasty. The authors reported that the final success rates were similar between the two groups (100%). They concluded that robotic anastomosis did not show any quantifiable benefits. However, robotic procedures were performed only for anastomosis, and the benefits of robotic sur-

**TABLE 1.** Robotic pyeloplasty case series and comparative studies between robotic and open pyeloplasty in children

| Author | Case | Mean age (y) | OT (min) | Hospital stay (d) | Complication rate (%) | Follow-up (mo) | Success rate (%) |
|---|---|---|---|---|---|---|---|
| Comparative studies | | | | | | | |
| Yee et al. [12] (2006) | | | | | | | |
| RP | 8 | 11.5 (6.4–16.5)[a] | 363 (255–522)[a] | 2.4 (1–5)[a] | 12.5 | 14.7 | 100 |
| OP | 8 | 9.8 (6.0–15.6)[a] | 248 (144–375)[a] | 3.3 (1–8)[a] | 0 | 53.2 | 87.5 |
| Lee et al. [13] (2006) | | | | | | | |
| RP | 33 | 7.9 (0.2–19.6)[a] | 219 (133–401)[a] | 2.3 (0.5–6.0)[a] | 3 | 10 | 94 |
| OP | 33 | 7.6 (0.2–19.0)[a] | 181 (123–308)[a] | 3.5 (2.7–5.0)[a] | 0 | 20 | 100 |
| Sorensen et al. [14] (2011) | | | | | | | |
| RP | 33 | 9.2 | 326±77[b] | 2.2 | 15 | 17 | 97 |
| OP | 33 | 8.2 | 236±54[b] | | 9 | 19 | 97 |
| Barbosa et al. [15] (2013) | | | | | | | |
| RP | 58 | 7.2 (147 d–18.2 y)[a] | NA | NA | 1.7 | 33 | 76.9 |
| OP | 154 | 1.2 (13 d–26.6 y)[a] | | | 4.3 | 31 | 67.9 |
| Case series | | | | | | | |
| Olsen et al. [10] | 67 | 7.9 (1.7–17.1)[a] | 146 (92–300)[a] | 2 (1-6)[a] | 17.9 | 12.1 | 94 |
| Minnillo et al. [11] | 155 | 10.5±6.5[b] | 198.5±70.0[b] | 1.9 | 11.0 | 31.7 | 96 |
| Singh et al. [35] | 34 | 12 | 105 (75–190)[a] | | 5.8 | 28.5 | 97 |

OT, operative time; RP, robotic pyeloplasty; OP, open pyeloplasty; NA, not available.
[a]:Mean (range). [b]:Mean±standard deviation.

gery, such as 3-dimensional visualization, articulated instruments, and tremor filtration, were not taken into account in this study.

In conclusion, pyeloplasty seems to be a good indication for the use of a robotic system. Many surgeons have observed that ureteropelvic anastomosis is easier to perform with robotic assistance that closely resembles the movement and techniques used during open surgery. Moreover, the learning curve for robotic pyeloplasty may be markedly shortened, demanding little previous robotic or laparoscopic experience [18].

## 2. Ureteral reimplantation

The gold standard surgical treatment for distal ureteral reconstruction and reimplantation in children is open intravesical or extravesical surgery, which has shown high success rates (92%–98%) and low complication rates. Minimally invasive surgery has also been investigated by several researchers. Although laparoscopic surgery has been applied since the first report by Ehrlich et al. [19] in 1994, few additional reports have been published in the literature, confirming the difficulty of the laparoscopic technique. Robot-assisted surgery has attracted surgeons as a minimally invasive alternative for the surgical treatment of vesicoureteral reflux. In 2005, Peters and Woo [20] reported an early series of six children who underwent robotic-assisted laparoscopic intravesical ureteral reimplantation. Kutikov et al. [21] published their experience of intravesical ureteral reimplantation and showed that the rate of complications and failure increased in younger children with bladder capacities less than 130 mL. The first robot-assisted ureteral reimplantation in adults was reported by Kang et al. [22] in 2009; however, there have been no published data regarding pediatric robotic reimplantation surgery from Korea until now.

