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KIDNEY DISEASES (G CIANCIO, SECTION EDITOR)

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Robotic Repair of Ureteral Strictures: Techniques and Review

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Abstract

Purpose of Review To provide an overview and description of the different surgical techniques for the robotic repair of ureteral strictures.

Recent Findings The robotic repair of ureteral stenosis has emerged as a useful option for treating strictures unsuitable for endoscopic resolution with good results, lower morbidity, and faster recovery than open techniques. Depending on the stricture's length and location, the reconstructive options are reimplantation, psoas hitch, Boari flap, ureteroureterostomy, appendiceal onlay flap, buccal mucosa graft (BMG) ureteroplasty, ileal replacement, or renal autotransplantation. The robotic approach offers a magnified vision and the possibility of adding near-infrared fluorescence (NIRF) imaging, indocyanine green (ICG), and Firefly™ to facilitate the technique. Multicenter studies with extended follow-up still have to confirm the good results obtained in published case series.

Summary Robotic reconstructive techniques are useful for repairing ureteral strictures, obtaining good functional results with less morbidity and faster recovery than open procedures.

Keywords Robotic ureteral repair · Ureteral stricture · Ureteroplasty · Robotic buccal mucosa graft (BMG) ureteroplasty · Robotic ureteral reimplantation

Introduction

The etiology of ureteric strictures can be iatrogenic, traumatic, congenital, and immunological, and due to lithiasis; previous endourological procedures are the most frequent iatrogenic cause [1]. Strictures < 2 cm are amenable for endoscopic treatment; however, often, endoscopic treatment fails for strictures longer than > 2 cm.

Depending on the extension and location of the stricture in the distal, middle, or proximal part of the ureter, surgical techniques for strictures > 2 cm include ureteroureterostomy (UU), ureteral reimplantation, psoas hitch, Boari flap, appendiceal flap, buccal mucosa graft (BMG) ureteroplasty, ileal replacement, and renal autotransplantation [2].

The technique and surgical route remain a surgeon's choice; the open repair carries high morbidity; a laparoscopic approach requires high skill. Robotic repair of ureteral stricture has emerged as an option with excellent results and multiple advantages of ergonomics, magnified visibility, and the ability to adjunct near-infrared fluorescence (NIRF) imaging, indocyanine green (ICG), and Firefly™ [2, 3••]. For patients, this translates into less morbidity, faster recovery, and good functional outcomes. This article reviews the different types and latest advances in robotic ureteral repair for ureteral strictures' surgical treatment.

Surgical Technique Considerations

The preoperative workup should include a renal function study and a CT scan to determine stricture's location and

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length. It is also possible to perform a pyelography or nephrostography or a flexible ureteroscopy with transillumination in the operating room. The placement of trocars for distal ureteric strictures is similar to other pelvic procedures (e.g., radical cystectomy or RALP). For mid and proximal ureter strictures, a 60-degree lateral flank position, without breaking the table to avoid overstretching, is preferred. The trocars are positioned in the midclavicular line, lateral to the rectus abdominis muscle [4•].

Minimally invasive reconstruction of the ureter must follow the same reconstructive principles of the open approach: (1) Gentle manipulation of the ureter to avoid ureteric damage, (2) maximal protection of ureteric vascularization, (3) all anastomoses must be tension-free, and (4) reinforcement of the reconstruction with a flap of omentum or perinephric fat to provide an additional vascular source and contain a possible leakage.

The combination of NIRF and indocyanine green (ICG) is a welcomed advance that recently has dramatically facilitated this surgery [5]. After intravenous administration of ICG, green fluorescence is observed in well-vascularized tissues, while there is no fluorescence in the scarred tissue. ICG can be injected into the ureter through a nephrostomy or retrogradely through a previously placed ureteric catheter, or combining both approaches simultaneously. This allows for precise localization and understanding of the stricture's anatomy that helps decide the optimal reconstructive strategy intraoperatively [6, 7].

