ROBOTIC ASSISTED LAPAROSCOPIC SURGERY (RALS) IN PEDIATRIC UROLOGY

EDITED BY: Miguel Alfedo Castellan and Mohan S. Gundeti
PUBLISHED IN: Frontiers in Pediatrics and Frontiers in Surgery

frontiers Research Topics

ISSN 1664-8714
ISBN 978-2-88963-681-5
DOI 10.3389/978-2-88963-681-5

About Frontiers

Frontiers is more than just an open-access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers Journal Series

The Frontiers Journal Series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the Frontiers Journal Series operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to Quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews.
Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view.
By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the Frontiers Journals Series: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area! Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers Editorial Office: researchtopics@frontiersin.org

ROBOTIC ASSISTED LAPAROSCOPIC SURGERY (RALS) IN PEDIATRIC UROLOGY

Topic Editors:
Miguel Alfedo Castellan, University of Miami, United States
Mohan S. Gundeti, University of Chicago, United States

Citation: Castellan, M. A., Gundeti, M. S., eds. (2020). Robotic Assisted Laparoscopic Surgery (RALS) in Pediatric Urology. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-88963-681-5

Table of Contents

frontiers in Pediatrics

EDITORIAL
published: 11 March 2020
doi: 10.3389/fped.2020.00085

Editorial: Robotic Assisted Laparoscopic Surgery (RALS) in Pediatric Urology

*Mohan S. Gundeti[1] and Miguel A. Castellan[2,3]**

[1] Pediatric Urology, Section of Urology, Department of Surgery, The University of Chicago Medicine, Comer Children's Hospital, Pritzker School of Medicine, Chicago, IL, United States, [2] Department of Pediatric Urology, Nicklaus Children's Hospital, Miami, FL, United States, [3] Joe Di Maggio Children's Hospital, Hollywood, FL, United States

Keywords: robotic surgery, pediatric urology, RALS (robot-assisted laparoscopic surgery), minimaly invasive surgery, pyeloplasty

Editorial on the Research Topic

Robotic Assisted Laparoscopic Surgery (RALS) in Pediatric Urology

Since its inception within pediatric urology in early 2000, robotic assistance has become more widely accepted due to its aid in reconstructive aspects. Numerous procedures have been performed, from pyeloplasty to complex augmentation cystoplasty and Catherizable channels with bladder neck procedures. After the initial period of learning curve and feasibility assessments, quality outcomes and comparative studies have since been published, and these include some prospective studies. The ongoing challenges of the cost effectiveness, wider availability, and miniaturization of the instruments is a work in progress, and these will hopefully prove to be a short-term issue.

This Research Topic is intended to highlight the evolution of robotic surgical technology and its application in Pediatric Urology. In this collection of articles published on this subject, we have a wide selection of studies that will contribute to the further progress of the field. This topic continues to be of growing interest among the pediatric urology community and, in this Editorial, we have reviewed 14 accepted and included papers.

Authors from Chicago, IL, USA (Andolfi et al.), described the implementation, at their institution, of a 5-day mini-fellowship in robotic urologic surgery in children, and this was with a mentor, preceptor, and a proctor. The goal was to assist practicing pediatric urologists in incorporating robotic surgery into their practice. Between 2012 and 2018, a total of 29 national and international pediatric surgeons and urologists underwent robotic surgery training. Authors reported that this intensive program enabled surgeons to successfully incorporate the robotic platform into their practice and to advance the complexity of minimally invasive procedures.

An article from Toronto, ON, Canada (Fernandez and Farhat), described a comprehensive analysis of Robot-Assisted Surgery Uptake in Pediatric Surgery. This article described the historical publication uptake of RAS in pediatric urology and other surgical disciplines using a bibliometric comparison of the most cited manuscripts. They showed how the production of literature on the topics of pediatric laparoscopic and robot-assisted surgery has grown rapidly. Authors concluded that future directives need to focus on increasing the amount of evidence to support the innovation and development of pediatric instruments.

With newer technology, the learning curve is an important aspect, and (Sahadev et al.) described some the excellent tips to overcome this for the purposes of robotic-assisted laparoscopic extravesical ureteric reimplantation (RALUR- EV). Based on the institutional experience, it has been demonstrated that the learning curve of RALUR can be shortened with specific modifications predicated on experience; with technical adaptations, clinically significant improvements in surgical outcomes may be expected. The salient tips described are useful in order for early adopters

OPEN ACCESS

Edited and reviewed by:
Ricardo González, Kinder- und Jugendkrankenhaus Auf Der Bult, Germany

****Correspondence:***
Miguel A. Castellan
mgundeti@surgery.bsd.uchicago.edu

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *28 January 2020*
Accepted: *20 February 2020*
Published: *11 March 2020*

Citation:
Gundeti MS and Castellan MA (2020) Editorial: Robotic Assisted Laparoscopic Surgery (RALS) in Pediatric Urology. Front. Pediatr. 8:85. doi: 10.3389/fped.2020.00085

to optimize the outcomes. The role of VCUG in the demonstration of reflux resolution is mandatory until a large volume of cases, such as open surgery, have been performed.

A manuscript from New York, NY, USA (Kim et al.), reviewed the specific considerations that are necessary to safely perform robotic-assisted laparoscopic procedures in infants, including physiological changes associated with pneumoperitoneum in infants, positioning, trocar placement, and docking. Young infants warrant special consideration when carrying out robotic surgery, and this paper has described the technical factors unique to this patient population.

Authors from Puerto Rico, USA (Morales-López et al.), reviewed current concepts in pediatric robotic-assisted Pyeloplasty. In this article, they have described the technique as it relates to the different robotic platforms, reviewed the surgical experience, and compared its results to other surgical approaches. They have also discussed patient and parent satisfaction, cost and financial considerations, along with evaluating the future of robotic surgery in the treatment of UPJ obstruction.

A minimal invasive approach for stone management is challenging, and (Ballesteros et al.) have carried out an excellent review of stone management; it has a special role in circumstances where other minimal invasive approaches have failed, complex urinary tract calculi, failed prior procedures, or abnormal genitourinary anatomy. The use of flexible or rigid ureteroscopy and a laparoscopic ultrasonic probe aid in the location of stones. A robotic approach remains the first choice of treatment for concomitant renal stones and ureteropelvic junction obstruction.

Infantile robotic surgery has been a challenge due to the generic system and instruments of the current robotic surgical system. Kim reviewed the early outcomes. According to the literature, the advantages of the reduced hospital stay and cosmetics with at par outcomes have been demonstrated. The main application has been pyeloplasty and heminephrectomy.

A manuscript from Atlanta, GA, USA (Bilgutay and Kirsch), has described the advantages and challenges of using robotic surgery in reconstructive surgeries involving the ureter in pediatric patients. This article described different applications, including upper ureteral reconstruction (e.g., pyeloplasty, UPJ polypectomy, ureterocalycostomy, and high uretero-ureterostomy in duplex systems), mid-ureteral reconstruction (e.g., mid uretero-ureterostomy for stricture or polyp), and lower ureteral reconstruction (e.g., ureteral reimplantation and lower ureter-ureterostomy in duplex systems). The different robotic procedures have been described in detail.

The robotic approach is beneficial in pelvic organ surgery, and (Gargollo and White) have described its role in bladder neck surgery for incontinence. The placement of an artificial sphincter to sling and close has been described along with the feasibility and safety of expanding the range of RAL surgical candidates to include selected patients with urinary incontinence.

Subramaniam, from Leeds, UK, reviewed the robotic approach to creating continent catheterizable channels (CC). This article described his personal experience with the robotic approach (18 consecutive cases), and has reviewed the published literature with regards to potential benefits, status, and outcomes. He reported that a robotic approach to CC is feasible and safe and that it has excellent outcomes and minimum morbidity.

The application of robotic assistance within general pediatric surgery was incredible already in early 2000, but it later did not gain much popularity due to the obstacle of miniaturization. Navarrete Arellano and González have described their experience of its successful application in nearly 100 patients, including infants and children, in cases involving the hepatobiliary-gastrointestinal tract and oncological and thoracic abnormalities.

Authors from Dallas, TX, USA (Chen and Peters), reviewed the status and future directions of robotic-assisted surgery in Pediatric Urology. This manuscript described very well the advantages and limitations of the system. The authors have described very clearly some of the reasons why other applications of robot-assisted surgery have failed to be adapted into routine practice in pediatric patients. The authors have also emphasized the importance of an open communication between physicians and engineers to develop new technology that can broaden the applicability of robot-assisted surgical technology in children.

The worldwide adoption of robotic assistance has been limited for multiple reasons, and important factors include the financial aspect of purchase and maintenance. Like other developing countries, South America has been no exception. Moldes et al. performed a survey of pediatric urologist from Brazil, Chile, Uruguay, and Argentina and elaborated upon some of these constrains from their experience. The most striking aspect compared to the USA was the lack of financial coverage of the procedure by insurance companies. The number of robots or trained surgeons available is minimal compared to the large pediatric population needed.

The future is always promising! The passion of innovators to overcome and offer the best services to patients in need drives further innovation. Sheth and Koh reviewed new robotic platforms and determined that they should include improved haptic feedback systems, flexible scopes, easier maneuverability, and even adaptive machine learning concepts to bring robotic-assisted laparoscopic surgery to the next level. The combination of virtual reality technology and robotic surgery may lead to a new era of digital surgery that may, in future, include automated robotic surgery.

AUTHOR CONTRIBUTIONS

MG and MC conceived of the presented idea, read all the manuscript and developed the Editorial together. Both supervised the findings of this work and discussed the results and contributed to the final manuscript.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

REVIEW
published: 07 January 2019
doi: 10.3389/fped.2018.00411

Robotic-Assisted Urologic Surgery in Infants: Positioning, Trocar Placement, and Physiological Considerations

*Soo Jeong Kim[1], John S. Barlog[2] and Ardavan Akhavan[1]**

[1] *Institute for Pediatric Urology, Komansky Children's Hospital, New York Presbyterian-Weill Cornell, New York, NY, United States,* [2] *SUNY Downstate Medical Center, Brooklyn, NY, United States*

Pediatric robotic-assisted laparoscopic procedures are becoming increasingly common. They have been shown to be safe in younger patients, including infants. Successful adoption of robotic-assisted surgery in infants requires an understanding of the technical factors unique to this patient population. This review will delineate the specific considerations to safely perform robotic-assisted laparoscopic procedures in infants, including physiological changes associated with pneumoperitoneum in infants, positioning, trocar placement, and docking.

Keywords: robotic-assisted laparoscopic surgery, surgery in infants, positioning and orientation, trocar placement, robotic-assisted laparoscopic pyeloplasty, robotic-assisted laparoscopic reimplant, robotic-assisted laparoscopic nephrectomy

OPEN ACCESS

Edited by:
Mohan S. Gundeti,
University of Chicago, United States

Reviewed by:
Marcos Raymond Perez-Brayfield,
University of Puerto Rico, Puerto Rico
Juan Manuel Moldes,
Hospital Italiano de Buenos Aires, Argentina

****Correspondence:***
Ardavan Akhavan
apa9010@med.cornell.edu

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *20 September 2018*
Accepted: *10 December 2018*
Published: *07 January 2019*

Citation:
Kim SJ, Barlog JS and Akhavan A (2019) Robotic-Assisted Urologic Surgery in Infants: Positioning, Trocar Placement, and Physiological Considerations. Front. Pediatr. 6:411. doi: 10.3389/fped.2018.00411

INTRODUCTION

Since the introduction of laparoscopy in children (1), indications have expanded from simple diagnostic procedures to complex, reconstructive surgeries. While the most commonly performed pediatric robotic-assisted laparoscopic procedures are pyeloplasty, ureteral reimplantation, nephrectomy, and heminephrectomy (2), more complex procedures like appendicovesicostomy, bladder neck reconstruction, and augmentation cystoplasty are being performed by early adopters. Robotic surgical assistance has potentiated this adoption by adding high definition three-dimensional (stereoscopic) visualization as well as superior articulation, thereby allowing for more accurate movements and improved ergonomics (3). In addition, the magnified image can be combined with tremor filtration and motion scaling, allowing for delicate motions in small areas, which is particularly beneficial in pediatric cases. These benefits have propelled the adoption of robotically-assisted cases by 17.4% per year ($P < 0.0001$) between 2008 and 2013 (2). Furthermore, as experience has grown, the lower age of patients suitable for robotic surgery has declined, and several studies have demonstrated the safety of using robotic-assisted surgery in infants (4, 5).

Successful adoption of robotic-assisted surgery in infants requires understanding of the technical factors unique to this patient population. This review focuses on both the physiological changes associated with pneumoperitoneum in infants, as well as the positioning, trocar placement, and docking considerations that must be addressed in order to successfully execute robotic surgery in the youngest patients.

PHYSIOLOGICAL CONSIDERATIONS

Robotic-assisted laparoscopic surgery requires distension of the peritoneal cavity, and given the infant anatomy, there are several physiological factors to consider during robotic-assisted laparoscopic surgery in infants.

Respiratory

Increased intra-abdominal pressurefrom pneumoperitoneum can exert pressure on the lungs by cephalad displacement of the diaphragm, which decreases total lung capacity, and increases the peak inspiratory pressure, further decreasing the functional residual capacity. The Trendelenberg position can exacerbate these changes. Using CO_2 to maintain pneumoperitoneum also leads to direct increases in CO_2 absorption. These changes lead to acidosis, which is pressure-dependent. An increase in ventilatory minute volume is necessary to limit the respiratory perturbations following insufflation (6). This increase in CO_2 has been shown to be inversely correlated with age, possibly because the peritoneum of infants is relatively larger, and better perfused (7). Also, unlike adults, where the level of CO_2 tends to plateau during surgery, in infants the level of CO_2 continues to rise with the duration of surgery (6).

Cardiovascular

Pneumoperitoneum also exerts cardiovascular effects due to an increase in intraabdominal pressure, peritoneal absorption of CO_2, and stimulation of the neurohumoral vasoactive system. In young children aged 6–36 months, an intraabdominal pressure of 10 mmHg or greater (i.e., higher than the right atrial pressure) causes a decrease in venous return, right ventricular cardiac output, and left ventricular preload and cardiac output (8). In addition, increased intraabdominal pressure may cause a catecholamine release which could contribute to increased mean arterial pressure and systemic vascular resistance (9). Pediatric patients can also develop bradycardia due to a robust vagal reflex induced by pneumoperitoneum, which may require emergent desufflation (10, 11). In a prospective study evaluating 33 pediatric patients aged 1–14 years (median 5 years) undergoing laparoscopic surgery, no significant cardiovascular changes occurred during CO_2 insufflation if the intraabdominal pressure was maintained lower than 10 mmHg (12).

