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TOPIC PAPER

Robot-assisted laparoscopic ureteral reimplantation in children: a valuable alternative to open surgery

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Abstract

Introduction Robot-assisted laparoscopic surgical systems have led to new minimally invasive options for complex reconstructive procedures in children including for vesicoureteral reflux (VUR). Robot-assisted laparoscopic ureteral reimplantation has been shown to be a viable minimally invasive surgical option for children with VUR. However, higher-than-expected complication rates and sub-optimal reflux resolution rates at some centers have also been reported.

Methods This article provides a focused literature review as well as current perspectives on open reimplantation and robot-assisted laparoscopic ureteral reimplantation as non-endoscopic surgical options for pediatric VUR.

Results The heterogeneity of surgical outcomes may, in part, be due to the learning curve inherent with all new technology and procedures. As a result, the current gold standard surgical option for VUR continues to be open ureteral reimplantation. While it remains to be seen if robot-assisted laparoscopic surgery will gradually replace open surgery as the most utilized surgical option for VUR in pediatric patients, robot-assisted laparoscopic ureteral reimplantation with the current robotic surgical systems may be just one step toward an eventual minimally invasive option that all experienced surgeons can offer with the requisite high success rates and low major complication rates.

Conclusion Robot-assisted laparoscopic ureteral reimplantation remains a viable minimally invasive surgical option for children with VUR, but with the expected learning curve associated with all new technologies.

Keywords Vesicoureteral reflux · Robotic surgery · Children · Ureteral reimplantation · Laparoscopic surgery · Pediatric

Introduction

Vesicoureteral reflux (VUR) results from a deviation of the normal urinary tract anatomy that leads to retrograde flow of urine from the bladder into the ureters and the kidneys. VUR can be simply categorized into primary and secondary VUR. Primary VUR is due to a congenital defect in the creation of the ureterovesical junction (UVJ) leading to inadequate ureteral tunnel length within the detrusor muscle. Secondary VUR is often due to lower urinary tract dysfunction, or bowel and bladder dysfunction (BBD), with resulting decompensation of the UVJ as a result of exposure to high bladder pressures. The incidence of lower urinary tract dysfunction occurring in patients with VUR varies in the literature from 18 to 75% [1]. When BBD is present, review panels of both the American Urological Association and European Association of Urology recommend correction of the BBD prior to surgical intervention for VUR [2, 3]. Given the need for correction of lower urinary tract dysfunction when addressing secondary VUR, we will focus this article's attention on primary VUR going forward.

Primary VUR is a common condition for which the families of pediatric patients seek consultations with pediatric urologists due to its relatively high prevalence in children. VUR has been estimated to occur in 0.4–1.8% of the asymptomatic pediatric population that have no known signs or symptoms of urinary tract infections (UTIs) [4, 5]. However, in patients with UTIs, the incidence of VUR significantly increases to 20–50% in the affected population [3, 6]. VUR may also have a hereditary component, as multiple studies have demonstrated increased rates of VUR in siblings and offspring (27.4% and 35.7%, respectively) [7]. Furthermore,

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when antenatal hydronephrosis is present, a postnatal diagnosis of VUR occurs in 16.2% of patients [7].

The management of VUR includes both medical and surgical approaches, and can differ on a case-by-case basis. The decisions of how to manage VUR in children have been facilitated by the American Urological Association's most recent VUR management guidelines [2]. While these guidelines explicitly state that the creation of a definitive algorithm to standardize the management of these patients is most likely not feasible given the tremendous variation in viable treatment options, these guidelines, nonetheless, provide a management framework for the care of pediatric patients with VUR. The guidelines provide different recommendations for patients based on their age (< 1 year of age and > 1 year). For the asymptomatic and uninfected infant under 1 year of age, the guidelines recommend observation with continuous antibiotic prophylaxis for patients with both low-grade VUR (grades 1–2) as well as high-grade VUR (grades 3–5), which can allow for the opportunity for self-resolution [2]. Circumcision of the male infant under 1 year with VUR also can help reduce the risk for UTIs in the first year of life and can be offered to parents as part of a male infant's care.

In general, for the older child (> 1 year), a detailed assessment for the presence of BBD should be included, and especially before a recommendation for surgical intervention is made, while also placing the child on protective continuous antibiotic prophylaxis. When BBD is not present, continuous antibiotic prophylaxis can be continued or discontinued after a thorough discussion of the risks and benefits with the parents.

