Review

The robot-assisted ureteral reconstruction in adult: A narrative review on the surgical techniques and contemporary outcomes

Kulthe Ramesh Seetharam Bhat a,*, Marcio Covas Moschovas a, Vipul R. Patel a, Young Hwii Ko b

a Department of Urology, AdventHealth Global Robotics Institute, Celebration, FL, United States
b Department of Urology, Yeungnam University, Daegu, Republic of Korea

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Abstract Despite the rapid increase in the use of robotic surgery in urology, the majority of ureteric reconstruction procedures are still performed using laparoscopic or open approaches. This is primarily due to uncertainty regarding the advantages of robotic approaches over conventional ones, and the unique difficulty in identifying the specific area of interest due to the lack of tactile feedback from the current robotic systems. However, with the potential benefits of minimal invasiveness, several pioneering reports have been published on robotic surgery in urology. By reviewing the literature on this topic, we aimed to summarize the techniques, considerations, and consistent findings regarding robotic ureteral reconstruction in adults. Robotic applications for ureteral surgery have been primarily reported for pediatric urology, especially in the context of relieving a congenital obstruction in the ureteral pelvic junction. However, contemporary studies have also consistently demonstrated that robotic surgery could be a reliable option for malignant, iatrogenic, and traumatic conditions, which generally occur in adult patients. Nevertheless, the lack of comparative studies on heterogeneous hosts and disease conditions make it difficult to determine the benefit of the robotic approach over the conventional approach in the general population; thus, qualified prospective trials are needed for wider acceptance. However, contemporary reports have demonstrated that the robotic approach could be an alternative option for ureteral construction, even in the absence of haptic feedback, which can be compensated by various surgical techniques and enhanced three-dimensional visualization.

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* Corresponding author.
E-mail address: Seetharam_bhat2003@yahoo.co.in (K.R. Seetharam Bhat).
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1. Introduction

The widespread use of robotic surgery has motivated urologists to apply robotics in typical surgical settings where open and laparoscopic approaches have long been the standard of care [1]. Ureteral reconstruction encompasses a wide spectrum of diseases with different etiologies, including iatrogenic, congenital, and malignant conditions, across the upper and lower ureter, each requiring unique approaches for surgical correction. Owing to their minimal invasiveness and high dexterity, robotic ureteral reconstruction procedures for the upper tract were initially applied in the field of pediatric urology. As such, there are limited data on the outcome of robotic surgery for the repair of the upper urinary tract in adults.

In the case of lower ureteral disease, there has been increasing interest regarding robotic ureteral surgery as a kidney-sparing procedure for distally located upper tract urothelial carcinoma (UTUC), including distal ureterectomy and segmental ureterectomy [2]. Both procedures, concomitant with or without a psoas hitch or Boari flap, are recommended in recently available guidelines as reliable alternatives to replace the standard radical nephroureterectomy [3]. Nevertheless, the lack of comparative studies based on heterogeneous conditions makes it difficult to perform a meta-analysis and establish a solid conclusion on the unique benefit of the robotic approach over the open approach and conventional laparoscopy in the general population. Thus, by reviewing contemporary published articles, we sought to establish consistent findings regarding robotic ureteral reconstruction in adult patients. Given the retrospective, single-arm design of the majority of reported studies, we also aimed to investigate the feasibility and benefit of robotic surgery in different etiologies and provide a summary of the suggested surgical techniques.

1.1. Identification of the area of interest in a robotic environment

Despite recent technological advances, the absence of tactile feedback in currently available robotic surgical systems is a significant drawback that makes it difficult to identify an area of interest [4]. Therefore, conducting imaging studies before robotic ureteral procedures is a pivotal step in planning surgery. Because of the variety in the location and size of tumors in UTUC, each robotic ureteral procedure is performed in an individualized fashion. Computed tomography imaging is currently the gold standard technique for the identification and localization of the lesion. If the area of interest is narrow, pre-insertion of a ureteral catheter up to the area of interest before surgery could provide additional information. In a patient with a pre-existing percutaneous nephrostomy (PCN) tract, a ureteral access sheath can be inserted under general anesthesia, enabling the insertion of a flexible ureteroscope in an anterograde fashion.

One of the unique benefits of robotic technology is the use of indocyanine green (ICG), which can be visualized under near-infrared fluorescence (NIRF) to identify lesions. A ureteral catheter and/or a PCN tract can be used to inject 10 mL of ICG into the diseased ureter, above and below the stricture point. Intraoperatively, NIRF is activated to assist in the identification of the ureter and localize the margins of ureteral strictures [5].