Robotic Ureteroureterostomy

Ureteroureterostomy (end-to-end anastomosis) is an excellent technique for repairing strictures located in the proximal and mid-ureter [8•, 9, 10]. In 1992, Nezhat performed the first laparoscopic ureteroureterostomy (LU) obtaining similar functional results and better cosmesis than open surgery [11]. However, LU requires significant laparoscopic dexterity.

In 2006, Yee did the first robotic-assisted ureteroureterostomy (RAUU) [12]; for some authors, this is the best surgical treatment for short ureteral stenosis (3 cm or less) that is refractory to endoscopic approach.

With the patient in the lateral flank position, dissection preferably starts from a healthy segment of the ureter and then progress towards the stricture; ICG and NIRF may be useful for identification and dissection of the stricture (Fig. 1). The adventitia which contains the vascular supply must be preserved; both ends of the ureter are spatulated, and an end-to-end anastomosis is performed using a running monofilament 4/0 suture (Fig. 1); a ureteral stent is inserted and then removed in the outpatient clinic 6 weeks after surgery; it is prudent to retroperitonealize the repair to decrease the risk of fistulization.

Lee et al. [13] and Villanueva et al. [14] comparing open vs RAUU in pediatric patients observed similar outcomes, surgical time, and complications. In adults, Sun et al. compared 65 robotic versus 61 laparoscopic surgeries finding shorter operative time (OR), suturing, and hospitalization time, in the robotic arm, without a difference in functional outcomes [15]. Recently, Wang et al. compared a series of recurrent ureteral stricture repairs (19 open vs 22 robotically assisted) finding the same results but shorter OR time and less estimated blood loss in the robotic arm [16].

Robotic Ureteral Reimplantation (With or Without Psoas Hitch)

Robotic ureteral reimplantation (ureteroneocystostomy) is indicated in distal ureteral stenosis within 5 cm from the ureteral orifice. In 1994, Reddy et al. performed the first laparoscopic ureteroneocystostomy. Since then, different techniques have been described [17].

Trocar placement is similar to when performing robot-assisted radical prostatectomy (RALP). The ureter is cut proximal to the stricture and spatulated in its posterior margin. A cystostomy allows reimplanting the ureter directly with full-thickness mucosa to mucosa stitches. The rear plate is sutured with a 4/0 running stitch, a double J is inserted, and the anastomosis is then completed anteriorly; a bladder catheter is left in place for 5–7 days.

A psoas hitch reimplantation allows reconstructing 6–10-cm gaps. In this scenario, the Retzius space is developed, and the contralateral bladder anterior pedicle is sectioned to mobilize the bladder. The bladder's lateral wall is stitched to the psoas muscle with 3–4 non-absorbable 2/0 stitches; the suture should be passed longitudinally along the psoas tendon to avoid damage to the genitofemoral nerve. Alternatively, the bladder can be anchored to the side wall peritoneum to a similar effect. This provides a tension-free anastomosis. The spatulated ureter is introduced through a submucosal tunnel. This tunnel should be proportionally longer in more dilated ureters. Finally, a double J is inserted and the bladder closed.

Patil et al. and Lee et al. published a series of patients without reporting intraoperative or postoperative complications [18, 19]. Wason et al. also published a series of robotic ureteral reimplantations with full resolution of the stenosis and no significant complications [20]. Only a few publications investigate the results of open vs robotic ureteral reimplantation. Kozinn et al. compared 24 open reimplantations with 10 robotic procedures, showing a shorter hospital stay and less estimated blood loss in the robotic group. Both groups were free of stricture recurrence at 2 years of follow-up [21].