There are certain clinical circumstances that often lead to recommendations for surgical intervention in the management of VUR. These include (1) breakthrough UTIs while on continuous antibiotic prophylaxis; (2) new or worsening renal scarring as seen on renal ultrasound and / or dimercaptosuccinic acid (DMSA) scan; (3) worsening VUR on subsequent voiding cystourethrograms (VCUG); or (4) lack of VUR resolution over time. These clinical events often spur a discussion of corrective surgical interventions that include endoscopic management with subureteric Deflux injections, open ureteral reimplantation, as well as laparoscopic ureteral reimplantation (conventional laparoscopic or robot-assisted laparoscopic).

In 2011, a panel associated with the American Association of Pediatrics (AAP) recommended significant modifications to imaging recommendations during the clinical investigation of UTIs in children [8]. This included the avoidance of VCUG in children who experienced only one febrile UTI that delayed this study until a second UTI had occurred. Subsequently, Bowen et al. noted that this guideline led to fewer ureteral reimplantations with a reduction of roughly 14% compared to the previous decade [9]. During this same time period, and similar to national trends in both the adult and pediatric surgical fields, minimally invasive approaches for the treatment of VUR became far more common with an increase from 0.3% in 2000 up to 6.3% in 2012 with more than 80% of these being robot-assisted laparoscopic approaches [9].

This article is primarily focused on ureteral reimplantation approaches for primary VUR, so discussion of subureteric Deflux injections, as well as the management of other ureteral conditions beyond primary and secondary VUR, such as obstructing megaureter, ureteral ectopia, and ureteral strictures for which ureteral reimplantation is also utilized for corrective surgical intervention are beyond the scope of this article. To date, the gold standard procedure for primary (and secondary) VUR is still open ureteral reimplantation with published success rates of approximately 95% or greater [2, 10], either via an intravesical or extravesical approach. With the ever increasing utilization of minimally invasive surgery approaches to surgery, robot-assisted laparoscopic ureteral reimplantaton (RALUR) also has grown into a viable option for surgeons who are experienced in robot-assisted laparoscopic surgery. Many studies have demonstrated comparable radiographic success rates with this approach to historical open success rates [11–13].

Minimally Invasive Ureteral Reimplantation

The first laparoscopic reimplantation was performed in a porcine model in 1993 [14]. While studies demonstrated the technical feasibility of this approach [15], others elucidated the larger complication rates [16]. The learning curve for this procedure was noted to be quite steep, as is seen with nearly all minimally invasive procedures at their outset. In their review of RALUR, Weiss et al., referenced the steep learning curve and significant physical stress on the surgeon as reasons for pure laparoscopic reimplantation's limited acceptance [17]. The development of the Da Vinci robotic surgical system (Intuitive Surgical, Sunnyvale, California) allowed for a less steep learning curve due to its more intuitive functioning and control compared to laparoscopic alone, as can be seen in multiple studies across a wide array of specialties [18–20]. However, as with all surgical procedures, a true learning curve exists with the robot-assisted laparoscopic surgical technique as well as with the utilization of the robotic technology. While no recent studies have extensively characterized the learning curves associated with open ureteral reimplantation, the multi-year urology training programs for urology residencies undoubtedly reflects a steep learning curve for both open and minimally invasive urologic procedures. This includes pediatric RALUR, where experienced laparoscopic surgeons have previously reported on the inevitable learning curve associated with RALUR, noting improvements in outcomes and operative times after at least the first 5–7 cases [21].

Intravesical robot-assisted laparoscopic ureteral reimplantation

The most common complications of open intravesical ureteral reimplantation include hematuria, bladder spasms, and other irritative voiding symptoms, all of which are related to the need for a cystotomy as a requisite for accessing the intravesical portion of the ureter. The intravesical RALUR approach is similar but with a minimally invasive approach, where multiple trocars are placed transabdominally and transvesically into the bladder with multiple small cystotomies. Marchini et al. performed a case-matched comparison between open reimplantation and RALUR for both intravesical and extravesical approaches. They reported that intravesical RALUR was associated with shorter urethral catheter durations, decreased bladder spasms, and shorter hospital stays when compared to the open intravesical cohort. On the other hand, they found that the intravesical RALUR cohort had more complications than with the open cohort [22]. The success rate, often defined as the radiographic resolution rate, for intravesical RALUR has been reported between 83 and 100% [22, 23]. In 2005, Peters and Woo described their experience with the intravesical RALUR approach to reimplantation—noting five of their six patients had radiographic resolution of VUR, but one patient suffered postoperative bladder leakage [24]. There are few articles describing intravesical RALUR, with the inherent technical challenges and relatively high complication rates when compared to extravesical cohorts as some of the reasons for poor adoption of this surgical option. Often, the extravesical approaches (open and robot-assisted laparoscopic) can avoid the side effects associated with the intravesical approaches (both open and robot-assisted laparoscopic) (Table 1).