1.2. General principles in patient positioning and trocar configuration

The position of the patient should be tailored according to the area of interest. In general, the patient position depends on the type of procedure and the location of the area of interest. For procedures on upper tract lesions, including the renal pelvis and upper ureter, lateral decubitus or modified decubitus position can be recommended. For procedures on lower counterparts, the patients usually placed in the dorsal lithotomy position and steep Trendelenburg position, and the robot is brought into position between the patient’s legs, as with conventional prostatectomy. In cases that require additional ureteral or bladder procedures by cystoscopy or ureteroscopy, the lithotomy position may be used, albeit with great caution, owing to possible collisions of the instrument arm with the patient’s leg or the bedside assistant. However, this conventional position limits access to the bladder, which is mandatory in many cases, especially for retrograde placement of a ureteral stent. Slater et al. [6] performed 14 distal ureteral reconstructions, including three Boari flap procedures using the da Vinci Si system, and suggested side-docking of the robotic patient cart. The da Vinci Xi series has an additional advantage that it provides a wider range of motion and minimizes external collisions between each robot arm [7]. Moreover, side-docking helps to provide adequate access to the perineum, and its interchangeable camera trocars help in placing the camera in any trocar, thus providing various angles and enhancing the visualization. The latest da Vinci SP system has been demonstrated to be safe and feasible in a small single surgeon series [8,9]. Trocar placement for robotic ureter reconstruction should be individualized depending on the area of interest, workload of the procedure, type of robotic system, and patient positioning.

2. Robotic pyeloplasty

Ureteropelvic junction obstruction (UPJO) is the most common condition that is treated robotically by pediatric urologists. The major case reports of adult patients are summarized in Table 1.

Anderson-Hynes pyeloplasty is considered the standard procedure of care for UPJO as it is widely applicable in different UPJO scenarios, with the exception of cases with lengthy or multiple proximal ureteral strictures and patients with anintrarenal pelvis. This procedure involves dismembering the ureter from the pelvis, excising the obstructed segment and redundant renal pelvis, and anastomosis of the ureter to the redundant pelvis after adequate spatulation. Flap procedures are particularly useful in patients with abnormal anatomy. Popular flap procedures include Foley Y-V plasty, which is usually performed for high insertion in the ureters, and Culp-DeWeerd spiral flap and Scardino-Prince vertical flap procedures for long segment proximal ureteral strictures [10,11]. The key to good repair is a widely patent, watertight, tensionless anastomosis that allows dependent drainage [12]. This
procedure can be performed transperitoneally or retroperitoneally [13,14]. Moreover, the use of the transmesenteric approach has also been described, particularly on the left side, which avoids reflection of the colon [15]. Robotic pyeloplasty has been popularized by many centers for over a decade, with success rates from 95% to 100% [16–19]. However, the definition of success in each study is not identical; although the commonly applied definition of success was relief of radiologic obstruction assessed by diuretic renogram or intravenous urography, some authors also consider the absence or improvement of the symptoms as a successful outcome [10,16]. In the US, from 2003 to 2015, the number of robotic cases increased annually by 29%, with robotic pyeloplasty used in 40% of all pyeloplasty cases in 2015 [20]. The use of robots in redo pyeloplasty can significantly reduce surgical time, with a success rate of 100% [21]. Compared to open and laparoscopic pyeloplasty, robotic pyeloplasty has been shown to have the highest operative success rate and a lower incidence of complications [22,23]. A recent systemic review demonstrated that robotic pyeloplasty had a 27-min shorter operative time and 1.2-day shorter hospital stay than the laparoscopic approach stay [24].

2.1. Pyeloplasty in difficult anatomy

Horseshoe kidney is the most common renal congenital anomaly and is seen in approximately 0.25% of the general population [25]. One-third of horseshoe kidneys have UPJO [26], and the challenges faced in horseshoe kidneys are due to anomalous lower pole vessels, presence of a renal isthmus, and altered lower pole anatomy [26,27]. The success rates of open pyeloplasty in horseshoe kidneys vary from 50% to 80%, and success rates of 78%–100% have been reported in different studies of robotic pyeloplasty in horseshoe kidneys [28–30]. Furthermore, the surgical technique varies because of anatomic complexities, which further justifies the use of robots as versatile tools in the surgical management of UPJO in horseshoe kidneys. A graft flap could be an alternative option in cases of deteriorated remnant ureteral tissue. The buccal mucosa is an excellent graft to substitute the diseased ureter, as it has a thick epithelium, thin lamina propria, and extensive blood supply that helps the process of insolation and imbibition. Zhao et al. [31] first described robotic buccal ureteroplasty in four patients with intractable ureteric strictures, particularly ones longer than 3 cm, with a 100% success rate and a median follow-up of 15.5 months. Zhao et al. [31] pioneered the use of NIRF imaging with intravenous ICG to evaluate stricture margins. The reconstructed segment can be supported using either omental or perirenal fat, depending on the site of the strictures. Lee et al. [32] reported the largest study using buccal mucosa to repair complex ureteral stricture, with a success rate of 83.3% confirmed both clinically and radiologically.