Positioning for robotic surgery can also affect cardiovascular status. The Trendelenberg position, for instance, can increase venous return to the heart and therefore cardiac filling pressure, while reverse-Trendelenberg reduces the two (13).

Renal

In adults, pneumoperitoneum is associated with a pressure-dependent, reversible decrease in renal blood flow, glomerular filtration, and resultant urinary output (14). When 8 patients aged 0–12 months with normal baseline renal function underwent laparoscopy with intraabdominal pressure maintained at 8 mmHg, 88% developed anuria (15). The anuria was reversible, however, with urine output significantly increased postoperatively, and maximum values were evident at 5 h after desufflation (15).

Pneumoperitoneum causes renal changes via stimulation of the renin-angiotensin-aldosterone system (increase in renin and subsequent aldosterone secretion) and excretion of anti-diuretic hormone. These hormonal changes contribute to salt and water retention with oliguria (16).

Insufflation

In addition to the physiologic changes as outlined above, mean postoperative pain score and requirement for analgesia have been shown to be positively correlated with pneumoperitoneal pressure during laparoscopic renal surgery in infants (17). Therefore, we recommend that the lowest possible insufflation pressure be used in infants [8–12 mmHg]. For infants and young children, we recommend beginning the insufflation with the lowest possible flow rate, in order to allow for any adverse physiological changes to be identified and immediately reversed, if necessary. Once the target pressure has been reached, the flow may be increased for the remainder of the case.

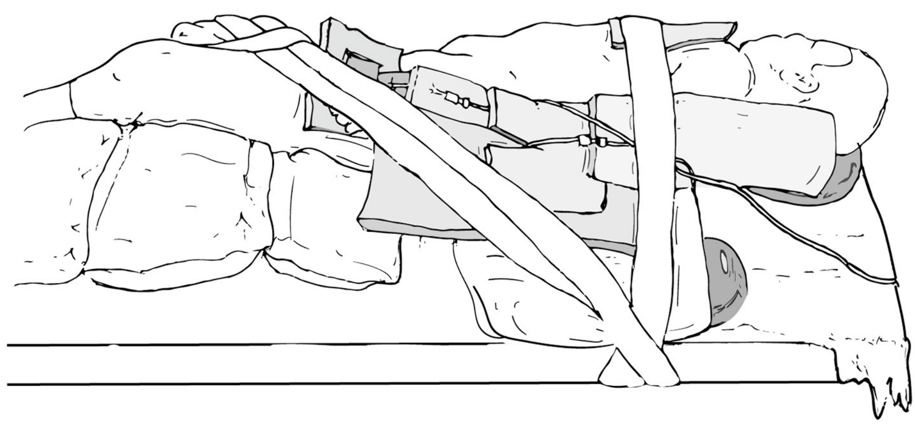

FIGURE 1 | Pad all pressure points and areas around tubing, wires, and nails.

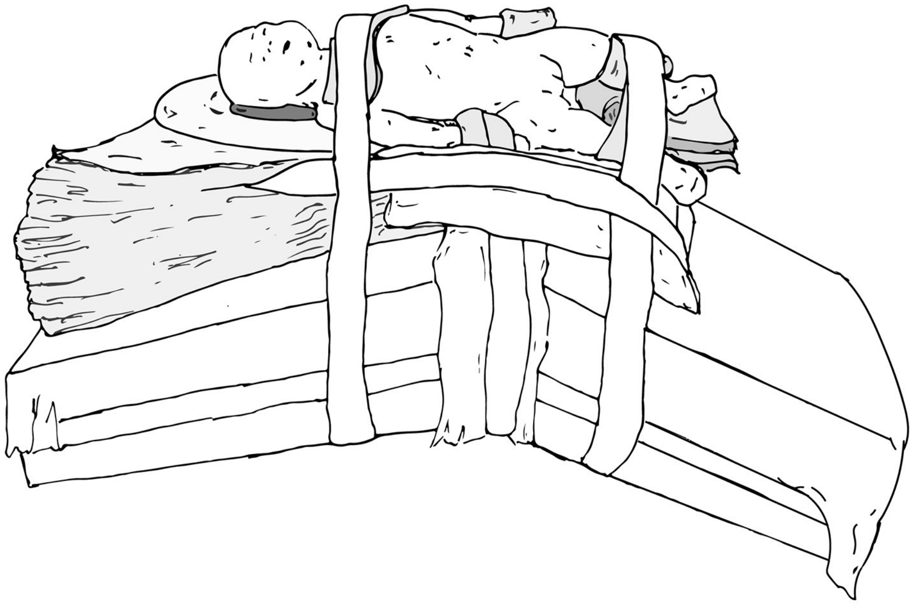

FIGURE 2 | Foam pads are used to elevate small infants (weight <10 kg) ∼10 cm above the operating table to prevent the robot arms from hitting the table.

Other Anesthetic Concerns

There are several additional anesthesia-related considerations. First, no nitric oxide should be used in infants during robotic surgery as nitric oxide can lead to bowel distension, obscuring the surgical field. Second, intubation with an endotracheal tube is recommended as laryngeal mask airways will leak at a pressure less than required for robotic surgery. Third, patients should be paralyzed to allow for increased intraabdominal distension. Fourth, the robot is cumbersome and positioning for robotic surgery frequently requires the head of the patient to be far from the anesthesiologist. Anesthesiologists should know how to access the patient in case of emergency, and a plan should be in place to quickly undock if necessary. Lastly, aerosolized bupivacaine can be used to decrease the length of hospitalization, postoperative, and total postoperative narcotic requirements (18).

Physiologic Conclusions

Given the increased time-dependent physiological effects of pneumoperitoneum in infants, providers should take an honest assessment of their operative times and limit patient selection to older children until they are experienced enough to reliably execute procedures within a reasonable length of console time. Furthermore, surgeons should be quick to recognize failure to progress and have a set threshold to convert to an open procedure, should the surgery take longer than is reasonable.

PATIENT POSITIONING

Pediatric patients, particularly infants, are susceptible to crush injuries, and positional injuries. Proper positioning and padding are of paramount importance.

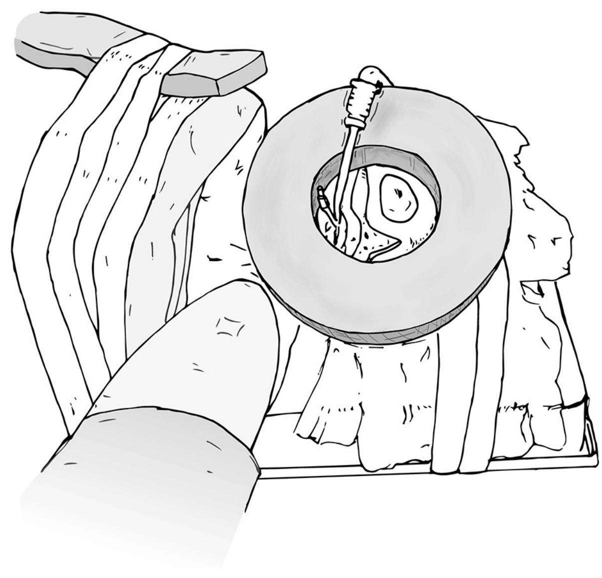

FIGURE 3 | Protect the face with foam to prevent injury or inadvertent manipulation of the endotracheal tube.

General Principles

The main goals of patient positioning and port placement are to avoid injuries to the patient and to allow maximum mobility of the robotic arms (3). All pressure points and areas around tubing, wires, and nails should be padded (**Figure 1**). We prefer to use cloth or silk tape and foam. Tape should not be applied directly to exposed skin. Small infants who weigh <10 kg should be elevated ∼10 cm above the operating table using a foam pad to prevent the robot arms from hitting the table (**Figure 2**). The face should also be protected with foam to prevent injury to the eyes or inadvertent manipulation of the endotracheal tube (**Figure 3**). Prior to draping the patient, the table should be provoked to the most extreme position expected during the case in order to confirm that the patient is secure, no body part or tubing shifts or kinks, and that there are no anesthetic concerns.

Upper Urinary Tract Positioning

When preparing patients for renal and upper tract surgery, we prefer modified flank positioning over lateral decubitus positioning, as the former allows for port placement in a near-supine position, as well as bowel displacement and renal access via a table tilt (**Figures 4**, **5**). For a modified flank position, arms can be placed on an arm board across the body or alongside the patient, depending on surgeon preferences. **Figure 6** illustrates the former. While there are many ways to secure the patient, we prefer placing a tape across the forehead in front of the face-foam, across the nipple-line of the chest, as well as diagonally from the arms across the legs on both sides (**Figure 5**). Egg crates, pillows, and/or an infant-sized bean bag may be used to help support the patient in position.

Lower Urinary Tract Positioning

When positioning a patient for lower urinary tract surgery, the patient may be placed in either lithotomy (**Figure 7A**), frog-leg position (**Figure 7B**), or supine (**Figure 7C**). If cystoscopy is necessary during the procedure, lithotomy is preferred.

TROCAR PLACEMENT

Trocar placement is a crucial step in robotic-assisted surgery in order to minimize instrument collision and operative time. A recent study demonstrated that collisions are minimized if the distance between both anterior superior iliac spines is >13 cm, or if the puboxyphoid distance is >15 cm (19).

Initial Access

Passerotti et al. published the outcomes of 806 laparoscopic procedures (conventional and robot assisted) and reported a 2% complication rate, 75% of which were access related (20). This finding is likely due to the fact that pediatric abdomens are more compliant than adult abdomens, and the pressure necessary to penetrate the pediatric peritoneum can easily cause injury. Therefore, we gain initial access using the open Hassan technique

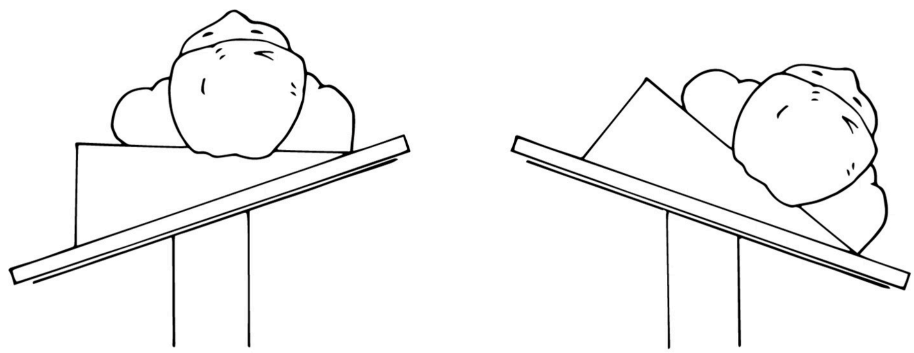

FIGURE 4 | Modified flank positioning used for upper tract surgery, which allows for port placement in a near-supine position (left), and subsequent bowel displacement and renal access via a table tilt (right).

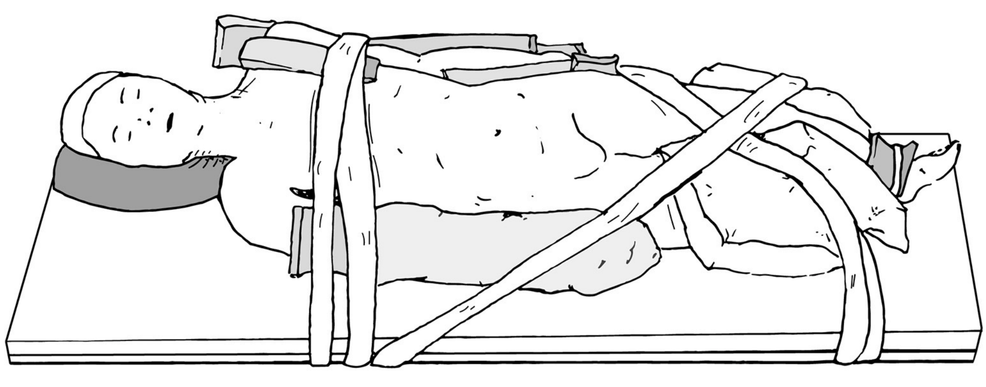

FIGURE 5 | Modified flank positioning used for upper tract surgery, with proper padding, and tape securing the patient to the operating table.

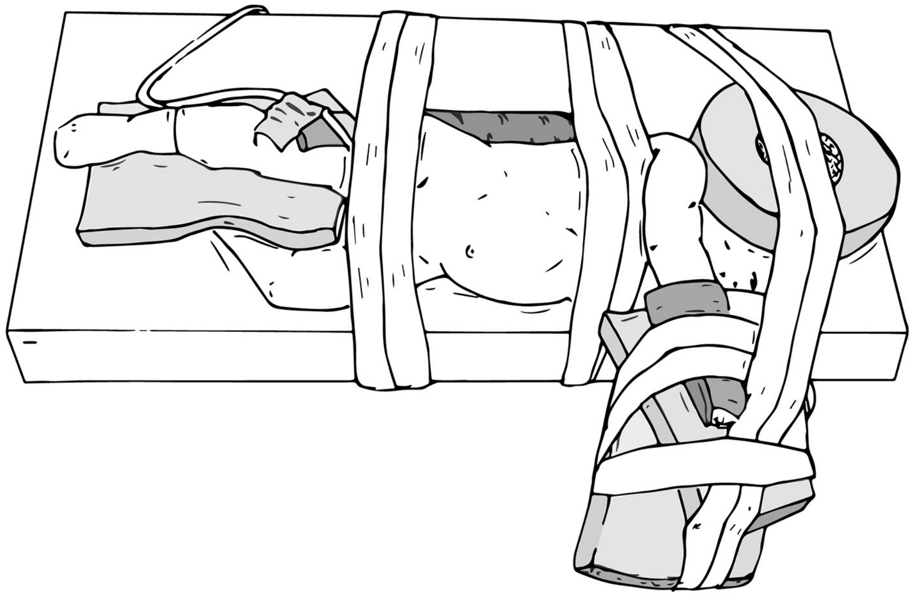

FIGURE 6 | Modified flank positioning with arms placed on an arm board across the body.

