Chapter 25
Robotics and the Avant-Garde Role of Urologic Surgery

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25.1 Introduction

Robot-assisted surgery is a consequence of the technological evolution of minimally invasive surgery and consists of the coupling of a robotic interface between the laparoscopic instruments and the main surgeon. This technology brought together characteristics such as precision, range of motion, strength, resistance and a privileged three-dimensional view of the operative field. Until now, robotic technology only interprets the surgeon's movements applied in a unit called "console" and projects them onto dedicated instruments with articulations capable of faithfully reproducing them (Fig. 25.1).

These characteristics allowed us to revisit the conventional surgical technique, as the capacity for more delicate and precise dissections forced urologists to improve their previous anatomical and functional knowledge. With this, it was possible to change the paradigm where the objective is not only to cure the disease but also to reduce surgical damage to the urinary tract, preserving its function.

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Fig. 25.1 DaVinci™ robotic operating system. (**a**) Surgeon console where the movements are performed and sent to the unit attached to the patient. (**b**) Robotic unit that performs the surgeon's movements, consisting of articulated robotic arms with instruments introduced into trocars located in the abdominal wall under supervision of an assistant. (Photo: with permission from Ricardo Miyaoka, 2021)

From the point of view of optimizing surgical techniques, robotic surgery is at the forefront and is the main representative of an inevitable path in the development of urology. It is noteworthy that it is not only a natural consequence of the evolution of diagnostic methods but also responsible for boosting the development of other areas in patient care, adding various technologies in care.

As robotic devices can become costly in many scenarios around the world and because they are at the frontier of knowledge along with other technologies, their acceptance and proof of effectiveness by the scientific community takes time. The evidence slowly becomes more robust and can prove the cost-effectiveness of robotic surgery.

In this chapter we will describe the main innovations in robotic surgery in urology and consequently in nephrology, as well as the prospects for the future. Thus, the focus will be on the description of techniques that impact the maintenance of renal function, whether preserving the renal parenchyma, restoring the functionality of the urinary tract or even in renal replacement therapies.

25.2 Nephron Sparing Robotic Surgery

The development and greater access to imaging methods has increased the incidence of small kidney lesions called incidentalomas, which are generally smaller than 4 cm in diameter and can be endophytic, exophytic, solid, or cystic.

The main concern of the urological community is to preserve renal parenchyma without compromising oncological safety. Solid and cystic lesions, until proven otherwise, should be evaluated for the possibility of resection with preservation of the affected kidney called partial nephrectomy [1].

The innovations of partial nephrectomy are moving toward achieving the following goals: preserving the renal parenchyma and reducing the time of warm ischemia in the intraoperative period, all these predictors of postoperative renal function.

25.2.1 Preservation of Renal Parenchyma

Partial nephrectomy is the gold standard technique for the treatment of localized renal cell carcinoma smaller than 7 cm (T1) and involves resection of the tumor with a safety margin, where it may be necessary to remove extensive areas of remaining renal parenchyma [2]. However, as many lesions have a pseudocapsule, enucleoresection of the renal lesion is currently being sought without compromising nephrons with oncological safety. Surgery that respects this precept and uses methods to do so is known as nephron-sparing surgery.

Even in a setting with larger tumors (>4 cm), close to the renal hilum and endophytic, robot assisted partial nephrectomy (RAPN) had similar positive surgical margin (PSM) and estimated glomerular filtration (eGFR) rates when compared to open and laparoscopic surgery [3]. Although robotic surgery is more costly, recent studies have shown no differences in other outcomes such as PSM, estimated blood loss (EBL), warm ischemia time (WIT), postoperative complications, and length of stay [4–6] when compared to other techniques. In another analysis, Choi et al. analyzed 2240 patients in a meta-analysis where no difference was found between EBL, operative time, PSM, but RAPN had lower WIT, conversion to open surgery and change in postoperative eGFR [7]. These results are attributed to the facilitation that the robot allows during dissection and reconstruction movements as well as the magnification of the 3D image and the tremor filter which optimizes time at a crucial moment in the surgery [8].

Several resources were being used to achieve the goal of preserving the greatest amount of healthy kidney tissue and robotic surgery is a consequence of this technological development that involves both pre- and intraoperatively.

Preoperatively, the correct staging allows for a more adequate operative planning allowing for a more precise and detailed approach. At this point, robotic surgery stands out as it allows the surgeon to more faithfully reproduce the previously planned tactic within a minimally invasive context.

The characteristics of solid lesions and their relationship with the rest of the kidney can be previously evaluated with scores that classify their complexity. Several methods of nephrometry have been described (R.E.N.A.L., PADUA score, c-index score, ABC scoring system) and are widely used in urological surgery studies as well as in clinical practice. These classifications aim to predict the chance of unfavorable outcomes in an attempt to preserve the organ such as PSM, perioperative complications, and prolonged WIT, as well as the volume of renal preservation [9, 10].

Still in the context of operative planning there are image reconstruction techniques to facilitate tumor lesion classification and surgical planning. Among the technologies used we have 3D printing models with representation of the main and segmental renal vessels [11] (Fig. 25.2), as well as the use of holograms with 3D vision, both capable of providing greater understanding and application of nephrometry described above [11, 12].

These reconstruction technologies can also be used during surgeries. Currently, robotic surgeons use ultrasound probes coupled with the robot's vision to facilitate