2.2. Robotic distal ureterectomy with ureteral reimplantation

Distal ureterectomy with various ureteral reimplantation techniques was the most popularly highlighted area in
robotic ureteral surgery in adults, since its first report in 2003 [33]. The series in this area published until the end of 2019 are summarized in Table 2. Identification of the affected ureteric segment, followed by meticulous dissection without compromising the tissue vascularity of the ureter and obtaining the maximal healthy ureteral length, are key to a successful procedure. In the cases of malignant stricture, especially by UTUC, tumor spillage can be prevented by placing a clip just above and below the affected ureter before transection of the ureter.

Among the numerous publications on robotic ureteral surgery in adults, almost all were retrospective studies from heterogeneous institutions with small sample sizes, and were focused mainly on safety and feasibility. Moreover, the definition of success was not clarified in the majority of the studies, which made comparison between techniques difficult. Nevertheless, for strictures with benign etiology, the reported success rate appears reasonable, despite the absence of long-term outcomes. In the 10 years since the first case, only a single case of anastomotic stricture has been reported [34]. In the largest study of 95 patients, Fifer et al. [35] reported three cases of recurrence during short-term follow-up. Inspired by these positive results, robotic distal ureterectomy was applied for UTUC, carefully expanding its indication from pT1 to beyond pT2 disease. However, the reported tumor recurrence rate was not negligible, implying that its oncologic safety remains to be established. Among nine patients with UTUC, Glinianski et al. [36] reported five intravesical and one ipsilateral renal pelvic recurrences. Furthermore, Eandi et al. [34], McClain et al. [37], and Musch et al. [38] reported a single systemic, intravesical, and ipsilateral pelvic and bladder tumor recurrence within 3 years of follow-up.

Because a relatively small incision was required, even with an open procedure, the actual benefit of the robotic approach can be only determined using a comparative study. However, the low incidence of UTUC presents another challenge in prospectively studying the robotic approach. Three studies have retrospectively compared robotic approaches with other approaches. When comparing 10 patients with benign stricture for robotic and open approaches, Kozinn et al. [39] reported significantly reduced estimated blood loss (30.6 mL vs. 327.5 mL) and lengths of hospitalization (2.4 days vs. 5.1 days) in the robotic group, with similar operative time between approaches (306.6 min vs. 270.0 min, p = 0.130). During 24 and 30 months of follow-up, respectively, none of the patients in either group experienced a clinical or radiologic recurrence of stricture. Moreover, Isaac et al. [40] compared 25 robotic cases with 41 open procedures, and reported a shorter hospital stay (3 days vs. 5 days), less narcotic pain requirements (104.6 mg vs. 290.0 mg) and less blood loss (100 mL vs. 150 mL) with the robotic approach. Furthermore, they reported similar reoperation rates of 7.6% (robotic) vs. 9.7% (open) for each group, although the follow-up period was approximately four times as long in the open group (11.6 months vs. 44.5 months), with a significantly shorter operative time (279 min vs. 200 min, p = 0.0008). Elsamra et al. [41] compared 105 minimally invasive cases (20 robotic, 85 laparoscopic) with 25 open cases and demonstrated a similar trend with shorter hospital stays and less blood loss in minimally invasive approaches. However, besides the heterogeneity in procedures and follow-up periods of each study, no distinct differences were seen between the laparoscopic and robotic groups. Thus, the unique advantages of robotic approaches over conventional open laparoscopic approaches are uncertain, despite their potential benefit of being minimally invasive.

3. Robotic Boari flap

In an attempt to cram the resected length of the affected ureter, a psoas hitch or Boari flap has been used as a component of distal ureterectomy, in which the main principle is to bridge the large gap between the healthy ureter and the bladder with a tubularized L-shaped bladder flap. A preoperatively low-capacity bladder is likely to be associated with inadequate Boari flap creation, leading to several voiding symptoms.

The first report on the use of a Boari flap in robotic ureteral reconstruction was published in 2008 for treating a benign stricture [42]. The published data on robotic ureteral reimplantation using a Boari flap are summarized in Table 3. Despite the limited number of patients, the feasibility and safety of the robotic approach have been reported consistently. However, in most cases, the follow-up after surgery was only over 1 year, with more complications than other ureteral reconstructive procedures. Among 33 reported cases of patients with short-term outcomes, a single patient required an additional robotic procedure owing to external iliac vein injury, and two experienced anastomotic leaks [42–44]. In a large study, Fifer et al. [35] reported three recurrent stricture cases within a median follow-up of 6 months, among nine cases of robot-assisted reconstruction with a Boari flap. In malignant conditions, special care with close follow-up should be provided, given that five among 33 patients had UTUC, and one of them had ipsilateral tumor recurrence within 1 year of surgery [42].

4. Robotic ureteroureterostomy

Ureteroureterostomy is the simplest way to deal with the narrowing of the affected ureter; however, it is contraindicated for long ureteral strictures that do not allow a tension-free end-to-end anastomosis. Robotic ureteroureterostomy was initially reported in 2006 for two adult patients with benign strictures, but recently gained popularity in the pediatric population (Table 4). Lee et al. [5] reported the advantages of a robotic platform in 25 pediatric patients compared with 19 patients who underwent open surgery. They showed comparable operative time, estimated blood loss, and complication rate, but the robotic group had slightly shorter hospitalization and higher rates of improved hydronephrosis or drainage in initial follow-up imaging than the open group.