Extravesical ureteral reimplantations have also been studied (Table 2). Casale et al. [23] published their experience with 41 patients who underwent robotic extravesical reimplantation for bilateral vesicoureteral reflux (Fig. 2). The authors reported success rates of 97.6% without complications. In 2012, a long-term analysis was reported by the same group with 150 patients who underwent bilateral extravesical robotic-assisted laparoscopic ureteral reimplantation [24]. The operative success rate was 99.3% for vesicoureteral reflux resolution on voiding cystourethrography without any occurrence of *de novo* voiding dysfunction.

Several researchers have reported comparative data between open and robot-assisted procedures for ureteral reimplantation in children. Sorensen et al. [25] reported the outcome of ureteral reimplantations and compared robotic cases with matched open controls. They demonstrated that the length of stay, complication rates, and success rates were similar but that the estimated blood loss was lower in the robotic group. The overall operative time was 53% longer in the robotic group (361±80 minutes vs. 236±58 minutes, $p<0.0001$). In a study by Smith et al. [26], the mean operative time was 12% longer in the robotic group than in the open surgery group. However, the mean length of stay (33 hours vs. 53 hours) and the use of postoperative narcotics were significantly lower in the robotic group. The success rate of robotic surgery was similar to that of the open approach.

Marchini et al. [27] compared a robotic group with an open group, differentiating extravesical from intravesical approaches in each group. The operative time was sig-

**TABLE 2.** Robotic intravesical and extravesical reimplantation case series in children

| Author | No. of renal units | Mean age | Operation method | Operative time (min) | Hospital stay (d) | Complications | Follow-up | Success rate (%) |
|---|---|---|---|---|---|---|---|---|
| Casale et al. [23] (2008) | 41 | 38 mo | Extravesical | 2.33 (1.40–3.19)$^a$ h | 26.1 (18–34)$^a$ h | None | 3–6 mo | 97.6 |
| Smith et al. [36] (2011) | 33 | 69 mo | Extravesical | 185.0±41.6$^b$ min | 33.0±12.5$^b$ d | Urinary retention (3) | 16 (2–44)$^a$ mo | 97.0 |
| Marchini et al. [27] (2011) | 39 | 8.6±9.1$^b$ y | Extravesical (20) | 233.5±60.2$^b$ min | 1.7±1.0$^b$ d | Bladder leak (IV-4) | 12.0±14.3$^b$ mo | 100 |
| | | 9.9±5.2$^b$ y | Intravesical (19) | 232.6±37.4$^b$ min | 1.8±1.2$^b$ d | Retention (IV-1, EV-2), ureteral leak (EV-2) | 19.4±18.2$^b$ mo | 92.2 |
| Kasturi et al. [24] (2012) | 150 | 42.6 mo | Extravesical | 1.8 (1.1–3.2)$^a$ h | 22.1 (18.0–34.0)$^a$ h | None | 3–24 mo | 99.3 at 3 mo |
| Hayashi et al. [37] (2014) | 15 | 132 mo | Extravesical | 268.7±88.4$^b$ min | 7.4±0.7$^b$ d | Grade 1 only | 3–4 mo | 93.3 |
| Akhavan et al. [38] (2014) | 78 | 7.2 y | Extravesical | NA | 2 (1–6)$^a$ d | Ileus (2), ureter injury (1), ureter obstruction (2), perinephric fluid collection (1) | 425.9 d | 92.4 |

NA, not available.
$^a$:Mean (range). $^b$:Mean±standard deviation.

nificantly longer in the robotic group for both extravesical and intravesical approaches. The duration of urinary catheter drainage, hospital stay, and frequency of bladder spasms were reduced in the robotic group for the intravesical approach. However, these differences were not observed when extravesical robotic-assisted reimplantation was compared with the extravesical open technique. Overall success rates were similar among patients who underwent robotic and open reimplantation.

In summary, robot-assisted ureteral reimplantation seems to be a good alternative in children. It is speculated that the use of the robotic technology for intravesical reimplantation allows the surgeon to obtain an angle of dissection that more closely mimics open surgery than does standard laparoscopy. However, the robotic data are thus far scarce. As such, larger studies involving multiple institutions with longer follow-up of patients with voiding cystourethrograms are necessary.