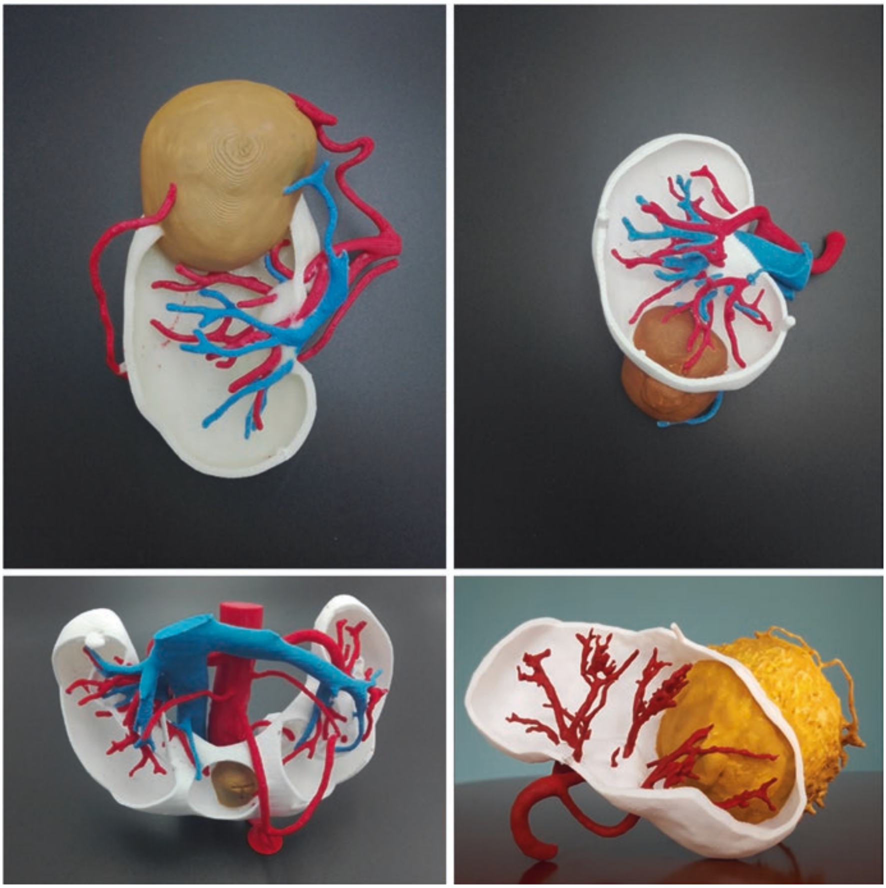

Fig. 25.2 Examples of reconstructions in 3D printed models of kidneys with renal tumors and their vascularization. (Photo: with permission from Francesco Porpiglia, 2021)

the location of lesions (Fig. 25.3). A trend for the future is to couple the image of the 3D reconstruction with the intraoperative image of the robot, and through the augmented reality with stereotaxic synchronization of the kidney, it allows real-time visualization of the renal vascularization and the tumor even for more complex cases [13] (Fig. 25.4).

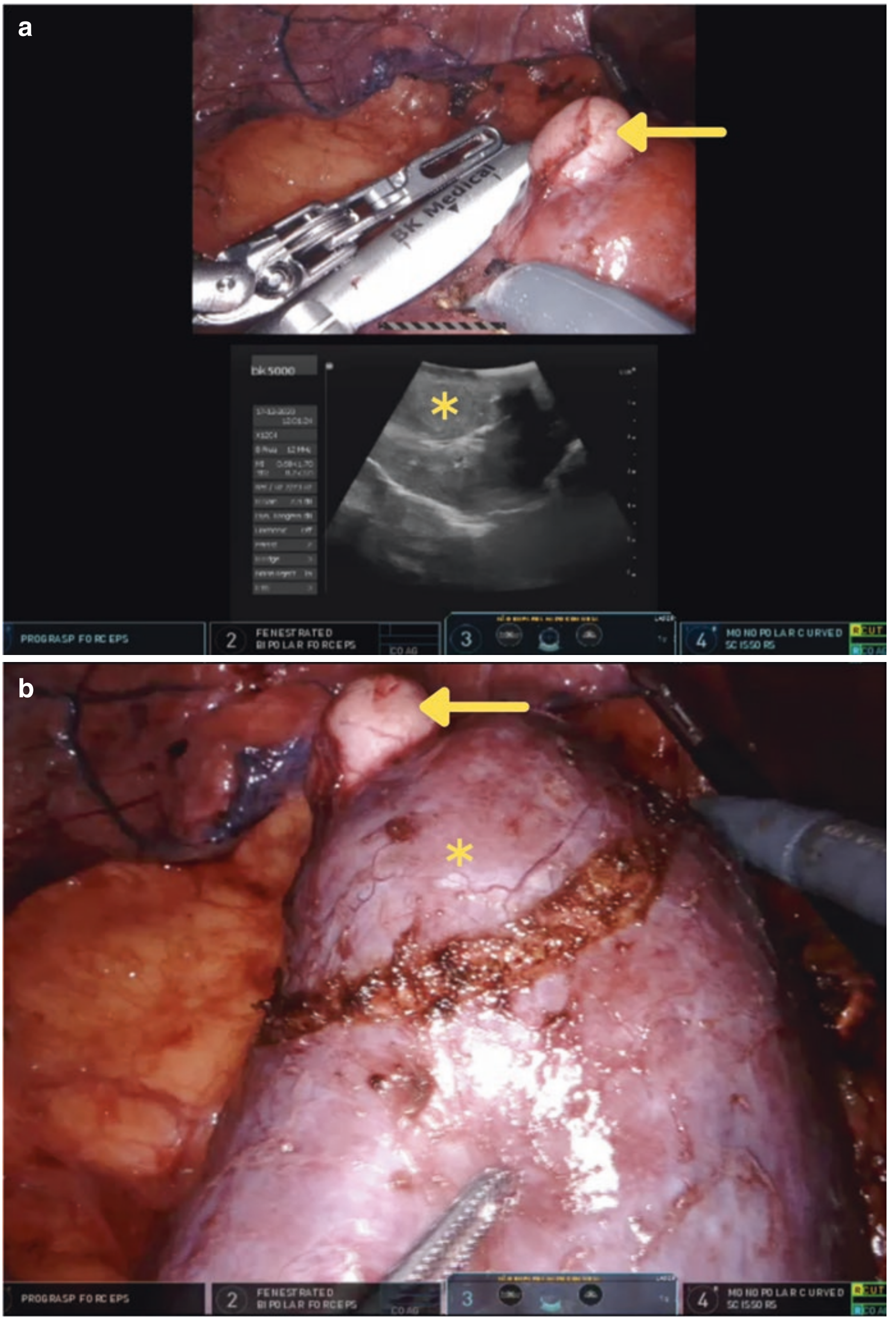

Fig. 25.3 Intraoperative image of robotic partial nephrectomy. (**a**) Real-time intraoperative ultrasound of right kidney upper pole lesion. (**b**) Demarcation of the resection area after identifying the extent of the lesion. Solid arrows: exophytic portion of renal tumor; asterisk: endophytic portion of the renal tumor. (Photo: with permission from Tomás B. C. Moretti, 2020)