Port placement for adults is usually performed in the modified flank position, which differs from that in the pediatric population [45]. The first robotic ureteroureterostomy for mid-to-distally located UTUC with intermediate-term outcomes was reported by McClain et al.
Table 2  Summary of articles on distal ureterectomy with reimplantation during robot-assisted ureteral reconstruction.

| Study                        | No. of patient | Pediatric/Adult | Benign/Malignant disease | Diagnosis                                                                 | Operation                                                                 | Total operative time (robotic time, min) | Complication | Follow-up (month) | Recurrence (in case of malignant disease) |
|------------------------------|----------------|-----------------|--------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------|------------------------------------------|--------------|-------------------|------------------------------------------|
| Yohannes et al., 2003 [33]   | 1              | Adult           | Benign                   | Stricture and endoscopic failure                                          | Distal ureterectomy and reimplantation                                     | 210           | None              | 5                           | None                                     |
| Mufarrij et al., 2008 [53]   | 4              | Adult           | Benign                   | 3—iatrogenic injury                                                       | Distal ureterectomy and reimplantation                                     | 239           | None              | 31.5                         | None                                     |
| Uberoi et al., 2007 [65]     | 1              | Adult           | Malignant                | UTUC                                                                      | Distal ureterectomy and reimplantation with a psoas hitch (endoscopic incision on ureteral orifice) | NA            | NA                | NA                          | NA                                       |
| Williams and Leveillee, 2009 [66] | 7              | Adult           | Benign                   | 3—Stone 2—iatrogenic injury 1—Ureterovaginal fistula 1—Endometriosis 6—UTUC 5—Benign stricture UTUC (5—below pT1) | Distal ureterectomy and reimplantation                                     | 247           | 1—Anastomotic stricture | 18                          | 1—anastomotic stricture |
| Schimpf and Wagner, 2009 [43] | 11             | Adult           | Malignant                | UTUC                                                                      | Distal ureterectomy and reimplantation                                     | 189.3 (average) | 2—Flank pain without radiologic evidence | 20.5 (average) | NA |
| Glinianski et al., 2009 [36] | 9              | Adult           | Malignant                | UTUC                                                                      | Distal ureterectomy and reimplantation                                     | 252           | 1—Ureteral stricture | 23                          | 5—intravesical recurrence |
| Eandi et al., 2010 [34]      | 4              | Adult           | Malignant                | UTUC (3—below pT1; 1—pT2) 5—iatrogenic injury 5—Stone 7—Stone 6—iatrogenic injury 1—UTUC 1—Psoas hitch | Distal ureterectomy and reimplantation                                     | 311           | 1—Aspiration pneumonia 1—Urine leak with ileus | 30.5          | None |
| Kozinn et al., 2012 [39]     | 10             | Adult           | Benign                   | UTUC                                                                      | Distal ureterectomy and reimplantation                                     | 306.6         | None              | 24                          | None |
| Baldie et al., 2012 [67]     | 13 (among 16 robotic series) | Adult           | Benign                   | UTUC                                                                      | Distal ureterectomy and reimplantation                                     | 266.7         | 2—Open conversion 6.4 | None                        | None |
| McClain et al., 2012 [37]    | 4 (among 6 robotic series) | Adult           | Malignant                | UTUC (1—CIS, 1—pT1, and 1—pT2) 1—B cell lymphoma 3—UTUC 1—Psoas hitch | Distal ureterectomy and reimplantation                                     | 279 (average) | None              | 32.7 (average) 1—intravesical recurrence | None |