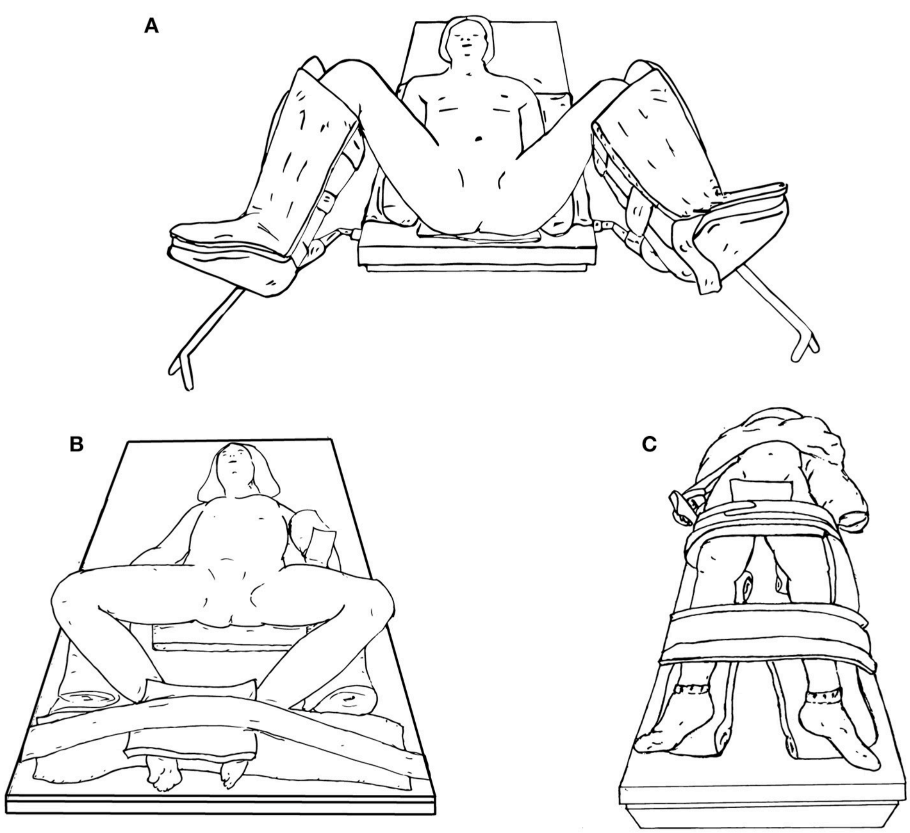

FIGURE 7 | Lower urinary tract surgery positioning options, including lithotomy **(A)**, frog-leg **(B)**, or supine **(C)**.

to place the 8.5 mm camera port, always using a blunt black obturator in order to minimize the risk of injury.

Instrument Ports

Under direct visualization, we employ sharp dissection through the peritoneum with an 11 blade, after injection of 0.25% bupivacaine. Once the port site is dilated with a mosquito clamp, the trocar is advanced with a blunt obturator. While the port is designed to be inserted at the level of the thick black line, in young infants, the port may often only be able to be placed a few mm into the peritoneum.

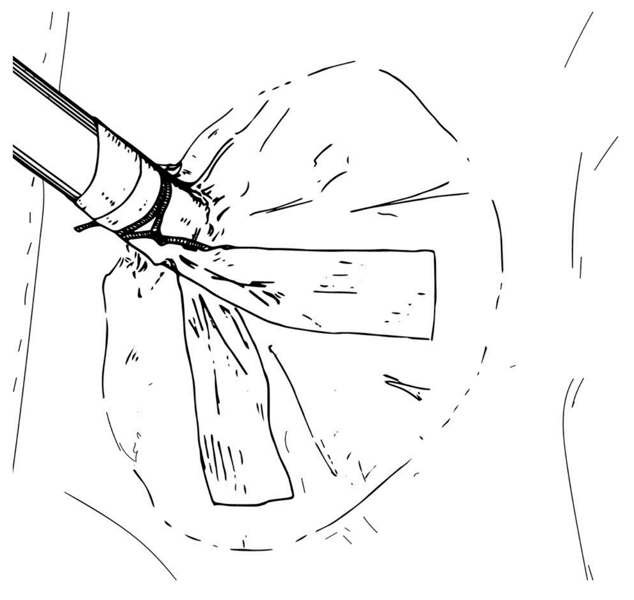

FIGURE 8 | Trocar secured to the skin using sutures, steri-strips, and Tegaderms.

When using an Si system, there is a longstanding debate regarding the preferred sizes of instrument ports in pediatric patients, as there is a pediatric option with an 8.5 mm camera and 5 mm instruments, compared with the standard option of a 12 mm camera and 8 mm instruments. Although the 5 mm ports require a slightly smaller incision, the 5 mm instruments paradoxically require an additional 2 cm intracorporeal working space due to the design of the instrument arms, as the articulating joints are further back on the 5 mm instruments than they are on the 8 mm instruments (3). In addition, the variety of instruments available in the 5 mm size is greatly limited compared to the 8 mm size, many of which are particularly useful during pediatric reconstruction cases, including Black diamond microforceps, and Potts scissors. We prefer to use a hybrid set with an 8.5 mm pediatric camera as well as the 8 mm instruments. On the Xi system, currently only 8-mm instruments are available.

While a 3–5 cm distance between ports is ideal, in infants, this distance is not always possible, so the trocars are just placed as far apart as possible. More distance will be evident after abdominal distension from the pneumoinsufflation. Furthermore, "burping" the ports out 1–2 cm after docking will tent the abdominal wall and also create some extra room. In order to prevent the trocars from falling out, in infants we advocate that they be secured to the skin using a combination of sutures, steri-strips, and Tegaderms (**Figure 8**). At the conclusion of the case, all ports are closed under direction vision.

14-Guage Angiocatheter Assist

A 14-guage angiocatheter in conjunction with cystoscopic tools can be used as an assistant port in order to avoid an additional port placement.

Trocar Positioning

Upper Urinary Tract Trocar Positioning

When performing upper urinary tract surgery such as pyeloplasty or nephrectomy in an infant, in order to prevent robotic

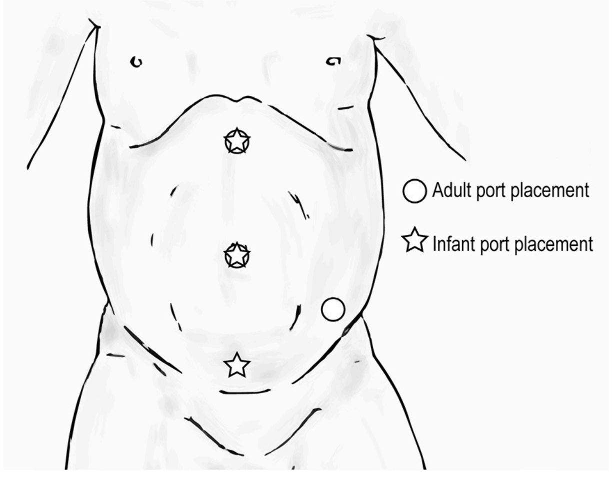

FIGURE 9 | Trocar positioning for upper urinary tract surgery in infants (☆) compared to that for adults (○).

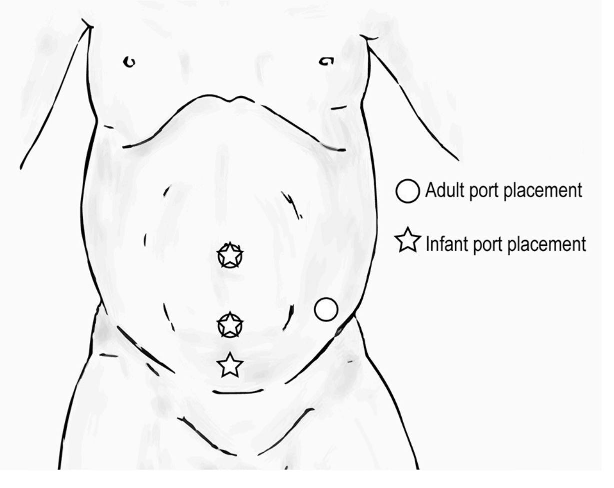

FIGURE 10 | Trocar positioning for upper urinary tract hidden incision endoscopic surgery (HIdES) in infants (☆) compared to that for adults (○).

arms from clashing, the most inferior port site can be moved medially (**Figure 9**). This adjustment is also useful when performing a pyeloplasty because a distended ureteropelvic junction can often be found in the lower abdomen in younger children. Of note, with the adjusted location of the most inferior port site, care must be taken to avoid injury to the bladder.

Upper Urinary Tract Hidden Incision Endoscopic Surgery (HIdES) Trocar Positioning

Hidden incision endoscopic surgery has been previously described for pediatric upper urinary tract surgery (21). The HIdES technique aims to eliminate visible scarring, and the robotic working port and camera port are placed below the line of a Pfannenstiel incision. A second working port is placed infraumbilically. Similar to standard upper urinary tract trocar positioning, the most inferior port can be moved medially in order to increase working room in an infant (**Figure 10**). Again, care must be taken to avoid injury to the bladder with this adjustment.

Extravesical Reimplant

When performing extravesical reimplant surgery with robotic assistance, the port site positioning will depend on the

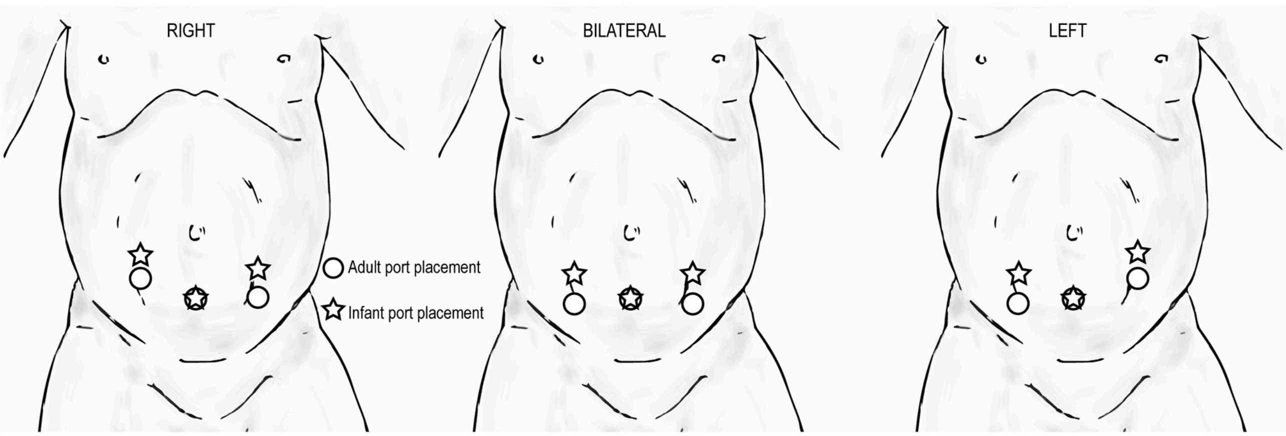

FIGURE 11 | Trocar positioning for extravesical reimplant surgery in infants (☆) compared to that for adults (○) based on laterality of procedure.

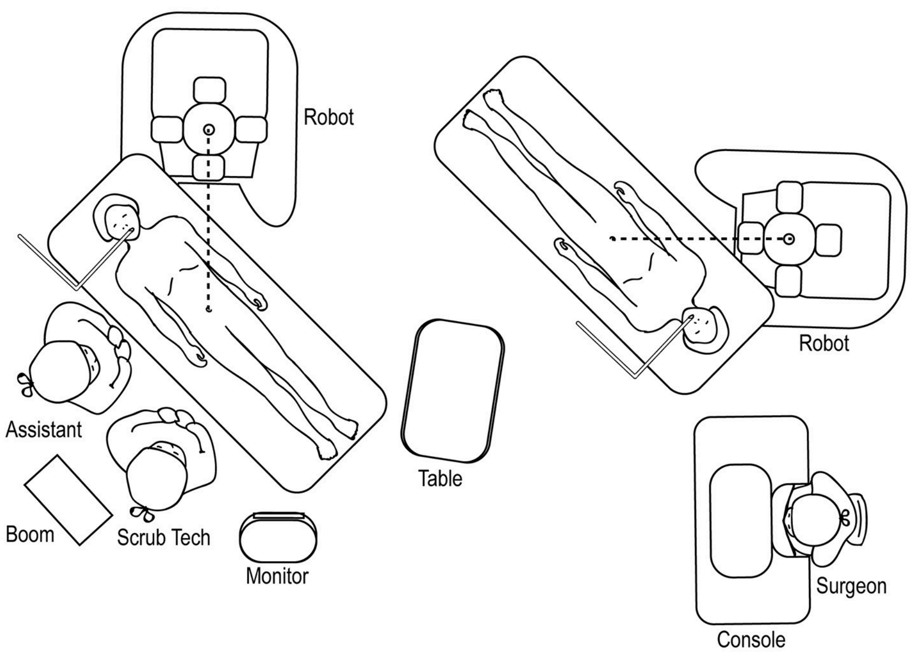

FIGURE 12 | Overhead view of room set-up for upper urinary tract surgery, with robot docked at ipsilateral shoulder.

laterality of the procedure. If bilateral, the port sites will be in a straight line. For infants, all port sites should be 2 cm above the umbilicus to ensure sufficient working room (**Figure 11**).

DOCKING/ROOM SET-UP

A standardized room set-up, including positioning of the robot, robotic console, scrub table, anesthesia machines, and surgical assistant, is important to maximize the utility of the robot while maintaining a safe and effective working environment. If using an Si system, we recommend maintaining the robot at one established location in the room and then moving/rotating the operating room table in position in order to minimize robotic manipulation. Communication with anesthesia is paramount, as extension tubing may be necessary. If using an Xi system, the robot arms can be rotated to the desired configuration without manipulating the operating room table.

Upper Urinary Tract Room Set-Up

The robot should be docked at a point that forms a straight line with the patient's umbilicus and the target location of the surgery (**Figure 12**), identified through either a preoperative retrograde pyelogram (if performing a pyeloplasty) or through direct gross inspection after the initial laparoscopy. The assistant and surgical technician stand on the contralateral side with an accessible table and Mayo stand.

Upper Urinary Tract Hidden Incision Endoscopic Surgery (HIdES) Room Set-Up

The room set-up for robotic-assisted upper urinary tract HIdES surgery is similar to that of standard upper urinary tract surgery, except that the robot is docked by coming in from above the ipsilateral shoulder. The feet of the robot should straddle the base of the operating room table (**Figure 13**).

Lower Urinary Tract Surgery

For robotic-assisted lower urinary tract surgery performed with the patient in the lithotomy or frog-leg supine position, the robot is docked at the patient's 6 o'clock position (**Figure 14**). The surgical tech, Mayo stand, and scrub table remain on one side of the patient, while the assistant stands at the other. For robotic-assisted lower urinary tract surgery performed with the patient in the supine position, the robot is docked laterally (**Figure 15**), with the feet of the Si system straddling the base of the table. The assistant and surgical technician remain on the contralateral side of the robot. If using an Xi system, the positioning of the robot is versatile as the arms can be rotated to the appropriate configuration.