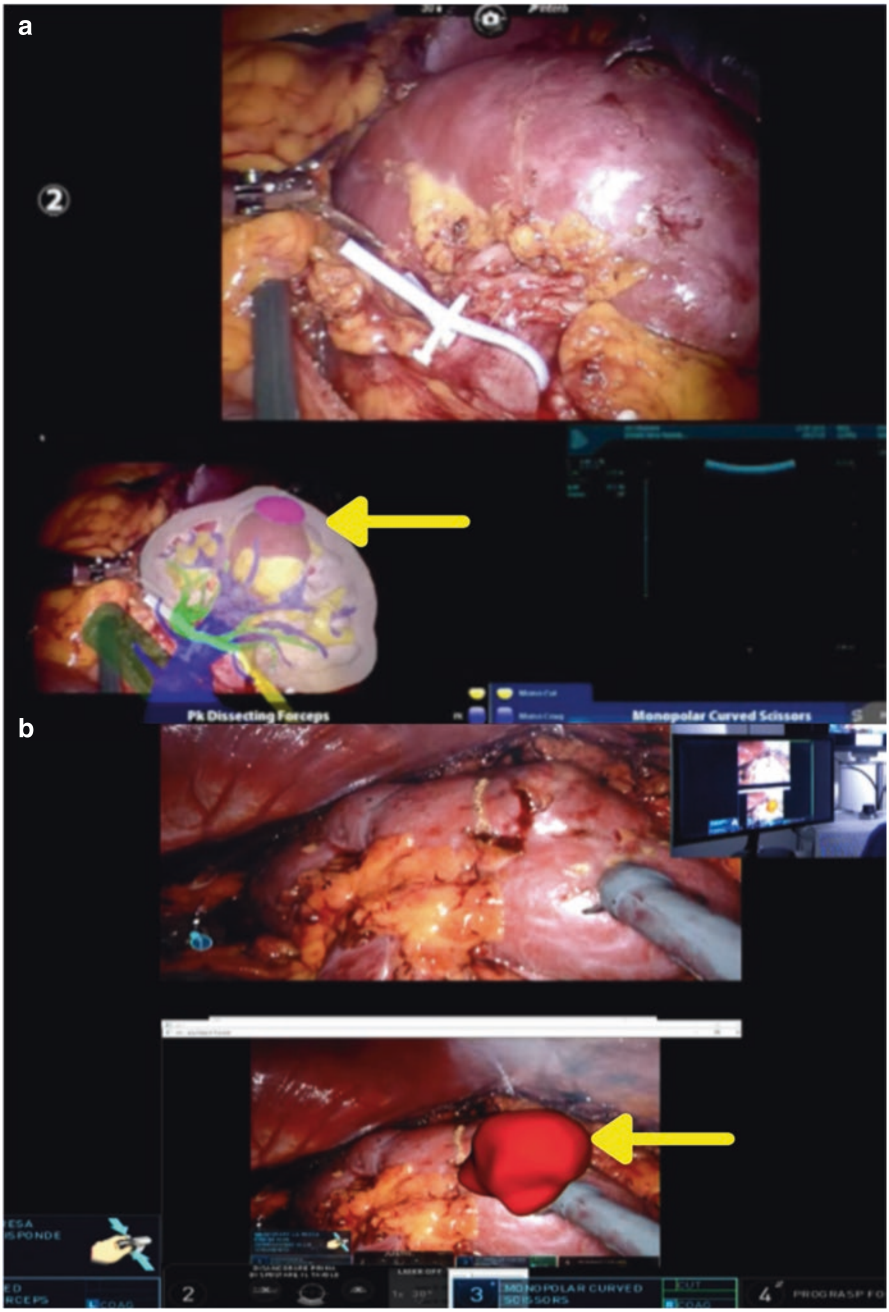

Fig. 25.4 Intraoperative image of robotic partial nephrectomy with augmented 3D reconstruction performed. (**a**) Intraoperative image fusion, 3D reconstruction, and intraoperative ultrasonography with renal vascularization. (**b**) Evidence of endophytic renal lesion on the renal surface with stereotaxic synchronization in augmented reality. In detail, image of a surgeon with 3D glasses for viewing a hologram for preoperative planning. Solid arrows: endophytic renal lesion. (Photo: with permission from Francesco Porpiglia, 2021)

25.2.2 Reduction of Warm Ischemia Time

Such pre- and intraoperative planning technologies, in addition to allowing a more precise resection of the lesion and preserving nephrons, enable the understanding of tumor vascularization, which, associated with the precision and delicacy of the robot's movements, allow for better dissection of the renal hilum and super-selective clamping of the affected renal area.

Segmental vascularization can be confirmed using perfusion markers such as indocyanine green. This substance is injected intravenously after clamping the artery and the camera with a fluorescence filter indicates the real area of ischemia confirming the tumor area to be resected and maintaining kidney perfusion (Fig. 25.5). Super selective clamping of secondary or tertiary branches of the renal artery is useful in patients with chronic kidney disease who have an earlier return of glomerular function postoperatively when compared to total clamping [14].

The preoperative study can allow the dissection of lesions without clamping the renal artery or vein since the ease of dissection with robotic technology allows better visualization of the dissection bed, reducing bleeding and maintaining renal perfusion, called off-clamp partial nephrectomy. For more complex tumors, total interruption of circulation has a better benefit, however, patients with smaller and superficial lesions can benefit from off-clamp surgery by reducing the WIT and with early recovery of renal function [15]. In a meta-analysis of late evaluation after 5 years, no difference was found in eGFR between the total clamping and off-clamp techniques [16].