(continued on next page)
| Study                  | No. of patient | Pediatric/ adult | Benign/ malignant disease | Diagnosis                      | Operation                                                                 | Total operative time (robotic time, min) | Complication                     | Follow-up (month) | Recurrence (in case of malignant disease) |
|-----------------------|----------------|------------------|---------------------------|--------------------------------|--------------------------------------------------------------------------|-------------------------------------------|-------------------------------|------------------|------------------------------------------|
| Lee et al., 2017 [32] | 10             | Adult            | 8—Benign 2—Malignant     | 1—UTUC 1—Endometrial stromal sarcoma | Distal ureterectomy and reimplantation (5—Psoas hitch)                    | 211                                       | 2—Clavien II (1—Hypoxia; 1—Hemorrhage) | 28.5             | 2—Stricture recurrence                   |
| Isac et al., 2013 [40] | 25—Robot      | Adult            | Benign                    | Robot—20 stricture (5 iatrogenic) | Distal ureterectomy and reimplantation (4—Psoas hitch and 10—Boari flap) | 297—Robot                                | 44.5—Open                      | 11.6—Robot     | Reoperation 4 (9.7%)—Robot               |
| Elsamra et al., 2014 [41] | 20—Robotic | Adult            | Malignant                 | Malignant 6—Robotic 14—Laparoscopic 9—Open | Distal ureterectomy and reimplantation (6/1/12—Psoas hitch and 8/44/8—Boari flap) | 236—Robot 235—Laparoscopic 257—Open | 2 (10%)—Robot 5 (5.9%)—Laparoscopic 5 (20%)—Open | 2 (7.6%)—Robot | Recurrence 2 (10%)—Robot                |
| Fifer et al., 2014 [35] | 55            | Adult            | Benign 45—Benign 10—Malignant | 35—Ureteroneocystotomy without psoas hitch 10—Distal ureterectomy 9—Boari flap 5—Ureterolysis 5—Ureteroureterostomy 2—Ureterolithotomy 1—Reimplant to neobladder | Distal ureterectomy and reimplantation (6/1/12—Psoas hitch and 8/44/8—Boari flap) | 233                                       | 2 over Clavien III (1—acute oxygen desaturation; 1—rebleeding) | 6                | 3—                                |
| Pugh et al., 2015 [68] | 8             | Adult            | 4—Benign 4—Malignant      | 2—Below pT1 2—Beoynd pT2 | Distal ureterectomy and reimplantation                                    | 285                                       | 1—Readmission for dehydration (I) | NA               | NA                                      |
| Kaouk et al., 2019 [8] | 3             | Adult            | 3—Benign                  | DaVinci SP system (2—extra port and 1—no extra port) | Distal ureterectomy and reimplantation (1—bilateral reimplantation) | 165                                       | 1—Nausea (I) | NA                                       |

CIS, carcinoma in situ; SP, single-port; UTUC, upper tract ureteral carcinoma; NA, not available.

* Comparative vs. open.

* Comparative vs. laparoscopic and open.

* All Boari flap (4 among 10 malignant had bladder recurrence).
**Table 3** Summary of articles on Boari flap during robot-assisted ureteral reconstruction.

| Study                        | No. of patients | Benign/malignant disease | Diagnosis          | Operation                                               | Total operative time (robotic time, min) | Complication                      | Follow-up (month) | Recurrence |
|------------------------------|-----------------|---------------------------|--------------------|---------------------------------------------------------|------------------------------------------|-------------------------------------|------------------|------------|
| Schimpf and Wagner 2008 [69] | 1               | Benign                    | Ureteral stricture | Distal ureterectomy and reimplantation with Boari flap  | 150 (Robotic)                           | Mild hydronephrosis                 | 6                | None       |
| Schimpf and Wagner 2009 [43] | 2 (Among 11 cases of distal ureterectomy) | 1—Benign, 1—malignant   | 1—Benign UTUC (Ta high grade) | Distal ureterectomy and implantation with Boari flap | 169 (Robotic)                           | 1—External iliac vein injury repaired robotically, 1—Ileus | 1—12             | None       |
| Allaparthi et al., 2010 [70] | 2               | Malignant                 | 2—UTUC (below pT1) | Distal ureterectomy and implantation with Boari flap   | 245                                      | None                               | 6                | None       |
| Yang et al., 2011 [71]      | 2 (Among 3 cases) | 1—Benign, 1—Malignant    | 1—iatrogenic pTa UTUC | Distal ureterectomy and implantation with Boari flap | NA                                      | 1—Arterial flutter                  | NA               | None       |
| Musch et al., 2012 [72]     | 1 (Among 9 cases of distal ureterectomy) | Malignant                | UTUC               | Segmental ureteral resection with lymphadenectomy and Boari flap | 320                                      | None                               | 12               | None       |
| Musch et al., 2013 [42]     | 5 (Among 16 ureteral reimplantation) | 2—Benign, 3—Malignant   | 2—UTUC, 1—Prostate Ca | Distal ureterectomy with reimplantation with Boari flap | 287 (In average)                        | 1—Recurrent tumor on bladder and ureter and renal pelvis, 1—Hydronephrosis due to anastomotic stricture, 1—Additional endoscopic treatment | 11.3 (in average) | 1—None     |
| Do et al., 2014 [44]        | 8               | 5—Benign, 3—Malignant    | 3—iatrogenic, 1—Trauma, 1—Stricture, 3—UTUC | Distal ureterectomy with reimplantation with Boari flap | 171.9                                   | 1—Prolonged anastomotic leak       | 12               | None       |
| Slater et al., 2015 [6]     | 3 (Among 14 distal ureterectomy) | 3—Benign                |                    | Distal ureterectomy with reimplantation with Boari flap | 315 (In average)                        | 1—Fever                           | 20.6 (in average) | None       |
| Stolzenburg et al., 2015 [73]| 11              | Benign                    |                    | Distal ureterectomy with reimplantation with Boari flap | 166.8                                   | 1—Prolonged catheterization due to anastomotic leak | 12.5              | None       |

UTUC, upper tract ureteral carcinoma; NA, not available.
in which two cases of robotic ureteroureterostomy for the mid ureteral tumor were performed safely with no recurrence 3 years after surgery. In a recently reported large series of 15 patients with UTUC, Campi et al. [46] reported one patient with surgical margins and three (20%) patients with ipsilateral upper tract recurrence in a median of 21 months. Robotic surgery has an advantage in that it is minimally invasive, which facilitates surgery even in fragile patients. Maximizing this potential, Raheem and colleagues [47] reported the case of an 80-year-old man with pT3 disease and severe medical co-morbidities who was successfully treated using robotic segmental ureterectomy. However, when this procedure is used for UTUC, surgeons need to consider that evidence supporting long-term oncologic outcomes is still lacking.