TEAM CONSIDERATIONS

Robotic surgery is a team effort. A successful program requires dedicated support from the hospital as well as an established nursing team. While infant robotic cases are rarely performed daily, preoperative huddles, and standardized algorithms can be invaluable in helping establish a protocol for staff to

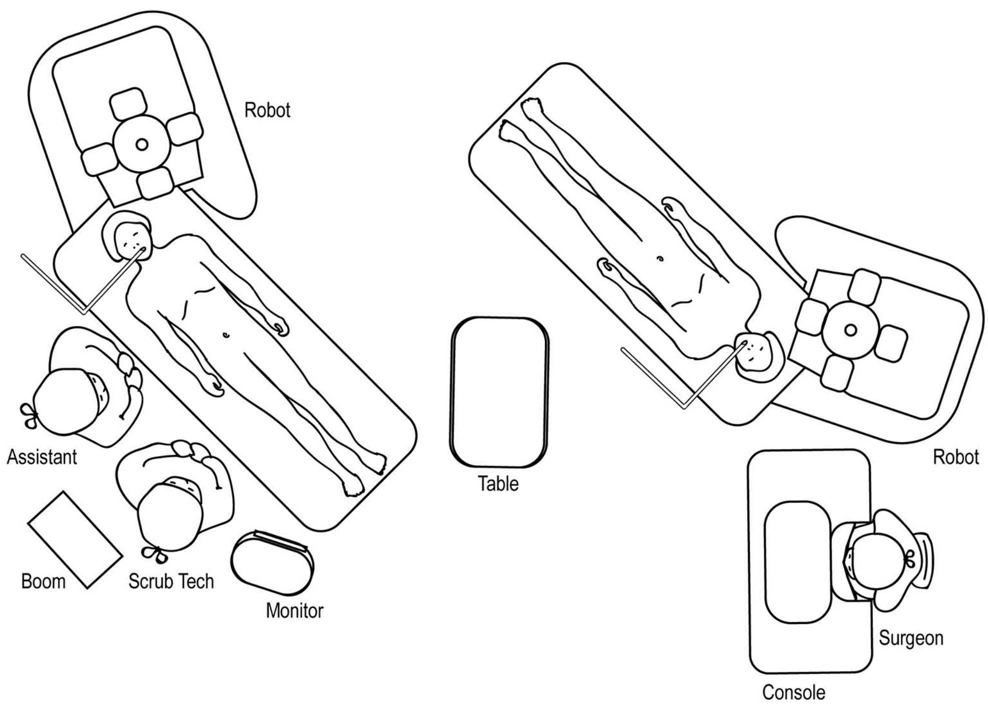

FIGURE 13 | Overhead view of room set-up for upper urinary tract hidden incision endoscopic surgery (HIdES), with robot docked at ipsilateral shoulder.

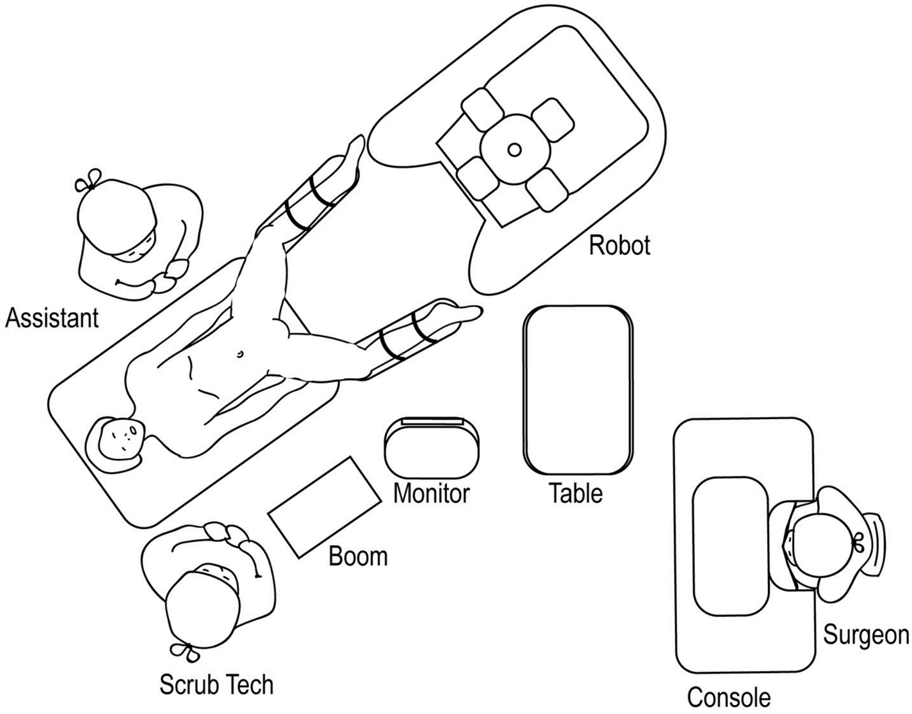

FIGURE 14 | Overhead view of room set-up for lower urinary tract surgery in the lithotomy or frog-leg supine positions.

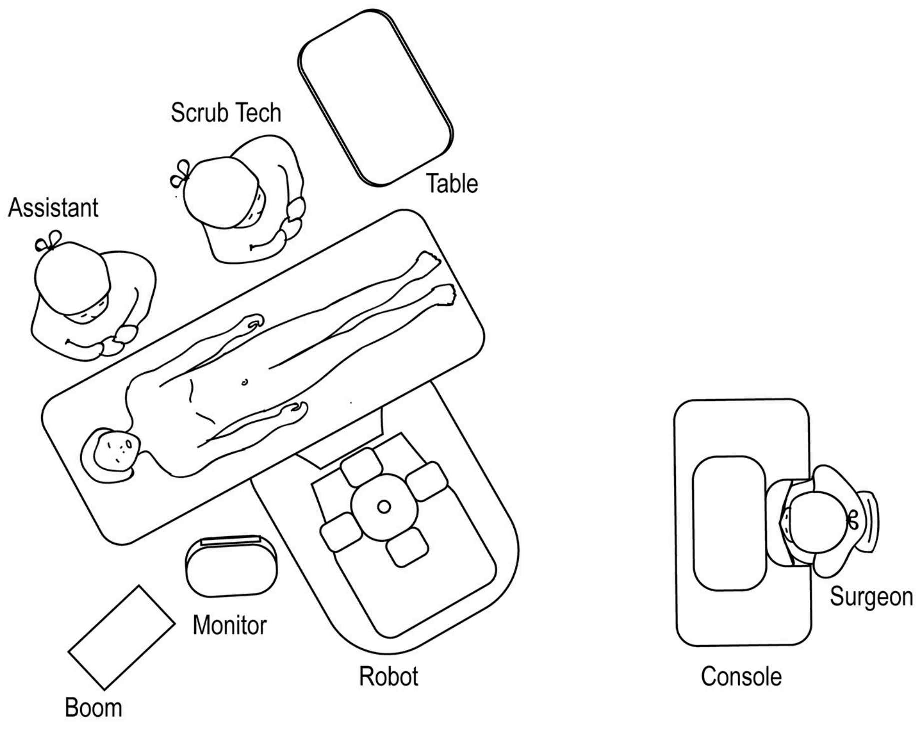

FIGURE 15 | Overhead view of room set-up for lower urinary tract surgery in the supine position.

follow, minimizing confusion, and variations in practice. Additionally, we recommend contingency plans for potential robotic emergencies. These include bleeding, loss of airway, equipment malfunction, and lost needle. Specific step-by-step plans and allocation of responsibilities should be established and practiced with the team in order to minimize reaction times.

CONCLUSION

Young infants warrant special consideration when considering robotic surgery. Their unique anatomy makes them particularly susceptible to the physiologic effects of pneumoperitoneum. When undertaking these cases, surgeons should strive to limit insufflation time and minimize the insufflation pressure to the lowest possible level in order to accomplish the surgery. Furthermore, while the DaVinci robotic system was designed to be used in adult patients, the machine can be used in young children, as long as the specific considerations outlined here are taken into account during positioning, port placement, and docking.

AUTHOR CONTRIBUTIONS

SK authored and edited the manuscript. JB edited the manuscript and contributed original illustrations. AA conceived focus of review and edited the manuscript.

REFERENCES

1. Cortesi N, Ferrari P, Zambarda E, Manenti A, Baldini A, Morano FP. Diagnosis of bilateral abdominal cryptorchidism by laparoscopy. *Endoscopy* (1976) 8:33–4. doi: 10.1055/s-0028-1098372
2. Mahida JB, Cooper JN, Herz D, Diefenbach KA, Deans KJ, Minneci PC, et al. Utilization and costs associated with robotic surgery in children. *J Surg Res*. (2015) 169–76. doi: 10.1016/j.jss.2015.04.087
3. Chang C, Steinberg Z, Shah A, Gundeti MS. Patient positioning and port placement for robot-assisted surgery. *J Endourol*. (2014) 28:631–8. doi: 10.1089/end.2013.0733
4. Avery DI, Herbst KW, Lendvay TS, Noh PH, Dangle P, Gundeti MS, et al. Robot-assisted laparoscopic pyeloplasty: multi-institutional experience in infants. *J Pediatr Urol*. (2015) 11:139.e1–5. doi: 10.1016/j.jpurol.2014.11.025
5. Kawal T, Srinivasan AK, Shrivastava D, Chu DI, Van Batavia J, Weiss D, et al. Pediatric robotic-assisted laparoscopic pyeloplasty: does age matter? *J Pediatr Urol*. S1477-5131:30215–8. doi: 10.1016/j.jpurol.2018.04.023
6. Kalfa N, Allal H, Raux O, Lopez M, Forgues D, Guibal MP, et al. Tolerance of laparoscopy and thoracoscopy in neonates. *Pediatrics* (2005) 116:e785–91. doi: 10.1542/peds.2005-0650
7. McHoney M, Corizia L, Eaton S, Kiely EM, Drake DP, Tan HL, et al. Carbon dioxide elimination during laparoscopy in children is age dependent. *J Pediatr Surg*. (2003) 38:105–10. doi: 10.1053/jpsu.2003.50021
8. De Waal EEC, Kalkman CJ. Haemodynamic changes during low-pressure carbon dioxide pneumoperitoneum in young children. *Pediatr Anesth.* (2003) 13:18–25. doi: 10.1046/j.1460-9592.2003.00973.x
9. Myre K, Rostrup M, Buanes T, Stokland O. Plasma catecholamines and haemodynamic changes during pneumoperitoneum. *Acta Anaesthesiol Scand*. (1998) 42:343–7. doi: 10.1111/j.1399-6576.1998.tb04927.x
10. Brady M, Kinn S, Ness V, O'Rourke K, Randhawa N, Stuart P. Preoperative fasting for preventing perioperative complications in children. *Cochrane Database Syst Rev*. 7:CD005285. doi: 10.1002/14651858.CD005285.pub2
11. Terrier G. Anaesthesia for laparoscopic procedures in infants and children: indications, intra- and post-operative management, prevention and treatment of complications. *Curr Opin Anaesthesiol*. (1999) 12:311–4. doi: 10.1097/00001503-199906000-00009
12. Mattioli G, Montobbio G, Pini Prato A, Repetto P, Carlini C, Gentilino V, et al. Anesthesiologic aspects of laparoscopic fundoplication for gastroesophageal reflux in children with chronic respiratory and gastroenterological symptoms. *Surg Endosc*. (2003) 17:559–66. doi: 10.1007/s00464-002-9077-2
13. Spinelli G, Vargas M, Aprea G, Cortese G, Servillo G. Pediatric anesthesia for minimally invasive surgery in pediatric urology. *Transl Pediatr*. (2016) 5:214–21. doi: 10.21037/tp.2016.09.02
14. Wever KE, Bruintjes MHD, Warlé MC, Hooijmans CR. Renal perfusion and function during pneumoperitoneum: a systematic review and meta-analysis of animal studies. *PLoS ONE* (2016) 11:e0163419. doi: 10.1371/journal.pone.0163419
15. Gómez Dammeier BH, Karanik E, Glüer S, Jesch NK, Kübler J, Latta K, et al. Anuria during pneumoperitoneum in infants and children: a prospective study. *J Pediatr Surg*. (2005) 40:1454–8. doi: 10.1016/j.jpedsurg.2005.05.044
16. Sodha S, Nazarian S, Adshead JM, Vasdev N, Mohan-S G. Effect of pneumoperitoneum on renal function and physiology in patients undergoing robotic renal surgery. *Curr Urol*. (2016) 9:1–4. doi: 10.1159/000442842
17. Sureka SK, Patidar N, Mittal V, Kapoor R, Srivastava A, Kishore K, et al. Safe and optimal pneumoperitoneal pressure for transperitoneal laparoscopic renal surgery in infant less than 10 kg, looked beyond intraoperative period: a prospective randomized study. *J Pediatr Urol*. (2016) 13:236. doi: 10.1016/j.jpurol.2017.01.003
18. Freilich DA, Houck CS, Meier PM, Passerotti CC, Retik AB, Nguyen HT. The effectiveness of aerosolized intraperitoneal bupivacaine in reducing postoperative pain in children undergoing robotic-assisted laparoscopic pyeloplasty. *J Pediatr Urol*. (2008) 4:337–40. doi: 10.1016/j.jpurol.2008.04.006
19. Finkelstein JB, Levy AC, Silva MV, Murray L, Delaney C, Casale P. How to decide which infant can have robotic surgery? Just do the math. *J Pediatr Urol*. (2015) 11:170.e1–4. doi: 10.1016/j.jpurol.2014.11.020
20. Passerotti CC, Nguyen HT, Retik AB, Peters CA. Patterns and predictors of laparoscopic complications in pediatric urology: the role of ongoing surgical volume and access techniques. *J Urol*. (2008) 180:681–5. doi: 10.1016/j.juro.2008.04.042
21. Gargollo PC. Hidden incision endoscopic surgery: description of technique, parental satisfaction and applications. *J Urol*. (2011) 185:1425–31. doi: 10.1016/j.juro.2010.11.054

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

ORIGINAL RESEARCH
published: 21 January 2019
doi: 10.3389/fped.2019.00001

Robotic Approach to Creation of Continent Catheterisable Channels—Technical Steps, Current Status, and Review of Outcomes

Ramnath Subramaniam [1,2,3]*

[1] *Consultant Paediatric Urologist, Leeds Teaching Hospitals NHS Trust, Leeds, United Kingdom,* [2] *Department of Paediatric Urology, University of Leeds, Leeds, United Kingdom,* [3] *Department of Paediatric Urology, University of Ghent, Ghent, Belgium*

Purpose: To report the current status of Robotic approach to creation of Catheterisable channel (CC) with the author's personal experience compared to published literature on technical steps, follow up, and outcomes.