Elsamra et al. studied 20 open, 20 laparoscopic, and 85 robotic ureteral reimplantations [22]. They found no differences in stricture-free rate and operative times in the

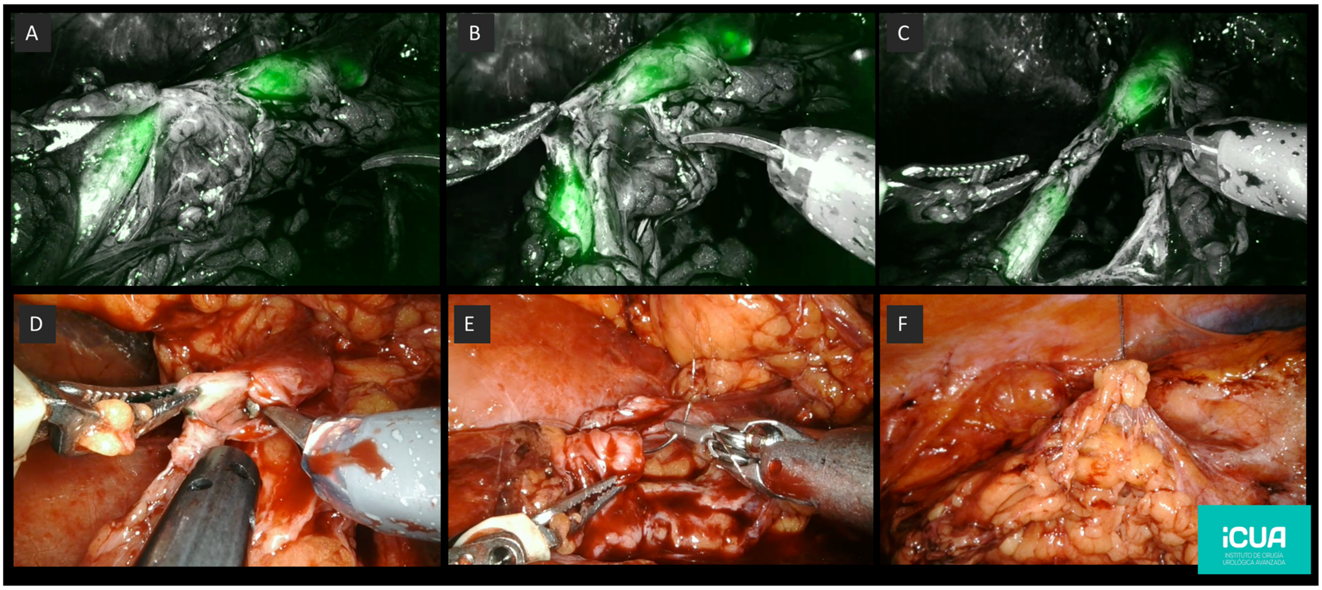

Fig. 1 Robotic ureteroureterostomy in a patient with ureteral stricture and injury after failed ureteroscopy. **A**–**C** Identification of the stricture with the help of intravenous indocyanine green (ICG) and Firefly^{TM}. **D** Incision of the stricture, lithiasis observed over the level of the stricture. **E** Ureter spatulated and reanastomosed. **F** Covering with perirenal fat

three groups. Still, they observed a decreased hospital stay and a reduced blood loss in the minimally invasive groups ($P < 0.02$).

Schiavina et al. performed a multi-institutional study comparing 16 laparoscopic and 12 robotic ureteral reimplantations (including cases with psoas hitch) with a median follow-up of 23 months. They found no difference in the stricture-free rate of complications and a slightly shorter time of hospitalization for the laparoscopic group ($P < 0.006$) and a reduced blood loss in the robotic group ($P < 0.004$) [23]. Further prospective studies that also include cost-effectiveness considerations in their design are necessary to define which approaches effectively treat this condition.

The Boari flap is an alternative technique designed to correct mid-ureteral defects when the diseased segment is too long to perform a ureteroneocystostomy or when the distal tissue has no mobility or viability. Boari described the open technique in 1894. Later in 2001, Fugita et al. published their initial experience with the laparoscopic approach [24].

The robotic technique uses the standard trocar configuration for urologic pelvic surgery; the bladder is mobilized bilaterally, then the umbilical ligaments and the contralateral vesical pedicle are ligated and divided. The superior vesical artery is identified and used as a reference for the base of the flap. The bladder flap continues obliquely through the anterior bladder wall until it reaches the length of the defect. The rear plate is anastomosed to the spatulated ureter with absorbable suture material. After this, a double J stent is placed, and the anterior aspect is tubularized and closed with a running suture. Finally, the bladder is fixed to the psoas with non-absorbable stitches [25].