Another approach is a mix between the total clamping technique and the off-clamp called partial clamp. Two suture planes are usually performed, one for the medullary layer and collecting system and the other for the cortical (Fig. 25.6). As usually the largest vessels are in the medullary layer, after suturing it, the renal artery can be unclamped and the cortical layer can be sutured without excessive bleeding, preserving the vitality of the kidney and less WIT. Pneumoperitoneum can cause kidney damage and the stability of the robot's arms, associated with devices that were developed with laminar gas injection flow as well as continuous aspiration of smoke from the electrocautery, allows the use of intra-abdominal pressures of less than 12 mmHg, which reduces exposure to CO_2 as well as less renal damage [17, 18].

For the future, robotic surgery finds itself in an era where new devices are in development making the technology more accessible. In addition, the emergence of new data transmission technologies, such as 5G, may allow remote surgeries to be performed, unifying practices and techniques around the world, as well as the fusion of technologies.

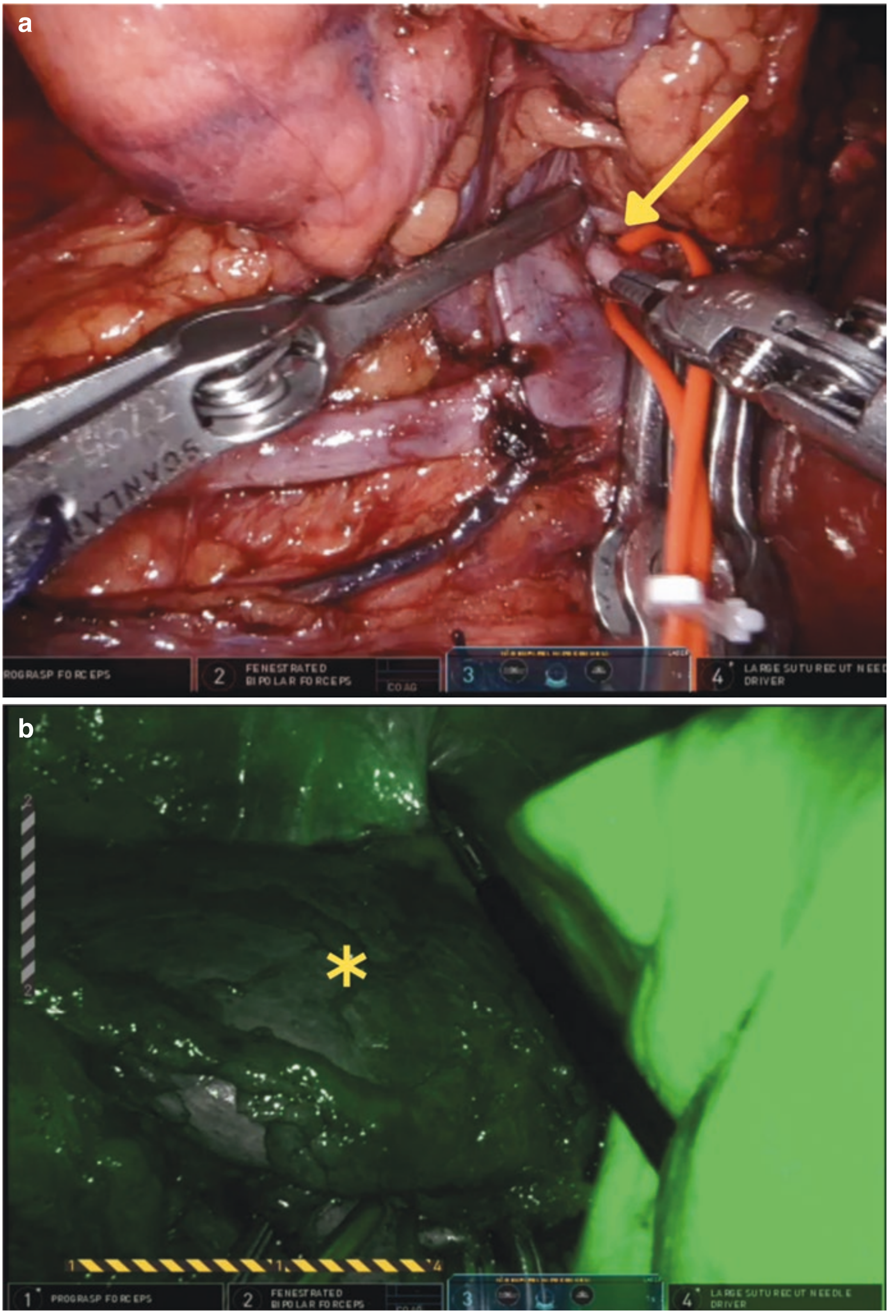

Fig. 25.5 Intraoperative robotic partial nephrectomy with study of renal perfusion with intravenous indocyanine green and fluorescence imaging. (**a**) Renal hilum dissected with clamping of veins and renal artery. (**b**) Fluorescence filter after indocyanine green with liver showing high uptake and kidney without perfusion after hilum clamping. Solid arrow: clamped renal hilum. Asterisk: kidney without indocyanine green uptake. (Photo: with permission from Tomás B. C. Moretti, 2020)