Methods: CC data was extracted from the prospective database set up for all Robotic pediatric urology procedures performed by the author at his institution. A literature search was then performed to look at the evidence base.

Results: Eighteen consecutive cases (8M:7F) of Robotic approach to creation of CC was identified and included. All attempted cases were successfully completed without any conversion to open approach. Median age at surgery was 10.75 years (IQR 6.9–16.5); Median OT 197 min (IQR 131–295) with concomitant procedures in 4 cases. Appendix was used in 14 cases as CC conduit and distal ureter in 4 cases. Median Length of stay (LOS) was 2.75 days (IQR 2–6) and Median FU 27.3 m. Whilst FU duration is comparable to published series, average OT and LOS was much lower in this series. The LOS in this robotic series is much lower than the author's experience with open approach (2.75 vs. 5.8 days). No major complications postoperatively except for one exit site wound infection managed conservatively. None of the CC have been revised in this series and all channels are patent with 12 F or 14 F admissible catheter size. There were no cases of incontinence related to technique of creation of CC and no incidence of exit site stomal stenosis with use of ACE stopper until channel matures and Clean intermittent catheterisation (CIC) is established.

Conclusion: Robotic approach to CC is feasible, safe with excellent outcomes and minimum morbidity. Robotic complex bladder reconstructive surgery offers some advantages to children compared to open approach but is only currently performed in few tertiary centers with expertise.

Keywords: catheterisable channel, robotic approach, pediatric urology, outcomes - health care, current status

OPEN ACCESS

Edited by:
Miguel Alfedo Castellan, University of Miami, United States

Reviewed by:
Marcos Raymond Perez-Brayfield, University of Puerto Rico, Puerto Rico
Juan Manuel Moldes, Hospital Italiano de Buenos Aires, Argentina

Correspondence:
Ramnath Subramaniam
R.Subramaniam@leeds.ac.uk

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *09 November 2018*
Accepted: *03 January 2019*
Published: *21 January 2019*

Citation:
Subramaniam R (2019) Robotic Approach to Creation of Continent Catheterisable Channels—Technical Steps, Current Status, and Review of Outcomes. Front. Pediatr. 7:1. doi: 10.3389/fped.2019.00001

INTRODUCTION

Congenital and acquired affections to the bladder can lead to poor bladder emptying with attendant consequences of recurrent urinary tract infections, damage to renal upper tracts, and incontinence. Two vital landmark developments in the management of bladder emptying include Clean intermittent catheterization (CIC) per urethra introduced by Lapides in 1970s (1) and subsequent extension of this concept by Mitrofanoff to create catheterisable channel (CC) using appendix to facilitate bladder drainage when CIC per urethra is not feasible (2). Up until recently, open surgical approach was favored by most pediatric urologists with few reports of laparoscopic assisted attempt to create the channel. Robotics has recently provided an alternative with enhanced minimally invasive option in creating such channels with its attendant benefits (3, 4), not least to the surgeon due to ergonomics (5). This article looks at the author's personal experience with the Robotic approach, description of technical steps, and a review of published literature as regards potential benefits, current status and outcomes.

FIGURE 1 | Preoperative picture of a patient with caecostomy button *in situ* for bowel washouts. Port sites are marked- 12 Camera port in epigastrium; two 8 mm working ports on the respective hypochondrium; Exit site at right iliac fossa.

METHODS

The methodology in this paper is set in two parts. The first is the patient series from the author's personal experience and the second is the review of literature to ascertain outcomes when possible and define the current status of Robotic approach to CC comparing different studies along with the author's experience.

Patient Database

A prospective database collating all information with regards to author's personal experience with Robotic approach to all procedures in pediatric urology was set up since 2013. Informed and written consent was obtained from the patients or their legal guardian in this study. Information related to creation of CC within this database was extracted and analyzed. A comparison to Length of stay (LOS) with similar group of cases with an open approach was made to calculate cost analysis together with patient level cost (PLICS) data from the author's institution. Formal ethical committee is not required for this type of audit.

Literature Search

A search was done from Institutional library resources using terms "Robotic," "Mitrofanoff" and "Catheterisable channel" and restricted to pediatric age group.

TECHNICAL STEPS IN THE CREATION OF THE CC

The technical steps described below are the author's preferred approach recognizing there might be variations amongst other surgeons to the approach. At the outset, it is important to note that the author's preferred exit site for CC is right iliac fossa; some other surgeons might prefer the umbilicus. The robotic platform mentioned in this series is the Si Da Vinci system.

Patient and Robot Positioning

Patient is placed supine on the operating table with extreme side docking of the robot from the left side. The right side therefore is available for exit site incision and placement of large step port to facilitate retrieval of the channel into the exit site. This assumes appendix or the right ureter as the chosen conduit for the CC. Side docking, often to the extreme is a useful maneuver in pediatric patients and has the advantages of leaving the patient supine on the table and the robot can be docked from either side (6). This is particularly important in small theaters where space can be a constraint given that existing theaters do not cater for the footprint of Robotic surgical equipment.

Port Sites

The 12 mm camera port is placed in the midline of epigastric region to stay as far away as possible from target organs, namely the appendix and bladder. Two 8 mm working ports are placed in the right and left hypochondrium. The exit site is marked up with a "V"; this will eventually be used for the VQ plasty to facilitate skin lined stoma at exit site (**Figure 1**). During the procedure, a large (10–12 mm) step port is placed through the base of the exit site incision. This facilitates retrieval of the CC onto the exit site. Given the complex needs for these group of patients, particularly with bowel affection for e.g., Spina bifida cases, often they have a caecostomy in place for bowel management. In the author's institution, the caecostomy is fashioned with a button for washouts (if not effective per rectum). In the **Figure 1**, the child has a caecostomy button placed previously.

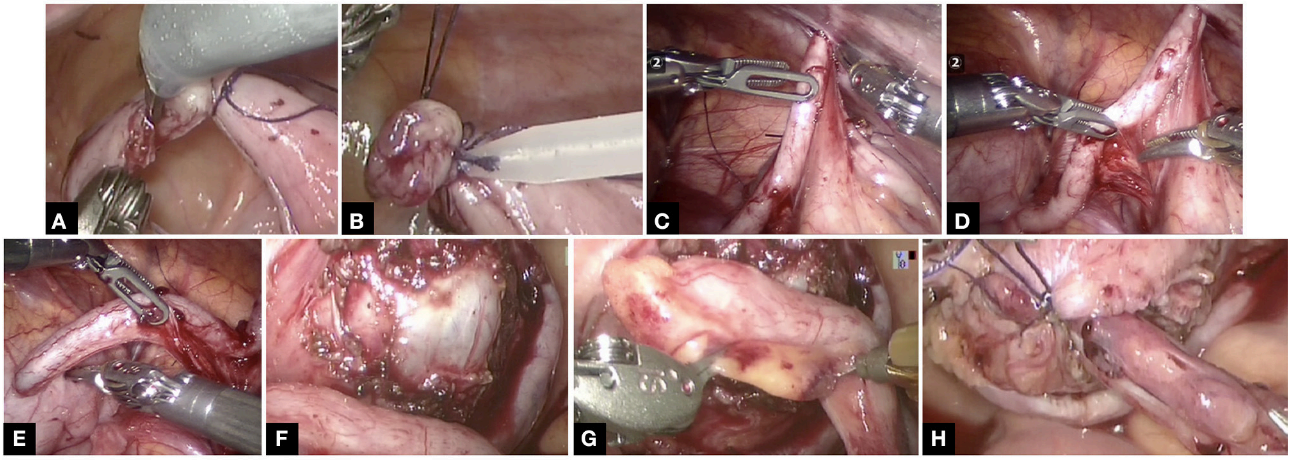

FIGURE 2 | The technical steps in the creation of CC is shown in this series of pictures. Note not all pics are from the same case study but does represent the relevant individual steps in the procedure. **(A)** Appendix divided from caecum with ligature at caecal base. **(B)** Endoloop to secure the caecal stump further. **(C)** Appendix routed into exit site. **(D)** Ensuring vascular pedicle on its mesentery is not under tension and adequately mobilized. **(E)** Appropriately sized Foley catheter inserted into appendix. **(F)** Adequately sized detrusorotomy performed. **(G)** Typically, a 4:1 ratio of detrusorotomy to length of appendix ensures continence to channel. **(H)** Extravesical implantation of the appendix completed.

Conduits for the Channel

It is generally agreed that appendix raised on its vascular pedicle is the best available conduit. The author has used the ureter in selected cases when a dilated tortuous ureter is available and there is no associated vesicoureteric reflux; when a nephroureterectomy has been performed for appropriate clinical indication or appendix is not available. The other option is to create a conduit with small bowel (Monti procedure); the author has no personal experience with this option by the Robotic approach. The outcomes from author's experience with appendix and ureter are detailed in the Results section.

Procedure

Once the ports are placed, the steps in creation of CC are illustrated in **Figure 2**. The appendix is mobilized on its vascular pedicle and divided from the caecum with a ligature and endoloop to secure the caecal stump. This is done through the step port placed by the assistant at the exit site. The appendix is then retrieved through the step port and an appropriately sized foley's catheter is placed into the lumen of the appendix. Typically, a 12 F catheter is placed, although in some cases, it might have to be a 10 F catheter, whilst some can accommodate 14 F catheter. However, this can later be sized up (if required) via fluoroscopy when CC is mature and established. Peritoneum over the bladder is opened and bladder mobilized and anchored with stay sure to the abdominal wall. A detrusorotomy is then performed to create a detrusor defect in the posterior wall of the bladder and facilitate extravesical implantation of the appendix. An incision at the proximal end of the detrusorotomy is made and the tip of the appendix is opened to allow the Foley catheter to be inserted into the bladder lumen and the balloon is inflated. The length of detrusor defect should be a minimum of 4:1 ratio in comparison to the width of the appendix. The appendix is anastomosed to bladder mucosa with 50 PDS sutures followed by the detrusor wrap using interrupted 40 PDS sutures, making sure that some stitches do incorporate the appendix to maintain the tunnel length within the detrusor. The peritoneum is then reposited making sure the CC is extraperitoneal. VQ-plasty is performed to fashion a skin lined exit site for the CC. The CC is accessible for CIC typically after 6 weeks once it is mature.

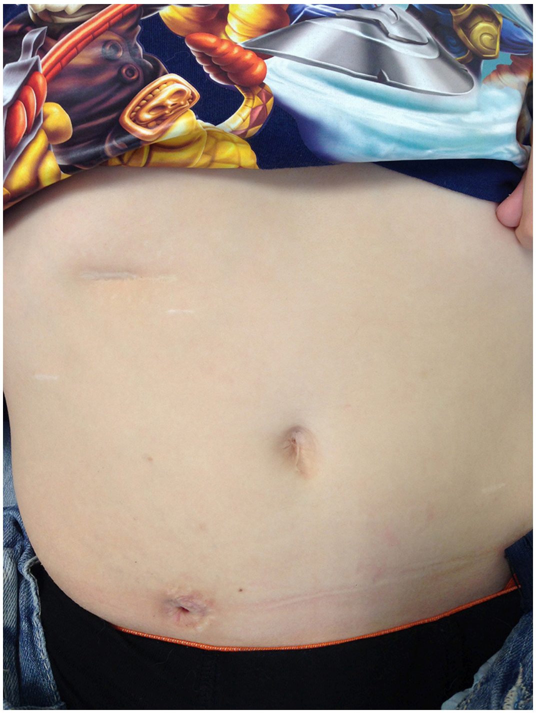

FIGURE 3 | Postoperative appearance of a child 6 months after creation of CC.

Post-operative Phase

All port sites are infiltrated with local anesthetic and none of the patients in this series have had epidural catheter for pain relief. The patients are allowed liquids the same afternoon with full feeds established shortly thereafter. The patients are discharged home with Foley catheter *in situ* via the CC. The Clinical nurse specialist supervises home care and starts CIC in ~6 weeks postop. A typical postoperative appearance of the CC approximately 6 months after the procedure is shown in **Figure 3**.

RESULTS

In this series, 18 children underwent procedure "Robotic approach to creation of CC." The demographic details for each of these patients are as shown in **Table 1**. All procedures attempted by Robotic approach were successfully completed and there were no open conversions. Literature search produced 6 relevant and comparable published reports summarized in **Table 2**, all retrospective studies from a total of 6 centers across USA. There is one multicenter series reporting an experience of 88 cases involving 5 tertiary children's hospital (12). Three papers highlighted in gray within **Table 2** are progressive reports over time from the same center in Chicago (led by Gundeti) (8–10). There is only one comparable series of CC procedure alone (7); all others have a mix of concomitant enterocystoplasty (EC). This makes the comparison challenging; nevertheless, the author has made an attempt to draw relevant conclusions from all the possible literature search yields.

Salient features from the author's series are the following:

a. Prospectively collected and analyzed data from a single surgeon series.
b. Exclusive report of Robotic approach to creation of CC without EC.
c. Median Operating time (OT) 197 min, much lower than 323 min from comparable series (Others have reported mean OT as 347 min for CC alone).
d. All patients in the author's series have had their CC exit site stoma sited at the iliac fossa.
e. No conversion to open and no immediate postoperative complications from the CC except one wound infection.
f. Median LOS is 2.75 days; lower than reported multicenter series at 5.2 days. Comparatively, average LOS for open cases in the authors institution was 5.8 days. As per PLICS data, average bed occupancy in the children's ward is ~£300/day. Therefore, with an average saving of £1,000 per patient episode from this series, that makes a saving of ~£15–18 K for the hospital by using the Robotic approach in this series alone.
g. Median FU is 27.3 months with the longest FU at 60 months and the average for the first 13 cases is 36.6 months i.e., over 3 years. All channels are patent currently with no incidence of exit site stomal stenosis. All patients use ACE stopper, the use of which has eliminated stomal stenosis as reported by the author in a previous publication many years ago (13).
h. Experience with using ureter in selected cases for CC conduit; out of 4 children with ureteric mitrofanoff (all boys), 2 of them (50%) complain of transient pain when catheter enters the bladder.
i. Three children have had some difficulty in accessing the CC at the very end toward its entry into the bladder at variable periods during FU. They underwent endoscopy to evaluate the channel ensuring patency and admitting 12 F catheter easily. One child who had 10 F catheter intraoperatively had interventional radiology support to upscale the catheter to 12 F, 4 months after the procedure.

DISCUSSION

This is a report of 18 consecutive cases with Robotic approach to creation of CC and is the first such report from a center outside the USA. Much of the published experience with the use of robot in pediatric urology is with pyeloplasty and upper tract procedures such as nephrectomy or heminephrectomy (3, 4, 14–17). Increasingly, the indications are expanding with reports on the use of robot for ureteric reimplantation (18–20).