The low frequency of this clinical problem and the complexity of the procedure make the experience limited. Castillo et al. reported in 2006 13 cases series with success, with just one patient requiring laparoscopic reintervention due to leakage. In 2016, Stolzenburg et al. published a robotic series with similar success and a 9% complication rate [26].

Robotic Appendiceal Onlay Flap

The use of appendix as a tissue substitute for lesions of the proximal and middle ureters (2–6cm) is an attractive option to using other intestinal segments such as ileum.

The first case was described in 1912 by Melnikoff, who used the appendix in a tubularized fashion. Other authors later adopted it with good results but experienced some complications (fistula and restenosis). It is mainly indicated in right ureteral strictures; however, it can also be used to reconstruct the left ureter [27].

In 2009, Reggio et al. published the first case of laparoscopic appendiceal onlay ureteroplasty to reconstruct ureteral strictures [28]. The technique consists of transecting the appendix at its base, keeping its vascularization and then detubularize it with an antimesenteric longitudinal incision. The stricture is recognized, incised, and its length measured with the help of a ureteric catheter. After that, the appendix is sutured in an isoperistaltic direction on a ventral position.

The technique results are promising, but the evidence is still limited by the few cases described yet. Duty et al. published their experience in 6 patients with laparoscopic onlay repair; 4/6 (66%) were successful [27]. Wang et al. have recently published the first robotic experience, performing an augmented anastomotic repair, with a 100% rate of success at 6 months [29]. As the technique develops, it could prove to be an attractive option soon.

Buccal Mucosa Graft Ureteroplasty

BMG ureteroplasty is a very attractive technique with apparent excellent outcomes for ureteral strictures that are too long (> 3cm) and not amenable to be treated by ureteroureterostomy. The BMG graft has been widely used for urethroplasty, but its use for ureteric reconstructions has been minimal.

BMG has many advantages for its use in the urinary tract. It is easy to obtain with low morbidity and has similar properties to the urinary tract mucosa being hairless, resistant to infection, and compatible with a wet environment. It also has a robust lamina propria that facilitates the imbibition and inosculation processes [30••].

Naude and Somerville reported their initial experience in baboons in 1983 [31]. Naude in 1999 [32] described the first human series, performing three different techniques, with no stricture recurrence at 24 months follow-up. Other short case series showed recurrence-free rates of 71–100% with BMG onlay or tubularized ureteroplasty. Kroepfl et al. using BMG onlay with an open approach for long ureter strictures reported 70% success (5/7 strictures, 1 patient bilateral stricture) with a median follow-up of 18 months. Interestingly, 5/7 strictures were located in the distal ureter, demonstrating the feasibility of the technique at this level [33].

Zhao et al. described the robotic BMG ureteroplasty in 2015 for proximal ureteral strictures (median length 4 cm) with no restenosis at 15.5 months of follow-up [4•]. Table 1 shows studies on robotic ureteroplasty (RU) with BMG.

Robotic BMG ureteroplasty is carried out with the patient in the lateral decubitus position; the ureter is identified and carefully dissected. Identification of the stricture location can be achieved using flexible ureteroscopy and intravenous ICG and NIRF imaging or with the combination of anterograde and retrograde intraureteral ICG. The ureteral stenosis is sectioned longitudinally. Depending on the length and degree of scarring, a BMG onlay or a BMG-augmented anastomotic ureteroplasty with omental or perirenal fat support is performed.

In 2017, Lee et al. described a series of 12 patients who underwent robotic BMG ureteral reconstruction. The stricture's median length was 3 cm, and they reported a success rate of 83.3% (10/12 patients) [34]. In 2018, Zhao et al. conducted the first multi-institutional study to evaluate the technique's reproducibility, 19 patients from 3 different centers; the median stricture length was 4 cm and the overall success rate was 90% [35]. Also recently, Lee and Zhao et al. evaluated three robotic techniques for long-segment (≥ 4 cm) strictures in the proximal ureter: robotic ureteroureterostomy + downward nephropexy (DN), robotic ureterocalycostomy + DN, and robotic ureteroplasty (RU) with BMG. They observed that 13/14 (92.9%) patients undergoing RU-BMG were successful at a median follow-up of 24 months (IQR, 14–39).