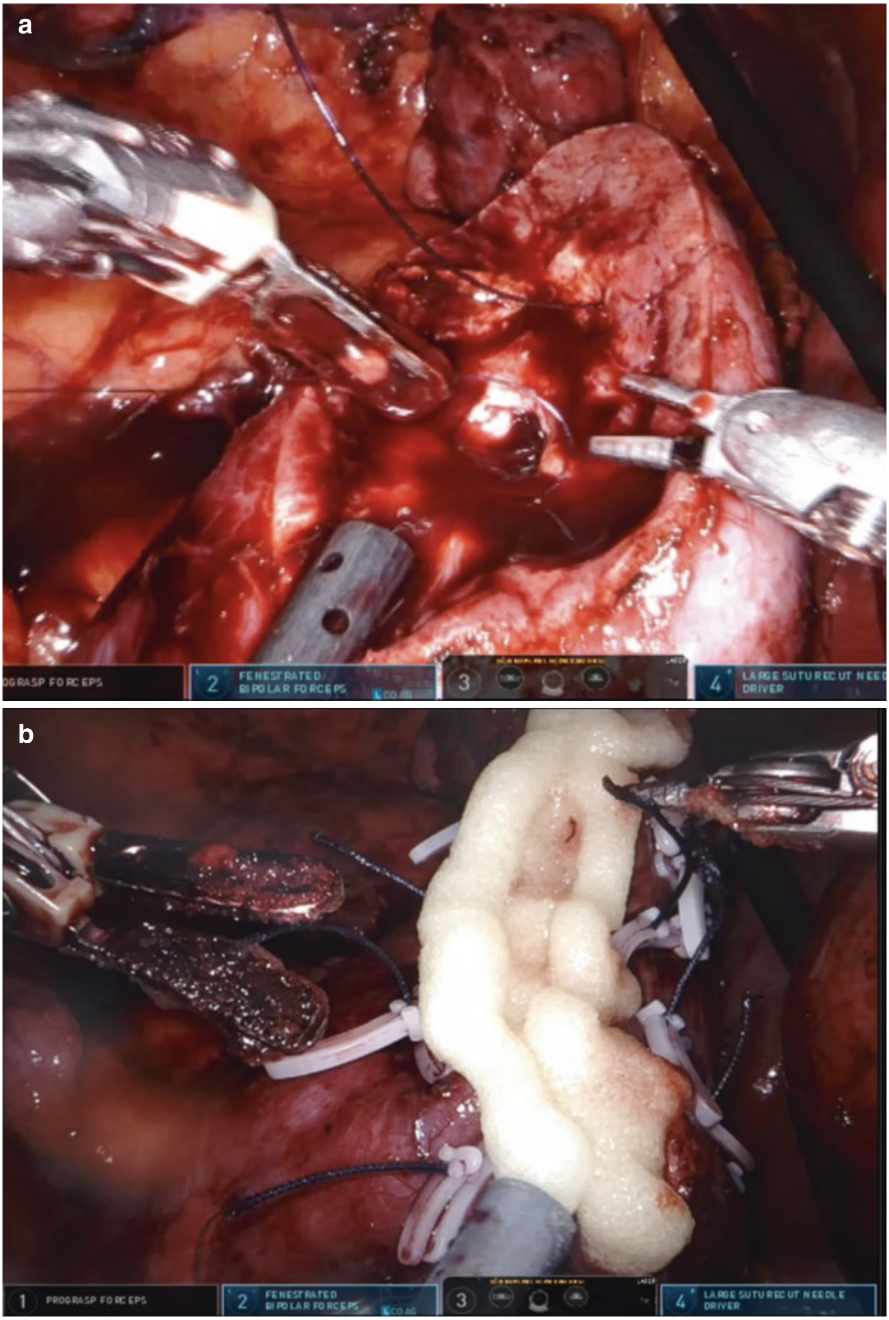

Fig. 25.6 Intraoperative image of robotic partial nephrectomy after tumor resection. (**a**) Appearance after tumor resection in the upper pole of the right kidney. (**b**) Final appearance after suturing and closing the defect with clips and hemostatic foam. (Photo: with permission from Tomás B. C. Moretti, 2020)

25.3 Robotic-Assisted Kidney Transplantation

Kidney transplantation is the gold standard treatment in patients with end-stage kidney disease. Robot-assisted laparoscopic surgery has been able to overcome many restrictions of classical laparoscopy, particularly in complex and demanding surgical procedures [19]. In 2016, the first robotic-assisted kidney transplant (RAKT) was performed in Europe, which is considered one of most challenging urological procedures due to its technical aspect [20]. Thanks to this robotic assistance, minimally invasive surgery in kidney transplantation growing progressively, not only in the most common living donor, but also in deceased donor scenario [21].

25.3.1 Surgical Technique

The patient is positioned in supine Trendelenburg and the robot is docked between the parted legs of the patient. Peritoneal flaps are raised, creating a peritoneal pouch over the psoas muscle. A small Pfannenstiel incision is made to insert the previously wrapped in an ice-packed gauze kidney allograft. The graft renal vein anastomosis is performed in an end-to-side continuous manner to the external iliac vein. Afterwards, the arterial anastomosis is accomplished in the same way to the external iliac artery (Fig. 25.7). Then, reperfusion of the graft is carried out followed by the ureteroneocystostomy (usually in a Lich-Gregoir technique) [22].

In order to reduce the vascular anastomosis complications, urologists prefer to implant left kidneys (longer vein) and single artery ones. However, some series report RAKT using right and multiple artery kidneys varying from 12.2 to 15.4% [23, 24].

Different techniques from the previously described, however, are possible. Felip et al. in 2021, published the first five cases of a robotic transvaginal-assisted living donor kidney transplantation. They describe the insertion of the graft through the vagina and, since they had no complications and a good median operative time (220 min), conclude that this new technique is feasible and safe [25]. Moreover, Adiyat et al. described a series of 34 RAKT with total extraperitonealization of the graft, reproducing closely the technique of the open renal transplantation, with good graft function [26].

25.3.2 Comparison to Open Kidney Transplantation

Open kidney transplantation is still the gold standard for renal transplant. However, as the number of RAKT grows, an increasing number of studies comparing both techniques emerge and some already conclude that the robotic operation is not