The first description of the use of robot for creation of CC is a case report in 2004 (21). It then took a further 5 years before the publication of a series from a single center (7) and literature search for similar experience with the Robotic approach yields only a handful of published material, testifying that the experience with the use of robot for bladder reconstructive surgery is limited to few centers at this point in time. Moreover, the published material from some of the centers have a combination of EC together with CC, making the process of drawing definite conclusions at best challenging. Nevertheless, there are important points to highlight from the collective experience with common themes, variations in technique, and reported outcomes.

There is not a lot to dwell on indications for the procedure, fairly well-recognized and similar with the author's experience and published literature; and the age range at which surgery is performed is well-matched.

Technical Aspects of the Creation of CC

In children, port placements are key to successful completion of the procedure by the robotic approach, because the recommended 8–10 cm distance between ports in adults is not realistically achievable. The author routinely places three ports, one for the camera, and two working ports corresponding to three arms of the robot as is the preference for other surgeons in published literature except for Grimsby et al. (11) where they prefer a 4th arm is deployed for assistance. In a pediatric program, the 4th arm is pretty much redundant for majority of the procedures. Some suggest use of a 5 mm laparoscopic port to exchange sutures (7), but the author relies on the assistants to exchange sutures via the working port, which of course needs excellent team effort. The author cannot emphasize enough the role of a well-trained first assistant as regards efficiency and minimizing the need for additional port in an already cramped set up. The benefits of side docking in pediatric robotic program and alluded to in the technical aspects earlier in the report has been published elsewhere (6).

TABLE 1 | Summary of the author's experience with Robotic approach to creation of CC.

		Comments
No of cases (Gender)	18 (8M:7F)	Consecutive cases with Robotic approach
Median age at op (IQR)	10.75 (6.9–16.5)	Clinical indication–neurogenic (10) valve bladder (3) and others (5)
No of ports	3	Additional Step port at exit site to retrieve channel
Median OT (IQR)	197 min (131–295)	4 concomitant procedures—1 nephroureterctomy; 1 caecostomy button for bowel management; 1 proximal ureter reimplant with distal ureter as CC; 1 detrusorotomy (autoaugmentation)
Exit site VQ plasty	18	4 had caecostomy button *in situ* pre-op and 1 had concomitant caecostomy button inserted during this episode.
Channel size (Foley catheter)	10 F—1	10 F channel was later upscaled to 12 F by interventional radiology team after 4 months.
	12 F—13	
	14 F—4	
Channel conduit	14 appendix and 4 distal ureter	(When Ureters used for CC- 1 had nephroureterectomy and 3 others had proximal ureteric reimplant)
Conversion to open	0	
Median LOS (IQR)	2.75 (2–6)	Comparative open cases LOS 5.8 days
Complications post op	1	1 Wound infection at exit site; managed conservatively with antibiotics; No revision of CC in this series.
Median FU	27.3 m	Longest FU is 60 m; in total first 13 patients have a median FU of 36.6 months. Last 5 patients have relatively short FU of <12 m.
Stomal stenosis	0	All patients use ACE stopper post op until channel matures in few months and CIC pattern established
Channel patency	18	3 patients had difficulty in accessing channel at entry into bladder; endoscopy confirmed no issues and 12 F Foley inserted easily. No sub-fascial channel issues.

CC, Catheterisable channel; FU, Follow up; OT, Operating time; LOS, Length of stay in hospital post-op.

One important difference in this series is where the ports are placed. The author places the camera 12 mm port at the midline in the epigastric region and two ports on the hypochondrium to stay further away from the target organs, bladder, and appendix. In comparison, all the other surgeons (in published literature) place the ports much closer to the target organs with the camera port at the umbilicus. It is also worth noting that the ureter has been used as a conduit in selected cases in this series, the use of which has raised some observations and is further explained in the outcomes section Follow up and Outcomes.

It appears in those published series in **Table 2**; the exit site is preferentially the umbilicus whilst the author routinely sites the exit stoma in the iliac fossa. The use of step port to retrieve the conduit onto the exit site is another variation in the author's practice. It is difficult to know for sure, but it appears that the author's technique described earlier has contributed to a much lower median OT at <200 min compared to >300 min in other reported series (7, 22).

Incidence of concomitant EC is high in the reports especially from Chicago group (9, 10, 22) and the multicenter report (12) where there is a 15% incidence of EC and 39% incidence of bladder neck procedures (BNP). Therefore, this series is matched and comparable only to the report from Boston group Nguyen et al. (7) with regards to creation of CC without concomitant EC. It is interesting to note when comparing open and Robotic approach to CC, Grimsby et al. in their series report an incidence of concomitant EC is 54% in the open group vs. 3% in the Robotic group (11). This could be explained by the complexity of adding EC to the procedure at the same setting, given that the Chicago group led by Gundeti report mean OT at 623 min with EC compared to 347 with CC alone (8–10). To put into perspective, that is over 10 h of operating with EC, one of the main reasons for the limited experience with such complex reconstructive procedures.

In this series, the site of implantation of the CC in to the bladder is in the posterior wall with the bladder hitched up ensuring straight run off to the exit site. Interestingly, Famakinwa et al. from the Chicago group (9) mention the difference in implantation site if the CC is performed concomitantly with EC; the anterior wall is preferred if CC is done alone and the posterior wall if combined with EC.

Postoperative Phase and Complications

Murthy et al. have highlighted the advantages of using the robot in this procedure with reduced hospital stay and eliminating the need for epidural (10), which the author is in complete agreement.

The average LOS is much lower in the author's series at 2.75 days compared to 5.2 days in the multicenter series (12). In the healthcare setting within the UK, LOS is crucial to costs and by reducing the LOS with robotic approach compared to open (2.7 vs. 5.8 days as explained in the results section), significant savings have been made

TABLE 2 | Summary of published articles on robotic approach to CC.

References	CC	EC	No of CC cases (MedianAge at surgery)	Summary of findings (All retrospective reviews from USA and vast majority of cases in these series had umbilical exit site stoma)
Nguyen et al. (7)	Yes	No	10 (11.9 y)	Mean OT 323 min; one conversion to open; Median Hosp stay 5 days; Median FU 14.2 m; one open revision due to urine leakage post op; minor channel incontinence 2 cases. Comparison with open cases-no difference
Wille et al. (8)	Yes	Yes (5)	11 (10.4 y)	Reports from same center over time; mean OT 494 min; 639 with EC and 347 min without EC; Median FU 24.2 m; Robot advantages: reduced hospital stay and eliminates epidural. Minimum recommended detrusor wrap length 4 cm. Appendix on anterior wall if without EC; otherwise posterior wall.
Famakinwa et al. (9)	Yes	Yes (10)	18 (11.7 y)	
Murthy et al. (10)	Yes	Yes (15)	11 (11 y)	
Grimsby et al. (11)	Yes	Yes	39 (9.1 y)	Comparison of complications between open (28) cases; 54% EC in open cases and 3% in Robotic; Median FU 2.7 y; no significant difference in complication rates between open and robotic; 3 Clavien III complications in Robotic series.
Gundeti et al. (12)	Yes	Yes (15%)	88 (10.4 y)	Multi center series; Mean FU 29.5 m; LOS 5.2 days; 29.5% complication rate; 6 Clavien III; 12% CC revision rate; Mean detrusor length 3.9 cm ± 1.0.

CC, Catheterisable channel; EC, Enterocystoplasty; FU, Follow up; OT, Operating time; LOS, Length of stay in hospital post-op. Gray shaded rows indicate progressive over time reports from same institution.

in the author's series. This is important when it comes to working collaboratively with the management to realize the feasibility of a robotic program as also observed by others (23). Differences in healthcare worldwide could explain the paucity of reports linked to affordability from centers outside USA.

In this series, there has been no conversion to open and no major immediate postoperative complications except for an exit site wound infection in one case unlike a reported 29.5% complication rate with 6 Clavien III episodes from the multicenter series (12). It must be noted that they had concomitant 17% EC and 39% BNP. However, Grimsby et al. also reported 3 Clavien III complications in the Robotic group of their series (11). Nguyen et al. report one conversion to open in their series with 10 cases with one post-op urinary leak (7).

Follow Up and Outcomes

The mean FU is 27.3 m in this series and is comparable to the FU in the multicenter study of 29.5 m (12). The longest FU in this series is 60 months and the first 13 cases have over 3 years FU. This should be sufficient time to look at outcomes given that majority of the revisions occur in the first 24 months (24, 25). Although this point is highlighted by Nguyen et al. in their report, their FU of just 14.2 m is relatively short (7). There have been no revisions of the CC or the exit site in this series. This is significant compared to 12% CC revision rate in the multicenter study (12). Grimsby et al. report ∼30% reoperation rates in both open and Robotic groups, although the reasons behind them is varied (11). They also have had 10% incontinence rates in the robotic group. It is difficult to know from the available reports whether the CC incontinence was technique related or due to other factors such as bladder dynamics.

There was no incidence of incontinence attributable to the technical aspects of CC in this series and it is worth mentioning the emphasis by the author on a minimum ratio of 4:1 when constructing then channel. The length of detrusor wrap is recognized as an important factor by others with a recommended length of 4 cm to ensure continence (8, 12). The author prefers to relate it to the width of the appendix akin to the principle with a ureteric reimplantation procedure.

It is important to mention that 4 boys in this series have had distal ureter as a CC conduit and 2 of them (50%) have reported considerable transient pain at point of entry into the bladder and 2 other boys (50%) in this series use the ureteric CC with no discomfort. This is also the author's experience with open cases and therefore now re-evaluating the use of ureter.

The author has published previously his experience with ACE stopper in the postoperative period (13) and this practice has continued over the years with stomal stenosis virtually eliminated and as is the case in this series. Wille et al. have reported 3 exit site revisions in their series of 11 cases (27%) (8). There is no incidence of CC access issues at sub-fascial plane in this series or other series with Robotic approach compared to reports by Indiana group who have the largest experience with CC using the open approach (26). Plausible explanation could be the direct alignment of the channel from within the abdomen with the robotic approach.

Summary

This is the first report of Robotic approach to CC from outside of USA with comparable outcomes and together with the collective experience from published literature albeit from few centers establishes the role of Robotics in creation of CC. There are common themes with some variation in technical aspects but the main advantages being reduced hospital stay and avoiding the need for invasive pain relief such as epidural compared to open approach. The series in this report has the lowest mean OT and LOS, both contributing to cost savings from a healthcare economic model point of view. The experience with robotic approach is limited to tertiary centers currently but there is sufficient expertise to allow other aspiring centers to take advantage of and avail the proctorship to facilitate safe introduction of complex reconstructive surgery into their individual Robotic program (27). This can only enhance the quality of care provided over time within pediatric urology.

ETHICS STATEMENT

This study material is part of an audit within the department. Informed consent for figures was obtained as per institution guidelines.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