Regarding benign stricture, the major concern after the procedure is recurrence of the stricture. In the largest study on using the robotic approach for cases of benign stricture, Buffi et al. [45] reported a multicenter experience of 183 men with benign strictures, including 17 who underwent ureteroureterostomy, and demonstrated a 2-year recurrence-free rate of 94.1% (n=16). While no intraoperative complications were reported, it should be noted that patients who underwent ureteroureterostomy had a higher complication rate (17.6%, n=3) than those who underwent pyeloplasty (8.3%, n=12). Although comprehensive data have not yet been reported, the first case of robot-assisted transureteroureterostomy was reported for an adult woman with bilateral congenital ureteral obstruction [48].

5. Robotic ileal ureter substitution

Ileal ureter substitution has long been a valuable procedure and the last resort for patients with problems encompassing the entire ureter, despite recurrent repair attempts. Due to the complexity and rarity of ileal ureter substitution, open surgery has been the standard approach, as it demonstrates good and durable results. The robotic team should be adept at changing positions during the operation, and high surgical dexterity is required for success when using a robotic device in ileal ureteral substitution [49]. In the reported cases, patients were first placed in a flank position to remove the affected ureter, repositioned to the supine lithotomy position to harvest an approximately 20-cm segment of the ileum (usually performed intracorporeally with an Endo-GIA stapler, with a cystotomy performed at the bladder dome after mobilization of the bladder), and finally repositioned to the original flank position for proximal pyeloileal anastomosis [50]. On the left side, the harvested bowel segment is relocated behind the descending colon during the procedure by the mesenteric window to the left side. Due to these complexities and the requirement for several instances of redocking, the introduction of the daVinci Xi system, in which the surgical table can be integrated and allow change of motion without undocking the entire device, may reduce the procedure time.

Since the first report in 2008 [49], few further reports have been published (Table 5), with the initial few reporting on extraperitoneal ileal anastomosis. The first
case of total intracorporeal ureteral reconstruction was reported in 2014 [50]. As the experience in this approach increased, the operative time decreased; however, the reported complication rate remains high, with severe cases requiring additional procedures.

6. Robotic ureterolysis for retroperitoneal fibrosis

Retroperitoneal fibrosis is a rare condition that causes extrinsic compression of the ureter because of extensive fibrosis of the retroperitoneum from either benign or malignant conditions, although two-thirds of the cases are idiopathic. Mufarrij and Stifelman [51] described the first case of robotic ureterolysis, where in the flank position, the colon is mobilized and the entire length of the ureter is exposed. Segments encased by the fibrous capsule are released by splitting the capsule until the adventitia of the ureter is visible. Finally, the ureter is intraperitonealized by wrapping the omentum around it. Since its initial description, multiple reports of cases have been published that demonstrate the feasibility and safety of robotic ureterolysis [52,53].

7. Experimental technology and newer studies

Stem cells comprise the basic building blocks of tissue engineering, biomaterial scaffolding, and growth factor supplementation. Biomaterials used as scaffolds for inducing ureter regeneration include small intestinal submucosa, decellularized ureter, or synthetic grafts, such as Gore-Tex [54]. A lack of animal models that can mimic human ureters is an important limitation that has prevented the further development of tissue engineering techniques. In addition, it is difficult to develop ureteral substitutes with peristalsis. In line with this, a collagen-based tubular scaffold with radial elasticity was recently developed by Versteegden et al. [55], which, in combination with a regenerated smooth muscle layer, was found to be ideal for restoring a neo-ureter. Moreover, the use of arteries as ureteral substitutes has also been described, as they have an intrinsic extracellular matrix ultrastructure, with collagenic composition similar to that of the ureters [56]. Furthermore, venous grafts and porcine ureter grafts have also been used as scaffolds, and in some cases, may be lined with smooth muscle tissue and urothelium. In addition, Zhao et al. [57] proposed the use of extracellular matrix blood vessels with mesenchymal stem cells to bridge the ureteral graft.