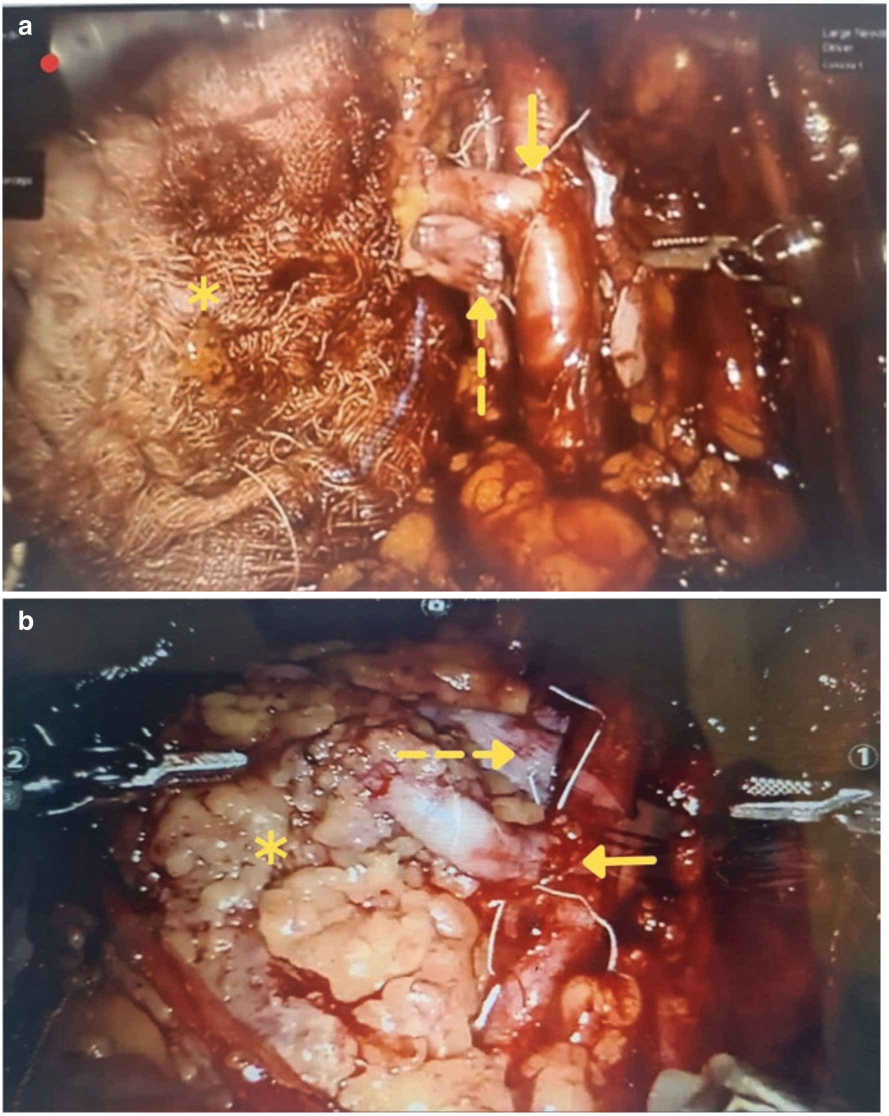

Fig. 25.7 Intraoperative imaging of robotic-assisted kidney transplantation. (**a**) Aspect of the arterial and venous anastomosis with the graft wrapped in a wet compress. (**b**) Aspect of the arterial and venous anastomosis with the perfused graft. Continuous arrows: arterial anastomosis; discontinued arrows: venous anastomosis; asterisk: graft. (Photo: with permission from Rafael F. Coelho, 2020)

inferior to the open approach [20]. A systematic review published in the European Urology evidenced not only no difference in graft or patient survival but also that minimally invasive surgery had lower site infection and incisional hernia rates; nevertheless, showed a prolonged cold and warm ischemia time, as well as total operation time [27].

A meta-analysis coordinated by Liu in 2020 demonstrated similar results: RAKT had significant higher rewarming time and total ischemia time compared to conventional operation, with a lower rate of surgical site infection. Furthermore, on an average follow-up of 31 months, patients had similar functional and clinical efficacy, besides similar all-cause mortality [28].

Moreover, other publications report similar outcomes. Mean total operation time was higher, as well as lesser lymphocele and wound healing disorders in RAKT than in open access; besides, they observe excellent short- and midterm results in graft function [20, 29, 30].

25.3.3 Learning Curve

Since RAKT is a relatively new procedure, there are no papers specifically about its learning curve. However, some authors do comment about their experience and results toward time.

Musquera et al. after analyzing 82 living donor RAKT published about the "lesson learned." They noticed a significant reduction in time between the first 20 cases versus the following ones (248 vs. 189 min, $p < 0.05$) [23].

The European Robotic Urologic Section (ERUS) published in 2021 a multicenter prospective observational study with 291 living-donor patients, in which the groups concluded that the learning curve for RAKT is relatively short. They compared the first 120 cases versus the following 171 and reported a significant reduction in surgical time (265 vs. 230 min, $p < 0.05$) [24].

25.3.4 Surgical and Functional Results

Regarding the functional outcomes of RAKT, studies report that it can already be considered an attractive minimally invasive method for kidney transplantation, but that further investigation must be done to consider it the standard approach. Recent paper observed a mean creatinine of 1.52 mg/dL and a renal graft survival of 98% after an average time of 1.8 years [23]. The ERUS publication, above mentioned, concluded that RAKT performed in wide experienced centers have good surgical and functional results, competitive with open kidney transplantation [24].

Several studies evaluate robotic renal transplant's surgical complications. Musquera et al. after 82 RAKTs, reported five conversions to open surgery due to abnormal graft vascularization, two embolizations for subcapsular and a hypogastric artery bleeding without repercussion, and one venous thrombosis leading to loss of kidney [23]. Moreover, the groups that participated in the ERUS series, with a total of 291 living-donor RAKT, observed 17 cases of postoperative bleeding (six required re-exploration due to hematoma), while one patient presented venous thrombosis, two arterial stenosis, three incisional hernias, six ureteric stenosis and nine lymphoceles [24].

25.3.5 Pediatric RAKT

Kidney transplantation (KT) is the gold-standard treatment for end-stage renal disease (ESRD) in children [31]. Applying techniques of minimally invasive surgery may contribute to the improvement of clinical outcomes for the pediatric transplant patient's population and help mitigate the morbidity of KT.

However, many challenges remain ahead. Minimally invasive surgery has been consistently shown to produce improved clinical outcomes as compared to open surgery equivalents. Despite the presence of these improvements, many challenges lie ahead, such as: anesthesia aspects (tolerance for cavity insufflation), robotic instruments specific for adults, anatomic aspects (small abdominal cavity) and no standard trocar placement (need to adapt to each child) [19]. Cost-effectiveness still is a barrier to overcome.

Finally, in this scenario, RAKT should be performed by a multidisciplinary experienced team, supported by a pediatric nephrologist, urologist and anesthesiology team. And although data on this procedure in children is still scarce, it seems a safe and feasible surgery, with excellent results in graft function [31]. Further studies to better determine the benefits of the robotic approach as compared to the laparoscopic and open approach are necessary.