REFERENCES

1. Lapides J, Diokono AC, Lowe BS, Kalish MD. Follow up on unsterile, intermittent self-catheterization. *J Urol.* (1974) 111:184. doi: 10.1016/S0022-5347(17)59922-X
2. Mitrofanoff P. Trans-appendicular continent cystostomy in the management of the neurogenic bladder. *Chir Pédiatrique* (1980) 21:297–305.
3. Orvieto MA, Large M, Gundeti MS. Robotic paediatric urology. *BJU Int.* (2012) 110:2–13. doi: 10.1111/j.1464-410X.2011.10877.x
4. Howe A, Kozel Z, Palmer L. Robotic surgery in pediatric urology. *Asian J Urol.* (2017) 4:55–67. doi: 10.1016/j.ajur.2016.06.002
5. Esposito C, Ghoneimi AE, Yamataka A, Rothenberg S, Bailez M, Ferro M, et al. Work-related upper limb musculoskeletal disorders in paediatric laparoscopic surgery. A multicenter survey. *J Pediatr Surg.* (2013) 48:1750–6. doi: 10.1016/j.jpedsurg.2013.01.054
6. Subramaniam R. Current use of and indications for robot-assisted surgery in paediatric urology. *Eur Urol Focus* (2018) 4:662–4. doi: 10.1016/j.euf.2018.08.020
7. Nguyen HT, Passerotti CC, Penna FJ, Retik AB, Peters CA. Robotic assisted laparoscopic mitrofanoff appendicovesicostomy: preliminary experience in a pediatric population. *J Urol.* (2009) 182:1528–34. doi: 10.1016/j.juro.2009.06.055
8. Wille MA, Zagaja GP, Shalhav AL, Gundeti MS. Continence outcomes in patients undergoing robotic assisted laparoscopic mitrofanoff appendicovesicostomy. *J Urol.* (2011) 185:1438–43. doi: 10.1016/j.juro.2010.11.050
9. Famakinwa OJ, Rosen AM, Gundeti MS. Robot-assisted laparoscopic mitrofanoff appendicovesicostomy technique and outcomes of extravesical and intravesical approaches. *Eur Urol.* (2013) 64:831–6. doi: 10.1016/j.eururo.2013.05.007
10. Murthy P, Cohn JA, Selig RB, Gundeti MS. Robot-assisted laparoscopic augmentation ileocystoplasty and mitrofanoff appendicovesicostomy in children: updated interim results. *Eur Urol.* (2015) 68:1069–75. doi: 10.1016/j.eururo.2015.05.047
11. Grimsby GM, Jacobs MA, Gargollo PC. Comparison of complications of robot-assisted laparoscopic and open appendicovesicostomy in children. *J Urol.* (2015) 194:772–6. doi: 10.1016/j.juro.2015.02.2942
12. Gundeti MS, Petravick ME, Pariser JJ, Pearce SM, Anderson BB, Grimsby GM, et al. A multi-institutional study of perioperative and functional outcomes for pediatric robotic-assisted laparoscopic Mitrofanoff appendicovesicostomy. *J Pediatr Urol.* (2016) 12:386.e1–e5. doi: 10.1016/j.jpurol.2016.05.031
13. Subramaniam R, Taylor C. The use of an antegrade continence enema stopper in catheterizable channels virtually eliminates the incidence of stomal stenosis: preliminary experience. *J Urol.* (2009) 181:299–301. doi: 10.1016/j.juro.2008.09.038
14. Cundy TP, Harling L, Hughes-Hallett A, Mayer EK, Najmaldin AS, Athanasiou T, et al. Meta-analysis of robot-assisted vs conventional laparoscopic and open pyeloplasty in children. *BJU Int.* (2014) 114:582–94. doi: 10.1111/bju.12683
15. Spinoit A-F, Radford A, Ashraf J, Gopal M, Subramaniam R. Modified tubularized incised plate urethroplasty in distal hypospadias repair: stepwise technique with validated functional and cosmetic outcome. *J Pediatr Urol.* (2017) 13:86–7. doi: 10.1016/j.jpurol.2016.09.014
16. Silay MS, Spinoit AF, Undre S, Fiala V, Tandogdu Z, Garmanova T, et al. Global minimally invasive pyeloplasty study in children: results from the pediatric urology expert group of the european association of urology young academic urologists working party. *J Pediatr Urol.* (2016) 12:229. e1–7. doi: 10.1016/j.jpurol.2016.04.007
17. Monn MF, Bahler CD, Schneider EB, Whittam BM, Misseri R, Rink RC, et al. Trends in robot-assisted laparoscopic pyeloplasty in pediatric patients. *Urology* (2013) 81:1336–1341. doi: 10.1016/j.urology.2013.01.025
18. Esposito C, Masieri L, Steyaert H, Escolino M, Cerchione R, La Manna A, et al. Robot-assisted extravesical ureteral reimplantation (revur) for unilateral vesico-ureteral reflux in children: results of a multicentric international survey. *World J Urol.* (2018) 36:481–8. doi: 10.1007/s00345-017-2155-9
19. Boysen WR, Akhavan A, Ko J, Ellison JS, Lendvay TS, Huang J, et al. Prospective multicenter study on robot-assisted laparoscopic extravesical ureteral reimplantation (RALUR-EV): outcomes and complications. *J Pediatr Urol.* (2018) 14:262.e1–6. doi: 10.1016/j.jpurol.2018.01.020
20. Marchini GS, Hong YK, Minnillo BJ, Diamond DA, Houck CS, Meier PM, et al. Robotic assisted laparoscopic ureteral reimplantation in children: case matched comparative study with open surgical approach. *J Urol.* (2011) 185:1870–5. doi: 10.1016/j.juro.2010.12.069
21. Pedraza R, Weiser A, Franco I. Laparoscopic appendicovesicostomy (Mitrofanoff procedure) in a child using the da Vinci robotic system. *J Urol.* (2004) 171:1652–3. doi: 10.1097/01.ju.0000116066.72132.9a
22. Wille MA, Jayram G, Gundeti MS. Feasibility and early outcomes of robotic-assisted laparoscopic Mitrofanoff appendicovesicostomy in patients with prune belly syndrome. *BJU Int.* (2012) 109:125–9. doi: 10.1111/j.1464-410X.2011.10317.x
23. Murthy PB, Schadler ED, Orvieto M, Zagaja G, Shalhav AL, Gundeti MS. Setting up a pediatric robotic urology program: a USA institution experience. *Int J Urol.* (2018) 25:86–93. doi: 10.1111/iju.13415
24. Welk BK, Afshar K, Rapoport D, MacNeily AE. Complications of the catheterizable channel following continent urinary diversion: their nature and timing. *J Urol.* (2008) 180(Suppl. 4):1856–60. doi: 10.1016/j.juro.2008.03.093
25. Jacobson DL, Thomas JC, Pope J, Tanaka ST, Clayton DB, Brock JW, et al. Update on continent catheterizable channels and the timing of their complications. *J Urol.* (2017) 197:871–6. doi: 10.1016/j.juro.2016.08.119
26. Szymanski KM, Lopez PJ, Corbetta JP, Reed F, Ruiz J, Pullin Y, et al. Do anterior catheterizable urinary channels have fewer complications than posterior channels? An international cohort study. *J Pediatr Urol.* (2018) 14:48.e1–7. doi: 10.1016/j.jpurol.2017.06.020
27. Bowen DK, Lindgren BW, Cheng EY, Gong EM. Can proctoring affect the learning curve of robotic-assisted laparoscopic pyeloplasty? Experience at a high-volume pediatric robotic surgery center. *J Robot Surg.* (2017) 11:63–7. doi: 10.1007/s11701-016-0613-9

Conflict of Interest Statement: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

MINI REVIEW
published: 24 January 2019
doi: 10.3389/fped.2019.00004

Current Concepts in Pediatric Robotic Assisted Pyeloplasty

*Ramphis A. Morales-López [1,2], Marcos Pérez-Marchán [1,2] and Marcos Pérez Brayfield [1,2]**

[1] Division of Urology, Department of Surgery, University of Puerto Rico School of Medicine, San Juan, PR, United States,
[2] HIMA-San Pablo Group, Caguas, PR, United States

Robotic surgery in pediatric urology has been gaining popularity since its introduction almost two decades ago. Robotic assisted pyeloplasty is the most common robotic procedure performed in pediatric urology. Advances in robotic technology, instrumentation, patient care and surgical expertise have allowed the correction of ureteropelvic junction (UPJ) obstruction in most patients using this minimally invasive technique. The excellent experience with robotic assisted pyeloplasty has challenged other approaches as a new standard for the treatment of UPJ obstruction. In this review, we will describe the technique as it relates to the different robotic platforms, review the surgical experience and compare its results to other surgical approaches. Also, we will discuss patient and parent satisfaction, cost and financial considerations, along with evaluating the future of robotic surgery in the treatment of UPJ obstruction.

Keywords: pediatric urology, robotics, pyeloplasty, UPJ obstruction, children

OPEN ACCESS

Edited by:
Miguel Alfedo Castellan, University of Miami, United States

Reviewed by:
Aseem Ravindra Shukla, Children's Hospital of Philadelphia, United States
Baran Tokar, Eskişehir Osmangazi University, Turkey

****Correspondence:***
Marcos Pérez Brayfield
mperezb1@yahoo.com

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *20 November 2018*
Accepted: *09 January 2019*
Published: *24 January 2019*

Citation:
Morales-López RA, Pérez-Marchán M and Pérez Brayfield M (2019) Current Concepts in Pediatric Robotic Assisted Pyeloplasty. Front. Pediatr. 7:4. doi: 10.3389/fped.2019.00004

INTRODUCTION

Despite its recent beginnings, robotic assisted surgery has been progressing in the treatment of many conditions in pediatric urology. Since the introduction of laparoscopic pyeloplasty in 1993 in adults and 2 years later in the pediatric population, minimally invasive laparoscopic approach for the treatment of ureteropelvic junction obstruction (UPJO) became an evident viable option. In 1994, the first robotic system used in the urological practice known as AESOP was introduced. Later, the evolution of these devices would bring the Zeus system and finally the Da Vinci system while continuously increasing their precision and effectivity (1). This new surgical approach was embraced by doctors throughout the US and promoted a statistical increase in use throughout the country (2).

When compared to classical laparoscopic surgery, robotic assistance offers several benefits. Tremor cancellation, three-dimensional vision and 7° of freedom allow the surgeon to optimally perform in confined working spaces such as those found during pediatric surgery while executing precise and delicate movements with ease (3). In 2002, the first pediatric robotic procedure performed was the robotic laparoscopic pyeloplasty (4). The high incidence of UPJO combined with the surgeons' previous experience with the laparoscopic approach naturally made it a pioneer procedure for robotics in pediatric urology.

Until now, the gold standard method for treating UPJO is open dismembered pyeloplasty with a success rate between 90 and 100%. Laparoscopic pyeloplasty had gain popularity but it struggled to be adopted by many pediatric urologists because of its technical difficulty and tedious learning curve. However, robotic assisted laparoscopic pyeloplasty (RALP) had all the advantages of the laparoscopic approach with an ease of use and a much shorter learning curve. This allows some surgeons to transition from open pyeloplasty to a minimally invasive robotic approach without any previous laparoscopic experience. RALP has been the most commonly reported robotic procedure in children to date (5). In this review, we will describe the technique as it relates to the different robotic platforms, review the surgical experience over the last 5 years and compare its results to other surgical approaches. Also, we will discuss patient and parent satisfaction, cost and financial considerations, along with evaluating the future of robotic surgery in the treatment of UPJ obstruction.

BACKGROUND

UPJO is a common cause of pediatric hydronephrosis occurring in 1 per 1,000–2,000 newborns (6). Widespread use of antenatal ultrasonography (US) and the increase availability of postnatal imaging have resulted in earlier and more frequent diagnosis of hydronephrosis. UPJO is found more commonly in boys than in girls with up to 67% of cases involving the left kidney, and up to 10% seen bilaterally (7). Renal dysplasia, multicystic dysplastic kidney, duplicated renal collecting system where the lower pole UPJ is usually the obstructed segment; horseshoe kidney; and ectopic kidney have been found in association with UPJO. The etiology can be described as lesions that involve the UPJ intrinsically, lesions that are extrinsic or a combination of both.

The initial postnatal evaluation is performed with a renal/bladder US in order to determine the presence of pelvocalyceal dilation with or without renal cortical thinning. The most widely used grading systems of the severity of hydronephrosis on US are the Society of Fetal Urology (SFU) system and the Anterior/Posterior (AP) diameter of the renal pelvis. In 2014, a multidisciplinary consensus group developed the urinary tract dilation (UTD) classification system pertinent to antenatal and postnatal evaluation. The new classification incorporated the following six US parameters: AP renal pelvis diameter (APD), calyceal dilation, renal parenchymal thickness, renal parenchymal appearance, bladder abnormalities, and ureteral abnormalities (8).

Diuretic renography is the most widely used non-invasive technique to determine the severity and functional significance of UPJ obstruction (9). Technetium-99 m mercaptoacetyltriglycerine (^{99m}Tc-MAG3) is the ideal tracer for the pediatric population. One of the most useful measurements in diuretic renography is the estimate of differential renal function. This is considered significant when it is <40%. This percentage usually is well-correlated with the half-life (T1/2) washout curve.

Other than US and MAG3 renal scan there are other imaging and diagnostic tests also less commonly utilized for diagnosis of UPJO. Magnetic resonance imaging has been used by some center as their study of choice to evaluate UPJO (10). Developments in magnetic resonance imaging (MRI) technology have made it possible to image kidneys while assessing anatomy, renal transit times as well as intracellular metabolic parameters independent of blood flow and tubular function.

Indications for surgical interventions are ipsilateral UPJO with <40% of differential renal function (DRF) on diuretic renography, bilateral severe UPJO with renal parenchymal atrophy, obstructive pattern on diuretic renography with abdominal mass, urosepsis, or cyclic flank pain with or without vomiting and recurrent UTI under antibiotic prophylaxis.

Robotic Assisted Laparoscopic Pyeloplasty (RALP)

RALP is now a well-established method of correcting UPJO (5). It has the advantage of being able to help overcome the difficulties encountered with laparoscopic dissecting and suturing. The basic principle is similar to that of laparoscopic pyeloplasty but facilitated by 3-D imaging and the help of an articulated instrument. The operative technique has evolved to the point where RALP can be successfully performed in most pediatric patients. Some limitations could be encountered in infants <5 mo. or patients with a small abdominal cavity due to the limited available working space.

Positioning

The procedure starts with a crucial element for success: proper positioning of the patient. The patient is positioned at the edge of the table with the arms resting on a folded arm board. This will allow the robot arms to use their full range without table interference. Our preferred patient position is the 45° or modified flank position. This position with the use of the table rotation allow access and trocar placement in a near supine position avoiding potential complications. Also, this position allows for the intraabdominal contents to move away from the surgical site. We use two large jelly rolls to support the patient's back with the upper arm placed across the body in a praying position. The lower leg is bended at a 90° angle and the upper leg is straight. It is of outmost importance that the patient is well-padded specially between the legs, arms, and face. The patient is secured to the table with wide tape across the arms and shoulders, chest, hip, knee, and ankles. Care is taken not to place tape directly on patient's skin. With the help of the anesthesiologist, proper positioning, and adequate access to the patient's airway and IV lines are confirmed before the start of the procedure.

Initial Access, Insufflation, and Trocar Placement

With the table tilted away from the surgeon' side, the access is performed on a nearly flat patient. Our preferred approach is percutaneous using the Veress needle. Others have preferred the open Hassan technique for smaller children (11). After CO_2 insufflation to 8–10 mmHg, a 5 mm optical trocar is placed under direct vision in the infraumbilical position allowing easy and safe access. The port position for robotic assisted laparoscopic pyeloplasty will be in straight line for most patients using the DaVinci Xi system (**Figure 1**). The 8 mm robotic trocars are placed under direct vision with the last trocar replacing the infraumbilical trocar. With the DaVinci Xi, the trocar should have at least 3 cm of separation in order to avoid robotic arms collision. Other have described the best trocar position for the Si system which needs to be modified depending on the patient's size. Several options include straight line, triangulation, and HIDES (12). The HIDES trocar positioning allows for better cosmetic results with an infraumbilical port and 2 additional

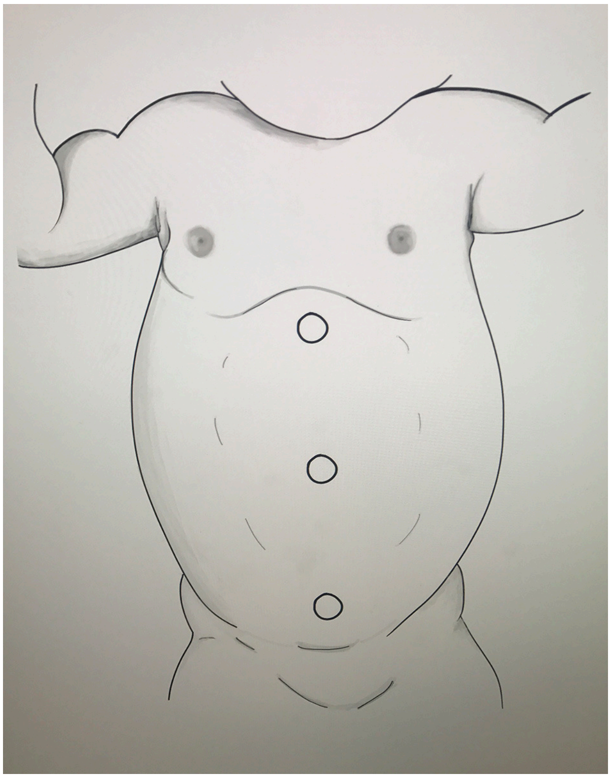

FIGURE 1 | DaVinci Xi port placement for RALP (Drawing by Carla Fernandez).

lower abdominal ports. "Burping" of all ports will give additional intraabdominal space needed in order to successfully perform the procedure on smaller children.