## OTHER PEDIATRIC ROBOTIC SURGERIES

### 1. Ureteroureterostomy

Most surgeons prefer the transperitoneal approach and preoperative retrograde pyelogram and placement of a ureteric stent [26]. Yee et al. [12] reported on three children who successfully underwent robotic ureteroureterostomy. The authors demonstrated that their operative times and total analgesic use were similar to those reported in the two largest series of pediatric robotic pyeloplasties. No complications were encountered and all children were discharged within 3.5 days. The authors insisted that the better visibility and ease of suturing provided by the robotic system allowed efficient reconstruction of the ureter.

### 2. Nephrectomy and heminephrectomy

Partial and total nephrectomy using the robotic system can be performed by a transperitoneal or retroperitoneal approach. No comparative studies of robotic and laparoscopic or open nephrectomy in children had been conducted until recently. Performing robot-assisted nephrectomy is even debatable, because robotic surgery is excessively expensive and it is unlikely that this approach offers any advantages over traditional laparoscopy [28].

The robotic approach could be more valuable for partial nephrectomy, which is technically more difficult. Heminephrectomy for nonfunctional moieties in a duplex kidney has been reported to be successful. Lee et al. [29] reported nine cases with a mean age of 7.2 years. The authors showed that the mean operative time was 275 minutes and the mean estimated blood loss was 49 mL. Operative time decreased with experience. They speculated that the enhanced visualization and dexterity of a robotic system could offer improved efficiency and safety over standard laparoscopy. Further studies are needed to confirm this hypothesis.

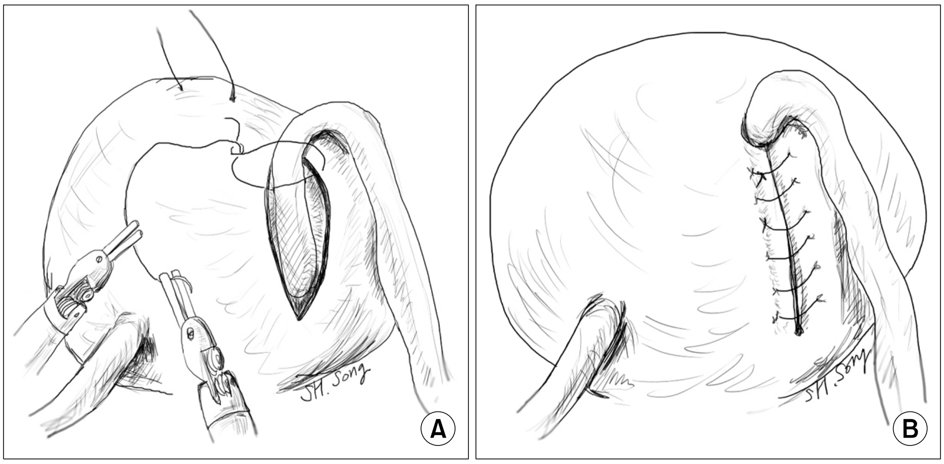


**FIG. 2.** Robotic extravesical detrusorrhaphy technique. Reapproximation of the detrusor creates a long submucosal tunnel (A) and completes the repair (B).

**3. Appendicovesicostomy and augmentation cystoplasty**

Pedraza et al. [30] reported the first case of Mitrofanoff appendicovesicostomy performed by robotic surgery. In 2008, Gundeti et al. [31] published a successful outcome of the first case of a child who underwent complete intracorporeal robot-assisted laparoscopic augmentation ileocystoplasty and Mitrofanoff appendicovesicostomy. Later, this same group reported a case series of 11 patients [32]. The mean patient age at surgery was 10.4 years (range, 5 to 14 years) and the mean operative time for the isolated appendicovesicostomy was 347 minutes. There were no intraoperative complications and stomal continence was achieved in 10 of the 11 children. Their continence rates were similar to those reported by Nguyen et al. [33] in 10 patients (80%) and Storm et al. [34] in 3 children (100% continence).

## CONCLUSIONS

A growing body of evidence supports the view that robotic technology in pediatric urological surgery is technically feasible and safe. Robotic technology provides additional benefits for performing reconstructive urologic surgery, such as in pyeloplasty, ureteral reimplantation, and enterocystoplasty procedures. The main limitation to robotic surgery is the high cost. Thus, the cost effectiveness of this technology remains to be validated.

## CONFLICTS OF INTEREST

The authors have nothing to disclose.

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