25.4 Reconstructive Urology

Reconstructive urology can be defined as a subspecialty field that manages and treats genitourinary conditions that affect normal voiding and sexual function [32]. The principles of robotic reconstructive surgery are similar to open surgery whilst offering the advantages of reduced tremor, better visualization and ergonomics, unlimited freedom of movement with improved dexterity and longer reach with better access to structures, and an assumed less steep learning curve than the one required for pure laparoscopy [32, 33].

There are multiple conditions that may require a reconstructive intervention. From a nephrological perspective, the main goal of any intervention would be maintenance of renal function which can be jeopardized by recurrent urinary tract infections (caused by urinary stasis following urethral stenosis, bladder neck stenosis or VUR), complete or partial obstruction of the upper urinary tract (ureteral stenosis, UPJ obstruction, ureteral compression by endometriosis, oncological pelvic pathologies or postsurgical adherences, etc.), or both.

We will review the main robotic surgical approaches to address these situations.

25.4.1 Pyeloplasty

Ureteropelvic junction (UPJ) obstruction consists in a congenital obstruction of the ureteral transition segment between the renal pelvis and proximal portion of the ureter. Regardless of the exact etiology, UPJ obstruction is most commonly treated with a dismembered technique (Anderson-Hynes). In this technique, UPJ is fully dissected off the surrounding tissue until it is clearly visible. If a crossing vessel is identified, it should be spared and ureter transposed anteriorly before anastomosis is performed (Fig. 25.8). The approach is exact the same of the one used for laparoscopy but offering the advantage of a more intuitive, ergonomic and easy-to-perform suture.

The first robotic pyeloplasty was described in 2002 by Gettman et al. [34]. There are no prospective studies comparing open, laparoscopic, and robotic approaches in adults, only case series suggesting very similar outcomes equally very effective with success rates over 93% even for beginners [35, 36].

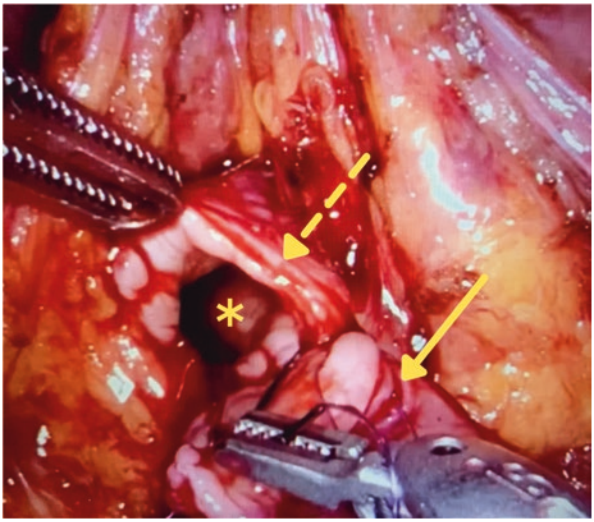

Fig. 25.8 Intraoperative image of robotic pyeloplasty for correction of ureteropelvic junction obstruction. The surgery is at the time of reconstruction with an anastomosis between the ureter and the renal pelvis. Solid arrow: ureter. Discontinued arrow: renal pelvis wall; asterisk: lumen of the renal pelvis. (Photo: with permission from Ricardo Miyaoka, 2021)

25.4.2 Ureteral Reimplantation

Ureteral reimplantation is required in cases of ureterovesical reflux, distal ureteral stenosis or trauma. Open approaches have historically been associated with high success rates (95–99%) but robotic technique offers a less invasive approach with comparable outcomes with decreased morbidity [37]. The first robotic reimplant was reported by Patil et al. in 2008 [38]. A small case series by Muffarij et al. reported 100% success for robotic ureteral reimplantation after a mean follow up of 31.5 months [39]. Stricture-free rate and operative time seem to be very similar for open, laparoscopic, and robotic techniques, although minimally invasive techniques are associated with a shorter hospital stay and reduced blood loss [40].

25.4.3 Boari Flap

The Boari flap technique consists in using a flap of the bladder to repair longer segment distal ureteral strictures which may be as lengthy as 15 cm. The first robotic procedure was described by Stolzenburg who reported on 8 cases with 100% success rate with 12-months follow up [41]. Although these initial results are promising, further studies with larger cohorts and long term follow up are needed comparing robotic versus open and laparoscopic approaches.

25.4.4 Ureteroureterostomy

End-to-end anastomosis may be an alternative to repair short (<3 cm) proximal or middle ureteral stenosis that fail endoscopic treatment (Fig. 25.9). Results are comparable for open, laparoscopic, and robotic approaches regarding outcomes, surgical time, and complications, both in pediatric and adult series. There may be a trend toward shorter OR time and less blood loss for the robotic approach, but data is still very scarce [42, 43].

25.4.5 Buccal Ureteroplasty

The buccal ureteroplasty is a resource for those with longer or multifocal strictures of the proximal or middle ureter that cannot be repaired with primary ureteroureteral anastomosis. Buccal mucosa is an excellent alternative when blood supply to the reconstruction site is at risk.

Recently, Lee and Zhao reported on a multi-institutional experience with a success rate of over 90% at a median follow-up of 24 months for robotic ureteroplasty with buccal mucosa [44].