In general, BMG ureteroplasty is an attractive option as a first or second line, for long proximal and middle ureteral strictures and potentially for distal ureter strictures too. Multi-institutional studies with longer follow-up are necessary to demonstrate all its advantages and limitations.

Ileal Replacement

Ureteral substitution with ileum is indicated in long ureteral strictures not amenable for endoscopic treatment or RAUU, serves as a salvage treatment after previously failed approaches and can be used for recurrent stone-formers. However, it is contraindicated in patients with inflammatory bowel disease, radiation enteritis, neurogenic bladder, bladder outlet obstruction, and liver or renal dysfunction [36].

The first laparoscopic procedure was performed in 2000 by Gill et al., with extracorporeal ileal anastomosis [37]. In 2008, Wagner et al. performed the first robot-assisted ileal ureter reconstruction [38]. In 2014, Brandao et al. described the first intracorporeal ureteral ileal substitution [39]. In all cases, the surgical time was long (> 6 hours), but patients had no severe complications and were free of recurrence.

The technique consists in performing a ureterectomy of the strictured segment, followed by the isolation of a sufficiently lengthy well-vascularized ileum, the use of staplers to reconstitute bowel continuity, the retroperitonealization of the ileal ureter, and the performance of watertight and isoperistaltic pyeloileal and ileovesical anastomosis, over a urinary stent.

There are only a few case series of ileal ureter replacement in the literature. In 2014, Shim et al. reported 5 patients treated with an intracorporeal ileal ureter (4 laparoscopic and 1 robotic) with a mean surgical time of 250 min, without significant perioperative complications and no stricture recurrence at 22 months of follow-up [40]. In 2016, Chopra et al. reported a four-patient series with a mean surgical time of 450 min [37]; Stein et al. (2009) showed that laparoscopic ileal ureter was superior to open surgery in terms of shorter time to recovery and hospital stay [41]. However, more prospective multi-institutional studies are necessary.

The robot-assisted strategy offers better field magnification and precision but requires time-consuming redocking and repositioning. Nevertheless, Ubrig et al. have published a robot-assisted technique that allows completing the procedure without the need to reposition the patient [42].

Table 1 Robotic ureteroplasty (RU) with buccal mucosal graft (BMG) studies. *LOS* length of hospital stay, *NR* not reported

Author	Technique	Year	N	Level of stricture	Stricture length cm	OR time	Length of stay (LOS) days	Complications Clavien ≥ 2	Failure/ restenosis	Follow-up months	Conclusion
Zhao	Robotic onlay or posterior BMG. Ureteroscope and ICG assisted	2015	4	Proximal (2/4) proximal and distal (1/4) UPJ (1/4)	1.5–6 cm	298 min	2–3	0	0	15.5 months	Robotic BMG may be a viable versatile option for complex ureteral reconstruction.
Arora	Robotic BMG ureteroplasty	2017	1	Distal ureter	Extensive NR	280 min	NR	No	No	6 months	Safe option for reconstruction of long ureteral strictures
Lee	Robotic BMG, ventral onlay	2017	12	Proximal 4/12 (33.3%), mid-ureter 4/12 (33.3%), UPJ 4/12 (33.3%)	3 (2–5) cm	217 (136–344)	1 (1–6)	2/12 (16%)	2	13 (4–30)	Effective for complex proximal and mid-ureteral strictures
Zhao	Robot-assisted BMG (RBU) ureteroplasty. Multi-institutional	2017	19	Proximal 74%, mid 26%	4 cm (2–8)	200min (136 - 397)	2 (1–15)	0	2 (11%)	26 months	RBU is a feasible and effective technique for managing complex proximal and mid-ureteral strictures.
Lee and Zhao	RU with BMG, ureteroureterostomy (RUU) with downward nephropexy (DN), ureterocalycostomy (RUC) + DN	2020	20	Proximal 85%, middle 15%	5 cm (4–5)	273 min (175–327)	2 (2–3)	0	BMG group 1/14 (7%)	24months (14–51)	RUC with DN and RU-BMG are effective for the treatment of long strictures.
Lee and Zhao	RU with BMG multi-institutional study	2020	54	Proximal 72%, middle 14%, proximal and middle 13%	3 cm	222 min	1 (1–3)	3/54 (5.6%)	13%	27 months	Low perioperative morbidity and excellent intermediate-term outcomes.