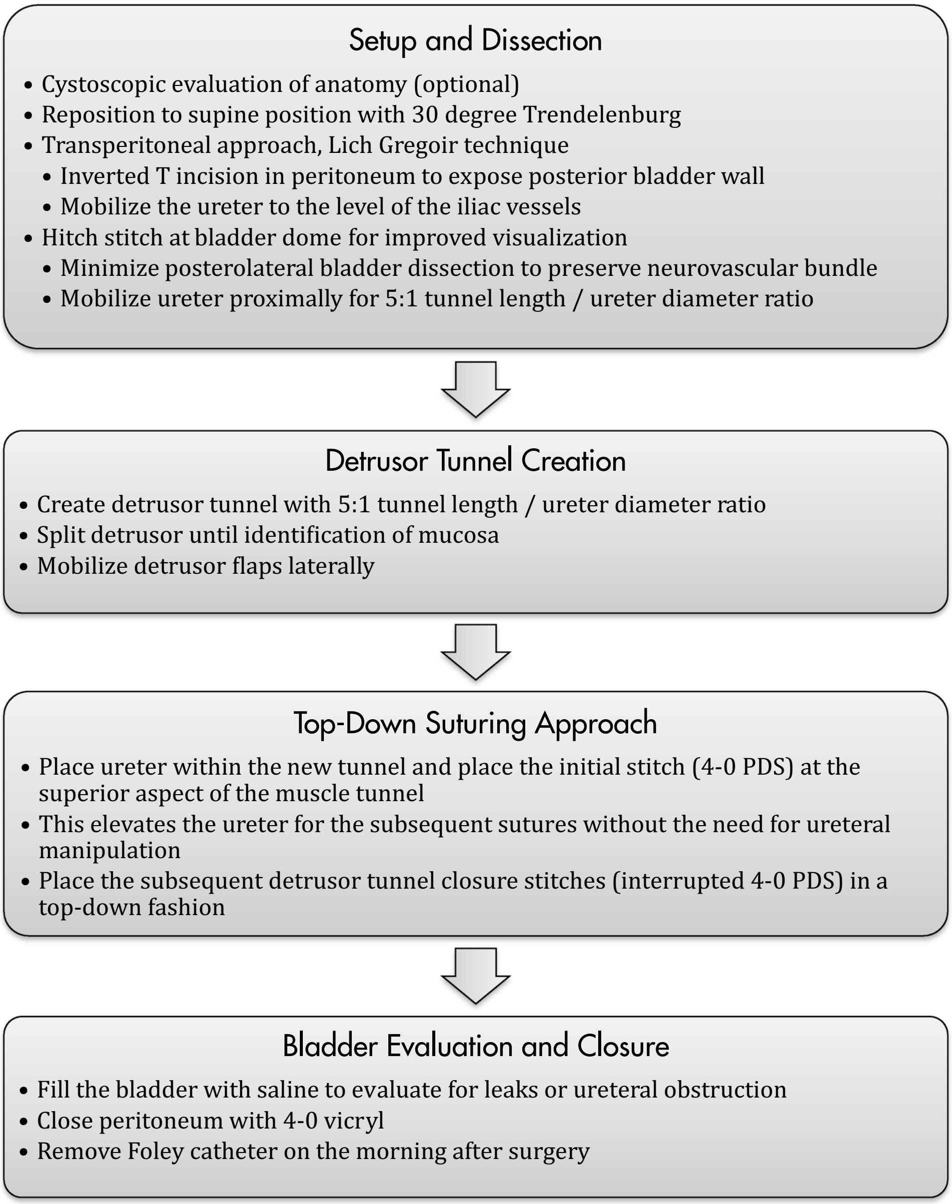
Extravesical robot-assisted laparoscopic ureteral reimplantation