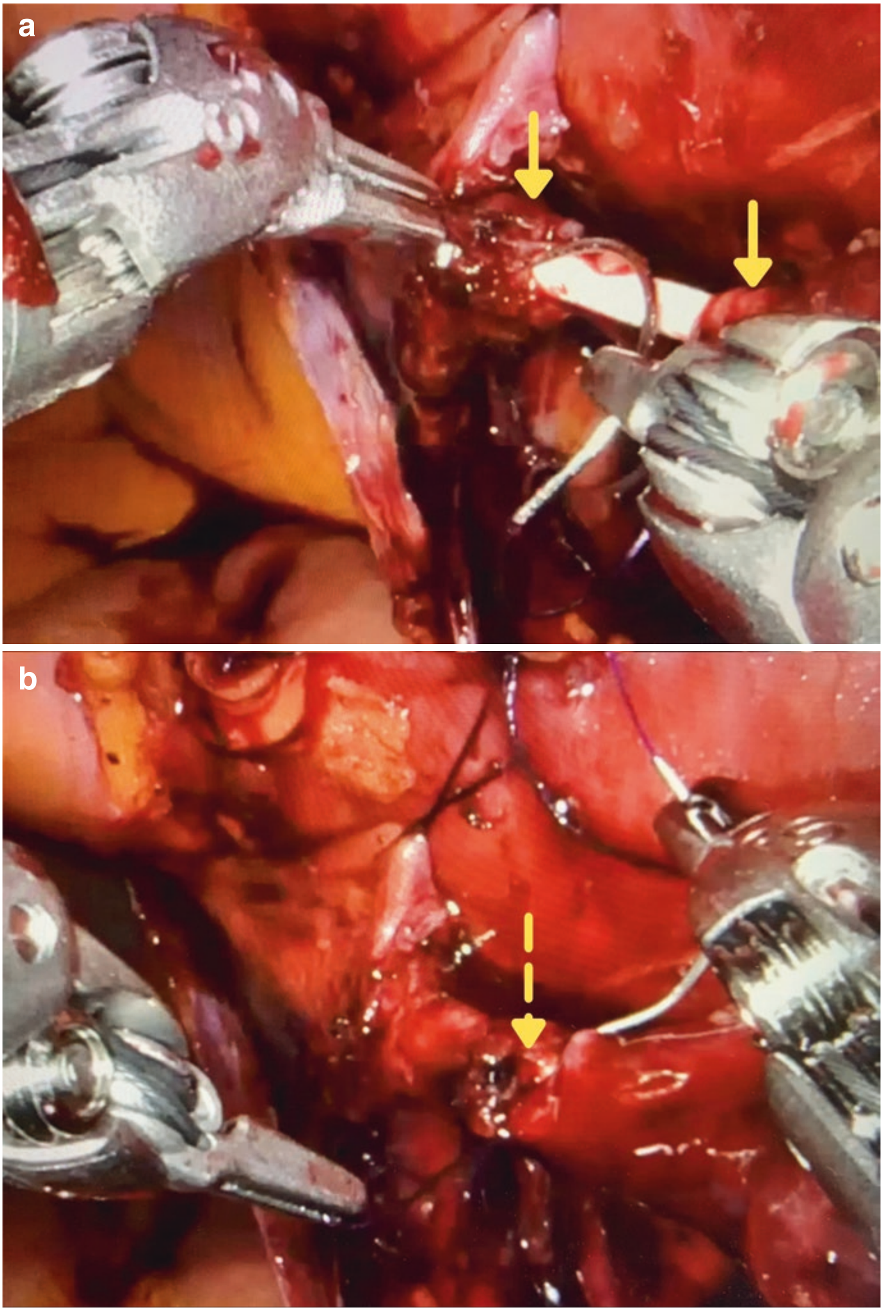

Fig. 25.9 Intraoperative image of robotic ureteroureterostomy for correction of short ureter stenosis. (**a**) Isolation of the ureteral stumps (continuous arrows) over a ureteral catheter. (**b**) Final appearance after anastomosis (discontinued arrow). (Photo: with permission from Ricardo Miyaoka, 2021)

25.4.6 Appendiceal Flap

Appendiceal flap ureteroplasty provides some advantages including relatively easy appendiceal mobilization, well-defined blood supply through the mesentery of the appendix, negligible absorption of urine, ability to replace totally obliterated ureteral segments, and lack of donor site morbidity (when compared with buccal mucosa graft). A case series from Reggio et al. [45] reported on six patients with no recurrences at 16 months of follow-up. All cases were right-sided with strictures averaging 2.5 cm.

25.4.7 Ileal Ureter

Ileal ureter should be used as a last attempt to replace an irreversibly damaged ureter when all previously described techniques do not apply or fail. Technique consists in interposing an ileal segment harvested approximately 20 cm before the ileocecal valve and attaching distally to the bladder or spatulated distal ureter and proximally to the proximal ureter, renal pelvis, or lower calyx as feasible [46].

Robotic ileal ureter was first described in 2008 by Wagner et al. [47], but to date, only few small case series with short follow-up are reported. Most reported cases provide encouraging satisfying outcomes.

25.4.8 Augmentation Cystoplasty

Augmentation cystoplasty (AC) was first described in 2008 in children by Gundeti et al. [48]. Since then, there have been description of only few case reports and one small case series involving 19 patients who underwent AC for different indications including low compliance, refractory detrusor hyperactivity and bladder pain syndrome. This series reported on no major complications and very good long-term outcomes [49]. The technique seems safe and feasible. Prospective comparative series are desirable but very difficult to become a reality as botulinum toxin and electrical nerve stimulation can resolve a significant number of cases that might have an indication for AC otherwise.

25.4.9 Bladder Neck Reconstruction

Bladder neck reconstruction is devoted to resolve bladder neck contracture (BNC) which usually develops after a radical prostatectomy for prostate cancer treatment but may also derive from simple prostatectomy for benign prostatic hyperplasia, transurethral resection of the prostate (TURP), thermal ablation by high intensity focused ultrasound (HIFU), or pelvic trauma. Robotic Y-V plasty consists in identifying the lesioned segment, incising it ventrally and creating a Y-V advancement flap on the anterior surface of the bladder.

The Kroepfl group reported on a series of consecutive adult male patients who underwent robotic Y-V plasty for recurrent BNC. At a median follow-up of 23 months, 10 patients (83%) had clinical success and no evidence of recurrence [50].

25.5 Conclusion

Since its inception, robotic surgery has remained at the forefront of technological development in urology. The reproducibility of robotic techniques is becoming more and more acceptable, with the economic barrier as a brake on this development. With the emergence of new robotic platforms, this technology becomes more accessible and allows its application in different settings.

The cost-effectiveness becomes more evident in more prevalent pathologies, such as partial nephrectomy and thus, allowed greater acceptance in the urological community and allowed better results to be achieved in a shorter time. In the case of reconstructive urology, as it has a lower incidence, it still needs more studies and greater volume to overcome costs, as well as kidney transplantation.

Thus, robotic surgery is an important technological link that brings together a common interest of urologists and nephrologists, preserving renal function.

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