8. Conclusion

While robotic applications for ureteral surgery have been reported prominently in the field of pediatric urology, especially for relieving congenital obstruction in the ureteral pelvic junction, contemporary studies across the world have consistently reported its potential for malignant, iatrogenic, and traumatic conditions, which are predominant in adults. Several pioneering reports have indicated that a robotic approach for ureteral
reconstruction is both safe and feasible. However, urologists should keep in mind that robotic assistance in ureteral surgeries has been primarily reported in studies involving highly skilled surgeons, and its oncological safety for malignant etiologies remains debatable. The lack of comparative study design and low-level evidence generated from the retrospective small series without long-term follow-up makes it difficult to identify the unique advantage of the robotic approach over conventional treatment. Thus, there is a need for qualified prospective trials for wider acceptance, as well as for resolving the uncertainty regarding the advantages of robotic approaches over the conventional ones. However, contemporary reports have demonstrated that the robotic approach can be used as an alternative option for ureteral construction, even in the absence of haptic feedback, which can be compensated using various surgical techniques and enhanced three-dimensional visualization.

Author contributions

Study concept and design: Kulthe Ramesh Seetharam Bhat; Young Hwii Ko Data acquisition: Kulthe Ramesh Seetharam Bhat Data analysis: Marcio Covas Moschovas Drafting of the manuscript: Kulthe Ramesh Seetharam Bhat; Young Hwii Ko Critical revision of the manuscript: Vipul R. Patel.

Conflicts of interest

The authors declare no conflict of interest.

References

[1] Yun JE, Lee NR, Kwak C, Rha KH, Seo SI, Hong SH, et al. Clinical outcomes and costs of robotic surgery in prostate cancer: a multinational study in Korea. Prostate Int 2019; 7:19–24.
[2] Seisen T, Granger B, Colin P, Léon P, Utard G, Renard-Penna R, et al. A systematic review and meta-analysis of clinicopathologic factors linked to intravesical recurrence after radical nephroureterectomy to treat upper tract urothelial carcinoma. Eur Urol 2015;67:1122–33.
[3] Rouprêt M, Babjuk M, Compréat E, Zigeeuner R, Sylvester RJ, Burger M, et al. European Association of Urology guidelines on upper urinary tract urothelial carcinoma: 2017 update. Eur Urol 2018;73:111–22.
[4] Babbar P, Yerram N, Sun A, Hemal S, Murthy P, Bryk D, et al. Robot-assisted ureteral reconstruction—Current status and future directions. Urol Ann 2018;10:7–14.
[5] Lee NG, Corbett ST, Cobb K, Bailey GC, Burns AS, Peters CA. Bi-institutional comparison of robot-assisted laparoscopic versus open ureteroureterostomy in the pediatric population. J Endourol 2015;29:1237–41.
[6] Slater RC, Farber NJ, Riley JM, Shilo Y, Ost MC. Contemporary series of robotic-assisted distal ureteral reconstruction utilizing side docking position. Int Braz J Urol 2015;41:1154–9.
[7] Lee Z, Moore B, Giusto L, Eun DD. Use of indocyanine green during robot-assisted ureteral reconstructions. Eur Urol 2015; 67:291–8.
[8] Kaouk JH, Garisto J, Eltemamy M, Bertolo R. Robot-assisted surgery for benign distal ureteral strictures: step-by-step technique using the SP® surgical system. BJU Int 2019;123:733–8.
[9] Hebert KJ, Joseph J, Gettman M, Tollefson M, Frank I, Viers BR. Technical considerations of single port ureteroneocystostomy utilizing da Vinci SP platform. Urology 2019; 129:236. https://doi.org/10.1016/j.urology.2019.03.020.
[10] Culp OS, Deweerd JH. A pelvic flap operation for certain types of ureteropelvic obstruction; preliminary report. Proc Staff Meet Mayo Clin 1951;26:483–8.
[11] Scardino PL, Prince CL. Vertical flap ureteropelvioplasty. South Med J 1953;46:325–31.
[12] Minnillio BJ, Cruz JAS, Sayao RH, Passerotti CC, Houck CS, Meier PM, et al. Long-term experience and outcomes of robotic assisted laparoscopic reconstruction in children and young adults. J Urol 2011;185:1455–60.
[13] Ener K, Altinova S, Canda AE, Özcan MF, Asil E, Ureş E, et al. Outcomes of robot-assisted laparoscopic transperitoneal pyeloplasty procedures: a series of 18 patients. Turkish J Urol 2014;40:193–8.
[14] Gupta NP, Nayyar R, Hemal AK, Mukherjee S, Kumar R, Dogra PN. Outcome analysis of robotic pyeloplasty: a large single-centre experience. BJU Int 2010;105:980–3.
[15] Potretzke AM, Mahapatra A, Larson JA, Benway BM. Transmesenteric robotic-assisted pyeloplasty for ureteropelvic junction obstruction in horseshoe kidney. Int Braz J Urol 2016;42:626–7.
[16] Autorino R, Eden C, El-Ghoneimi A, Guazzoni G, Buffi N, Peters CA, et al. Robot-assisted and laparoscopic repair of ureteropelvic junction obstruction: a systematic review and meta-analysis. Eur Urol 2014;65:430–52.
[17] Lee RS, Retlik AB, Borer JG, Peters CA. Pediatric robotic assisted laparoscopic dismembered pyeloplasty: comparison with a cohort of open surgery. J Urol 2006;175:683–7.
[18] Jensen PH, Berg KD, Azawi NH. Robot-assisted pyeloplasty and pyelolithotomy in patients with ureteropelvic junction stenosis. Scand J Urol 2017;51:323–8.
[19] Hemal AK, Mishra S, Mukharjee S, Suryavanshi M. Robot assisted laparoscopic pyeloplasty in patients of ureteropelvic junction obstruction with previously failed open surgical repair. Int J Urol 2008;15:744–6.
[20] Varda BK, Wang Y, Chung BJ, Lee RS, Kurtz MP, Nelson CP, et al. Has the robot caught up? National trends in utilization, perioperative outcomes, and cost for open, laparoscopic, and robotic pyeloplasty in the United States from 2003 to 2015. J Pediatr Urol 2018;14:336.e1–8. https://doi.org/10.1016/j.jspedu.2017.12.010.
[21] Baek M, Silay MS, Au JK, Huang GO, Elizondo RA, Puttmann K, et al. Quantifying the additional difficulty of pediatric robot-assisted laparoscopic re-do pyeloplasty: a comparison of primary and re-do procedures. J Laparoendosc Adv Surg Tech 2018;28:610–6.
[22] Bilgutay AN, Kirsch AJ. Robotic ureteral reconstruction in the pediatric population. Front Pediatr 2019;7:85. https://doi.org/10.3389/fped.2019.00085.
[23] Chang SJ, Hsu CK, Hsieh CH, Yang SSD. Comparing the efficacy and safety between robotic-assisted versus open pyeloplasty in children: a systematic review and meta-analysis. World J Urol 2015;33:1855–65.
[24] Light A, Karthikeyan S, Maruthan S, Elhage O, Danuser H, Dasgupta P. Peri-operative outcomes and complications after laparoscopic vs. robot-assisted dismembered pyeloplasty: a systematic review and meta-analysis. BJU Int 2018;122:181–94.
[25] Whitehouse GH. Some urographic aspects of the horseshoe kidney anomaly—a review of 59 cases. Clin Radiol 1975;26: 107–14.
[26] Lallas CD, Pak RW, Pagnani C, Hubosky SG, Yanke By, Keeley FX, et al. The minimally invasive management of ureteropelvic junction obstruction in horseshoe kidneys. World J Urol 2011;29:91–5.
Defining the pros and cons of open, conventional laparoscopy, and robot-assisted pyeloplasty in a developing nation. Adv Urol 2014;2014:850156. https://doi.org/10.1155/2014/850156.