In 2004, Peters et al. first described their experience with extravesical RALUR in pediatric patients with a reported success rate of 89% and a complication rate of 12% [25]. Subsequently, in 2008, presumably after overcoming the initial learning curve, Casale reported a comparable success rate to open surgery of 97.6% with no reported complications in 41 patients, with the exception of a single febrile UTI occurring in the setting of persistent VUR postoperatively [21]. Casale et al. then reported an update on their extravesical RALUR cohort of 150 patients, with a demonstrated success rate of 99.3% with no significant complications in that series [26]. Furthermore, Marchini et al. noted similar early postoperative sequelae of dysuria, bladder spasms, duration of foley drainage, and lengths of hospital stay for extravesical open and extravesical robot-assisted laparoscopic cohorts [22]. One key difference, however, was a higher reported rate of ureteral injury of 10% in the RALUR group that may reflect initial learning curve experiences. New approaches can reflect creativity for achieving as efficient and successful outcome as possible. One example is described in the paper by Silay et al. which gives detailed descriptions of a "top–down" suturing technique aimed at limiting ureteral manipulation and utilizing interrupted sutures in an effort to decrease complication rates and improve success rates [12]. A detailed description of this surgical technique is outlined in Fig. 1. Similarly, Gundeti et al. published multiple series on RALUR reviewing innovative approaches to overcome some of the limitations of the robot-assisted laparoscopic approach in an effort to normalize outcomes to that of the gold standard, open reimplantation [27].

As with most surgical techniques, an array of results is often encountered given the wide variation in surgical

Table 1 Success and complication rates for robot-assisted laparoscopic ureteral reimplantation (RALUR)

RALUR	Author (year)	# Patients (ureters)	Success rate (%)	Complications (VUR pts only)
Intravesical (IV)	Peters and Woo (2005)	6 (12)	83.3	1 (16.7%)
IV	Kutikov (2006)	27 (54)	92.6	3 (9.4%)
Extravesical (EV)	Casale (2008)	41 (82)	97.6	0
EV	Smith (2011)	25 (33)	97	3 (37.5%)
EV	Marchini (2011)	20	100	4 (20%)
EV	Kasturi and Casale (2012)	150 (300)	99.3	0
EV	Akhavan (2014)	50 (78)	92.3	6 (5 patients, 10%)
EV	Grimsby (2014)	61 (93)	72	6 (10%)
EV	Schomburg (2014)	20	100	2 (10%)
EV	Silay, Baek and Koh (2015)	89 (114)	97.9	2 (2.7%)
EV	Gundeti (2016)	58 (83)	82	1 (1.7%)



Setup and Dissection

- Cystoscopic evaluation of anatomy (optional)
- Reposition to supine position with 30 degree Trendelenburg
- Transperitoneal approach, Lich Gregoir technique
  - Inverted T incision in peritoneum to expose posterior bladder wall
  - Mobilize the ureter to the level of the iliac vessels
- Hitch stitch at bladder dome for improved visualization
  - Minimize posterolateral bladder dissection to preserve neurovascular bundle
  - Mobilize ureter proximally for 5:1 tunnel length / ureter diameter ratio

Detrusor Tunnel Creation

- Create detrusor tunnel with 5:1 tunnel length / ureter diameter ratio
- Split detrusor until identification of mucosa
- Mobilize detrusor flaps laterally

Top-Down Suturing Approach

- Place ureter within the new tunnel and place the initial stitch (4-0 PDS) at the superior aspect of the muscle tunnel
- This elevates the ureter for the subsequent sutures without the need for ureteral manipulation
- Place the subsequent detrusor tunnel closure stitches (interrupted 4-0 PDS) in a top-down fashion

Bladder Evaluation and Closure

- Fill the bladder with saline to evaluate for leaks or ureteral obstruction
- Close peritoneum with 4-0 vicryl
- Remove Foley catheter on the morning after surgery

Fig. 1 “Top–down” suturing technique for extravesical RALUR

experience amongst the different authors. RALUR is similar as can be seen in the bi-institutional review of RALUR by Grimsby et al. In the two centers, this group found a lower success rate of 72% and a higher complication rate—10% major complication rate and 11% reoperation rate—that differed from other previously reported studies [11].

A large multicenter study by Boysen et al. reported similarly low complication rates when compared to open ureteral reimplantation with mostly low-grade (grades 1–2) complications demonstrated [28]. One such potential complication that was investigated further at our center (publication pending) was that of postoperative hydroureteronephrosis (HUN). One theory was based on determination of surgical failure as those patients who demonstrate hydronephrosis on postoperative imaging. However, our series noted that while approximately 30% of successful repairs have transient postoperative hydronephrosis, essentially, all cases resolve within 1 year without the need for intervention.