Robotic Renal Autotransplantation

Robot-assisted renal autotransplantation (RATx) is a feasible option for treating long upper ureteric or pan-ureteric strictures, retroperitoneal fibrosis, loin pain-hematuria syndrome, and renal vascular problems (aneurysm, thrombosis, stenosis, and vascular trauma). The first autologous transplantation was performed in 1963 by open approach (midline xiphopubic incision) [43]; this approach offers good functional outcomes but is associated with high morbidity.

Laparoscopic nephrectomy followed by open autotransplantation has been described as an option with success rates of 68–90% [44, 45]. Gill et al. reported that in 4/5 patients who underwent autotransplant after retroperitoneal laparoscopic nephrectomy [46], the mean surgical time was 5.8 h and WIT 4 min, without significant complications. Hand-assisted laparoscopic nephrectomy has been described in renal artery aneurysm cases [47, 48].

Robotic renal autotransplantation (R-RATx) has emerged as a valid option with good results. The first complete intracorporeal R-RATx was reported by Gordon et al. [49]; the total surgical time was 425 min; warm ischemia time and cold ischemia time were 2.3 and 95.5 min, respectively. After robotic donor nephrectomy with hypothermic renal perfusion, the kidney is placed in the iliac fossa, and the robot undocked. The patient is repositioned in deep Trendelenburg, and the robot docked between the legs; then, the iliac vessels are prepared, and the vascular and ureteral anastomosis is performed.

Lee et al. [50] introduced some modifications on R-RATx to reduce renal ischemia time using a Vicryl endoloop device instead of a silk tie to secure the cannula and a cooled HTK with saline solution for perfusion, with a surgical time of 390 min, and WIT and cold ischemia time of 4 and 48 min respectively.

Sood et al. performed the first robotic hand-assisted R-RATx, and Araki et al., the first one outside the USA [51]. Decaestecker et al. reported the first case series of 7 patients combining hand-assisted and total intracorporeal approach; the surgical, WIT, and cold ischemia times were 370 min, 2 min, and 178 min, respectively [52].

In perspective, R-RATx is feasible for the treatment of complex ureteral stenosis. However, it should be considered an option after failure treatments in very experienced robotic surgeon hands with previous transplantation training.

Limitations in the Literature

The main limitation of currently available literature on robot-assisted ureteral repair techniques is that most published studies are small single-institution series with no clear assessment of success. However, robotic ureteral repair seems to be a viable and effective option with apparently good results and less morbidity than open techniques.

Other Patient Considerations

Ureteral strictures represent a surgical challenge when they are very long or refractory to endoscopic treatments, requiring surgical repair. Robotic surgery offers the surgeon magnified vision, greater precision, minimal invasion, less morbidity, faster recovery, excellent functional outcomes, and better cosmetic results.

Conclusion

Robotic ureteral stricture repair techniques have emerged as feasible options offering good functional outcomes with less morbidity than the open approach. Long-term, high-volume studies are needed. There is still a lack of scientific evidence due to the relatively low incidence of this challenging condition.

Declarations

Conflict of Interest Javier Reinoso Elbers, Moises Rodríguez Socarrás, Juan Gómez Rivas, Ana Maria Autran, Francesco Esperto, Leonardo Tortolero, Diego Carrion, and Fernando Gómez Sancha each declare no potential conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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