One- vs. 4-week stent placement after laparoscopic and robot-assisted pyeloplasty: results of a prospective randomised single-centre study. BJU Int 2014;113:931–5.

Robotic-assisted laparoscopic distal ureterectomy and ureteral reimplantation with psoas hitch. J Endourol 2007;21:368–72.

Expanding the horizons: robot-assisted reconstructive surgery of the distal ureter. J Endourol 2009;23:457–61.

Robotic management of benign mid and distal ureteral strictures and comparison with laparoscopic approaches at a single institution. Urology 2012;80:596–601.

Robotic distal ureterectomy with psoas hitch and ureteroneocystostomy: surgical technique and outcomes. Asian J Urol 2015;2:123–7.

Robot-assisted laparoscopic Boari flap ureteral reimplantation. J Endourol 2008;22:2691–4.

Robotic distal ureterectomy with boari flap reconstruction for distal ureteral urethelial cancers: a single institutional pilot experience. J Laparoendosc Adv Surg Tech 2010;20:165–71.

Robotic-assisted ureteral reimplantation with boari flap and psoas hitch: a single-institution experience. J Laparoendosc Adv Surg Tech 2011;21:829–33.

Experience with robot-assisted laparoscopic surgery of the lower ureteral segment in adults. J Robot Surg 2012;6:223–30.

Robotic-assisted laparoscopic distal ureterectomy and ureteral reimplantation with psoas hitch. J Endourol 2007;21:368–72.

Expanding the horizons: robot-assisted reconstructive surgery of the distal ureter. J Endourol 2009;23:457–61.

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Experience with robot-assisted laparoscopic surgery of the lower ureteral segment in adults. J Robot Surg 2012;6:223–30.

Robotic-assisted laparoscopic distal ureterectomy and ureteral reimplantation with psoas hitch. J Endourol 2007;21:368–72.

Expanding the horizons: robot-assisted reconstructive surgery of the distal ureter. J Endourol 2009;23:457–61.

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Robotic distal ureterectomy with psoas hitch and ureteroneocystostomy: surgical technique and outcomes. Asian J Urol 2015;2:123–7.

Robot-assisted laparoscopic Boari flap ureteral reimplantation. J Endourol 2008;22:2691–4.

Robotic distal ureterectomy with boari flap reconstruction for distal ureteral urothelial cancers: a single institutional pilot experience. J Laparoendosc Adv Surg Tech 2010;20:165–71.