Robot-assisted laparoscopic ureteral reimplantation and open ureteral reimplantation

When comparing the most commonly used approach to robot-assisted laparoscopic ureteral reimplantation—extravesical RALUR—to the gold standard of an open, intravesical, cross-trigonal ureteral reimplantation, Smith et al. found a comparable success rate between the two approaches. Extravesical RALUR had a 97% success rate compared to 100% for the open cross-trigonal technique. However, consistent with a large volume of studies demonstrating similar findings for minimally invasive approaches, the robot-assisted laparoscopic approach was associated with decreased lengths of stay and reduced pain medication utilization [29].

To date, one key difference between open and robot-assisted laparoscopic surgery in general is the overall cost of the procedure. Robot-assisted laparoscopic surgery has always fallen victim to the stigma of being a very costly modality, and rightfully so given its high upfront capital costs. Many studies have reviewed the cost effectiveness of RALUR. Kurtz et al. demonstrated a nearly $2000 increase in cost for RALUR compared to open ureteral reimplantation ($9128 vs $7273, respectively) [30]. Much of this increased cost has been associated with longer operative times, since operating room costs are usually the largest component of the total cost of care [29]. In addition, this study included costs for 90-day complications, which inherently increases the costs for robot-assisted laparoscopic procedures due to the upfront equipment costs and the initially higher complication rates incurred during the learning curve period. Other studies have taken a more simplistic approach by limiting cost analysis to include only costs of the operation and initial hospital stay. Baek et al. compared robot-assisted laparoscopic and open ureteral reimplantation hospital charges, finding the higher operative costs being offset by lower costs associated with shorter hospital stays [31]. In addition, with increasing experience with RALUR, complication rates for all surgeons should be equivalent to those seen with the gold standard of open reimplantation. The general conclusions from multiple studies are such that when taking into account operating room costs combined with postoperative hospital costs, the gap between robot-assisted laparoscopic and open approaches narrows significantly [9, 30, 32]

Complications with robot-assisted laparoscopic ureteral reimplantation and open ureteral reimplantation

The benefits of robot-assisted laparoscopic surgery are unique to the modality and are especially seen in the postoperative course. However, robot-assisted laparoscopic surgery and RALUR, in particular, can also be associated with complications similar to open reimplantation. Since open reimplantation and RALUR are inherently similar in their overall surgical plans, as could be expected, the complications associated with both approaches are similar, such as urinary retention, postoperative hydronephrosis, hematuria, oliguria/anuria, etc. [30].

In regards to extravesical RALUR, there has been a well-documented postoperative phenomenon of temporary urinary retention. Some have argued that extravesical RALUR should be avoided due to this; however, at similar rates of occurrence, temporary urinary retention is also seen with open bilateral extravesical ureteral reimplantation [33]. This has been reported to mostly occur when bilateral reimplantations are performed [21, 26, 34]. Other reports have argued that a higher rate of postoperative retention does not exist [35].

In terms of reproducible benefits to a robot-assisted laparoscopic approach, multiple studies have reported improved pain control, decreased lengths of hospital stay, and improved cosmetic appearances [29, 36]. All of these benefits are related to avoiding the large incision associated with open surgery, which greatly aids in pain reduction and in the postoperative appearance of the scars. These benefits remain constant across the full breadth of robot-assisted laparoscopic surgery in both the pediatric and adult populations.

Conclusion

The wide range of success rates and complication rates with robot-assisted laparoscopic surgery may be indicative of the relative novelty of robot-assisted laparoscopic surgery in the world of pediatric urology. While many of the more experienced pediatric urologists had no formal training in robot-assisted laparoscopic surgery, thus limiting their ability to easily adapt this technology, the more recent fellowship graduates are avoiding the steep learning curve by receiving training during their fellowships and residencies. The initial studies previously mentioned acknowledge this sentiment by reporting their outcomes both during and after the learning curve [21].

What is oft forgotten is the history of surgical innovation. In the development of what are now considered “routine” and “low-risk” surgical procedures, there existed a time when these same surgeries were associated with significant learning curves and potential complications. With time and practice, these complications were overcome and became an afterthought. With the adoption of new technologies and surgical aids, one should keep in mind that learning curves are a reality, including for RALUR, but which should be overcome as experience is obtained and newer technology is developed.

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Compliance with ethical standards

Conflicts of interest CJ Koh: Consultant and Course Director, Intuitive Surgical (Sunnyvale, California).

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