Docking With Si and Xi Systems

RALP requires the Xi robotic system to be docked at a 90° angle to the patient at the level of the infraumbilical port (camera site). We preferred to keep the robot at an established position and rotate the arms of the robot to adjust to the surgical site without moving the operating table. This allows the head of the patient to remain in the standard position and close to the anesthesiologists. Alternatively, the table could be rotated 180° to allow docking without rotation of the robotic arms. With the Si robotic system, the robot will need to be repositioned to come in a straight line with the camera site, trocar and the surgical site. As an example, the HIDES port placement the robot will dock from the inferolateral position (13).

Surgical Technique and Stent

Cystoscopy with a retrograde pyelogram can be performed selectively at the start of the procedure. Indication for cystoscopy with retrograde pyelogram included complex anatomy (ectopic/horseshoe kidney) and need to clarify preoperative testing. Our preferred surgical technique for the corrections of UPJO is the dismembered pyeloplasty. The procedure follows the same surgical principles described in the laparoscopic pyeloplasty (14). Instruments used during the procedure include: 2 dissecting forceps, scissors, 2 needle drivers, and a suction device. The approach to the UPJ area can be transmesenteric for left sided UPJO or with medial mobilization of the colon for Right sided UPJO and with selected complicated left sided UPJO. Caution is needed during the initial dissection of the UPJ area to avoid injury to a lower pole crossing vessels. Tethered stitches using 3-0 prolene on a CT needle can be placed to the renal pelvis and proximal ureter to help with exposure and ease of the operation. We preferred to place a stent in all patients undergoing robotic assisted pyeloplasty. The stent can be placed in an antegrade or retrograde fashion depending on the surgeon's preference.

Postop Care and Follow up

Indwelling urethral catheter is removed on POD # 1. Most patients are discharged within 24 h if they are able to void, tolerate diet and have adequate pain control. The ureteral stent is removed 6 weeks after the operation. Renal and bladder ultrasound is performed at 2 weeks., 3 mo., and 6 mo. post operatively. MAG-3 renal scan is reserved for symptomatic patients or significant residual hydronephrosis after 3 mo. follow up. Asymptomatic patients with residual hydronephrosis and good renal interval growth are followed with a renal and bladder ultrasound until resolution.

EXPERIENCE AND RESULTS

We retrospectively reviewed our experience with RALP using the DaVinci Xi robotic platform. We identified 41 patients with a mean age of 10.9 years (7 mo.—17 years). Ten patients were <1 year of age. Left RALP was performed in 27 patients and a right pyeloplasty in 14 patients. All procedures were performed using a transperitoneal approach. Our mean operative time was 135 min with a mean hospital stay of 1.5 days. The overall success rate for our series was 95%. Two patients had persistent SFU IV hydronephrosis requiring redo laparoscopic pyeloplasty and balloon dilatation, respectively. Four patients had post-operative complications including stent pain in 2 and non-obstructive small renal stone in 2. None of the patients less than a year of age had any complications. Residual hydronephrosis was identified in 29% of the patients.

Multiple authors have reported strong series with RALP (**Table 1**). A series of studies performed over the last decade show that when compared to open and laparoscopic pyeloplasty, the robotic assisted procedure has performed well in the treatment of UPJO (**Table 2**). These studies have shown comparable success rates with no statistically significance between the modalities.

In comparison to open or laparoscopic pyeloplasty, robotic pyeloplasty typically exhibit shorter hospital stay and less use of medication for pain management following the procedure (4). The only consistent negative variable has been the longer operative times exhibited by the robotic approach as compared to other modalities. Operative times seems to improve in center with high volume and surgeon's experience.

TABLE 1 | Series of reported robotic-assisted laparoscopic pyeloplasty cases.

Author	Procedure	# of pts	Mean age (yrs)	Laterality UPJ	Approach	Mean op time (min)	Hospital stay (days)	Complications	Success rate (%)
Kutikov et al. (15)	RALP	9	0.47	n/a	Transperitoneal	122.8	1.4	n/a	78
Avery et al. (16)	RALP	60	0.61	Bilateral (2)	Transperitoneal	232	1	7	91
Asensio et al. (17)	RALP	5	10.59	n/a	Transperitoneal	144	2.6	n/a	100
Olsen et al. (18)	RALP	65	7.9	n/a	Retroperitoneal	146	2	11	100
Minnillo et al. (19)	RALP	155	10.5	n/a	n/a	198.5	1.9	17	96
Singh et al. (20)	RALP	34	12	n/a	n/a	105	n/a	2	97
Atug et al. (21)	RALP	7	13	n/a	Transperitoneal	184	1.2	1	100
Franco et al. (22)	RALP	15	11.9	n/a	Transperitoneal	223	n/a	4	n/a
Perez-Brayfield	RALP	41	10.2	Right (14), Left (27)	Trans	135	1.5	5	95%

TABLE 2 | Series of reported cases comparing open pyeloplasty, laparoscopic pyeloplasty, and robotic-assisted laparoscopic pyeloplasty.

Author	Procedure (OP, LAP, RALP)	# of patients	Mean age (yrs)	Laterality UPJ	Approach	Mean operative time (min)	Hospital stay (days)	Complications	Success rate (%)
Barbosa et al. (23)	RALP	58	7.2	Bilateral (10)	Transperitoneal	n/a	n/a	1	76.9
	OP	154	1.2	n/a	n/a	n/a	n/a	7	67.9
Yee et al. (24)	RALP	8	11.5	n/a	n/a	363	2.4	1	100
	OP	8	9.8	n/a	n/a	248	3.3	0	87.5
Subotic et al. (25)	OP	8	9.8	n/a	n/a	248	3.3	0	87.5
Lee et al. (26)	RALP	33	7.9	n/a	n/a	219	2.3	1	94
	OP	33	7.6	n/a	n/a	181	3.5	0	100
Song et al. (27)	OP	30	8.5	Right (8), Left (22)	Transperitoneal	192.5	6.6	4	96.7
	LP	30	10.5	Right (6), Left (24)	Transperitoneal	197.4	5.8	4	89.7
	RALP	10	11	Right (3), Left (7)	Transperitoneal	254.1	3.2	1	100
Cundy et al. (28)	OP vs. RALP	157,166	7, 8.1	n/a	n/a	RALP (Longer OT)	RALP (shorter HS)	5, 9	88.5, 87.3
	LP vs. RALP	97, 151	6.5, 10	n/a	n/a	no significant diff.	RALP (shorter HS)	10, 10	96.9, 99.3
Salö et al. (29)	OP	92	6.2	Right (38), Left (54)	n/a	167	4.4	25	92
	RALP	31	8.3	Right (10), Left (21)	Retro (15), Trans (16)	249	3.4	9	94

COSTS AND CONSIDERATIONS

Several studies have delved into the evaluation of costs of the treatment options for UPJO. Some studies have even suggested a 2.7 time increase in cost in RALP as compared to other modalities of UPJO (30). In 2017 Jacobs et al. (31) published a cost analysis study in adult patients showing fairly similar costs for open pyeloplasty ($22,421) as compared to minimally invasive pyeloplasty ($22,843). Varda and colleagues evaluated the national trends of UPJO treatment modalities in children including analysis of the available data on cost (32). They reported evidence of an increasing trend toward utilization of minimally invasive pyeloplasty over open pyeloplasty. In the study, minimally invasive modalities had an increased cost with a significant increase in price related to RALP. Operating room costs were by far the greatest contributor to costs, with robotic supplies being the largest contributor to the rising cost. For example, when comparing laparoscopic vs. robotic approaches there was an average increase in costs of over $3,000.

In another study, Varda et al. again demonstrated an increased utilization of the RALP in children (33). They showed that within a 12-year period there was a persistent higher cost when RALP was compared with open pyeloplasty. The increased cost in RALP over open pyeloplasty persisted as the cost of operating room equipment for robotic cases remained high even when considering the cost associated with longer hospital stays related to open surgery. High volumes of RALP may be required for institutions to profit from the procedures as total investment cost is divided between an increased number of procedures performed. An estimated three to five robotic cases per week are necessary to profit from robotic surgery, which is a clear limitation for pediatric centers no matter their size (34). Reaching the required number of cases needed will be a challenge to children's hospitals with low to mid volume RALP programs.

Based on our analysis and personal experience there appears to be clear evidence that there is in fact a higher cost to RALP as compared to open and laparoscopic approaches. Published data seems to suggest than even with shorter length of stay attributed to RALP as compared to other treatment modalities, the high cost of training, maintenance and materials point to a greater cost as compared to other modalities. In the near future innovation in technology, robotic market competition and market tendencies may see a further normalization of RALP costs that could be comparable to other treatment options.

Parental Capital Gains

Other than the inherent cost analysis necessary for the evaluation and comparison of the treatment modalities of UPJO, there is also a further economic impact related to UPJO treatment as it pertains to parental gains/losses in the pediatric population. A 2011 study by Behan and colleagues evaluated the human capital gains associated to RALP in children (35). An evaluation of 44 patients most of which underwent RALP as compared to open approach was done retrospectively, in which indirect expenses to each procedure was estimated using already published financial models. Although parental work loss is sometimes used as the greatest variable to capital gains/loss other data was analyzed to evaluate the procedures. The results showed that the overall cost savings that are a result of decrease hospital length of stay for RALP may help compensate for the added operative costs previously alluded to. This study suggested that RP is associated with decreased lost parental wages and savings attributed to shorter length of stay, but the results are extremely dependent on the overall costs and amortization related to the robot. Prospective large center studies would be of great value to truly assess the impact of this variable in the treatment modalities of UPJO.

Satisfaction

In the pediatric population satisfaction is not merely based on patient satisfaction and outcomes, but also related to parental satisfactions. Freilich et al. evaluated parental satisfaction based on a modified Glasgow Children's Benefit Inventory (36). Groups of open and RALP were compared based in most part to the responses of the questionnaire. Overall the results of the study showed that even when objective success of surgery were similar between groups (i.e., decreased hydronephrosis on imaging, improved renal scan measures), RALP was favored overall by parents. In regard to specific variables such as postoperative pain, speed to normal activity, speed of return to normal sports, surgery incision scar, impact of surgery on parental life, burden of postop visits/studies, and overall satisfaction, parents seemed to find a greater difference between actual results and expected results within the robotic wing. Based on this study there is increased satisfaction when RALP is undertaken especially in regards to cosmesis and recovery, but expectations as compared to actual results are almost always improved notwithstanding the type of treatment modality employed.

The effect of cosmesis takes greater impact when novel treatment techniques are utilized within the endoscopic treatment realm. For example, hidden incision endoscopic surgery (port sites at level of a Pfannenstiel incision) did show greater satisfaction from patients and parents in regard to cosmetic results in a series of 12 patients published by Gargollo in 2011 (37). In our experience endoscopic approaches are preferred by parents based on the reported considerations as well.

Benefits vs. Risks

Apart from patient benefits like reduced pain, improved cosmetic results, shorter hospitalization, and rapid convalescence there are also added technical benefits to robotic surgery. Extensive published data exists on the benefits of magnified three-dimensional vision, the advantage of having an increased number of working arms, reduced tremors, and overall improved ergonomics. These qualities are an upside on robotic surgery when compared to both open and conventional laparoscopic approaches.

In a review of 5,400 laparoscopic cases performed Peters reported an overall complication rate of 5.4% (38). The greatest predictor of complication rate was surgeon experience.

Braga et al. published a systematic review and metanalysis of RALP vs. conventional laparoscopic approaches (39). RALP showed improved operative time reduction, and a significantly shorter stay at the hospital, but no statistical significance was found with regards to the rates of complications between the treatment modalities. The effects of reduced morbidity in robotic surgery, especially within the pediatric population, is also apparent due to a trend to its utilization in redo cases (40). Up to this point when compared to conventional laparoscopy there is no clear or definitive decrease in morbidity in RALP, especially in experienced hands.

Future of Robotic Pyeloplasty

The future of RP seems to lie both on achieving greater utilization of the currently described technique as well as in the development of new techniques and technology. Single ports, smaller surgical sites, telesurgery, and hidden surgical incisions all seem to be in development and may show promise as they become more available.

Further miniaturization of robotic arms, especially in the form of table mounted systems, will allow for increased dexterity (4). Baek et al. published data regarding the use of 5 mm instruments for RALP in children of different ages (infants and non-infants). Utilization of smaller port sites allowed for safe intervention of RALP in infant children with similar results when compared to older children (41). Improvement in the 5 mm instrument and miniaturization of the robotic arms will facilitate RALP in the smaller infant patients (4).

Another area of particular interest is further development of force-feedback mechanisms to the surgeon that can compensate for the lack of tactile feedback in robotic cases. This in conjunction with newer technologies like virtual reality and augmented reality may not only change robotic surgery as a whole but may also improve education in robotic surgery including RALP.

CONCLUSION

RALP is safe, effective, and well-accepted by surgeons, patients and their parents. There are real concerns regarding the longer operative times and cost associated with this procedure. As surgeons become better trained and have more experience with this technology operative time and associated cost should reduce significantly. Also, as more companies develop additional robotic technology, competition should produce more affordable robotic systems and instrumentations directly reducing the overall cost to the health systems. In the near future, RALP could become our new gold standard in the treatment of UPJO or at least be an equal to the open approach pyeloplasty.

AUTHOR CONTRIBUTIONS

RM-L, MP-M and MPB contributed in all aspects of the manuscript including research, writing, and editing of manuscript.

REFERENCES

1. Passerotti C, Peters CA. Pediatric robotic–assisted laparoscopy: a description of the principle procedures. *Sci World J.* (2006) 6:2581–8. doi: 10.1100/tsw.2006.399
2. Ekin RG, Celik O, Ilbey YO. An up-to-date overview of minimally invasive treatment methods in ureteropelvic junction obstruction. *Cent Eur J Urol.* (2015) 68:245–51. doi: 10.5173/ceju.2015.543
3. Orvieto MA, Large M, Gundeti MS. Robotic paediatric urology. *BJUJ Int.* (2012) 110:2–13. doi: 10.1111/j.1464-410X.2011.10877.x
4. Kearns JT, Gundeti MS. Pediatric robotic urology surgery—2014. *J Indian assoc Pediatr Surg.* (2014) 19:123–8. doi: 10.4103/0971-9261.136456
5. Howe A, Kozel Z, Palmer L. Robotic surgery in pediatric urology. *Asian J Urol.* (2017) 4:55–67. doi: 10.1016/j.ajur.2016.06.002
6. Vemulakonda V, Wilcox D, Crombleholme T, Bronsert M, Kempe A. Factors associated with age at pyeloplasty in children with ureteropelvic junction obstruction. *Pediatr Surg Int.* (2015) 31:871–7. doi: 10.1007/s00383-015-3748-2
7. Park JM, Bloom DA. The pathophysiology of UPJ obstruction. *Curr Consept Urol Clin North Am.* (1998) 25:161–9. doi: 10.1016/S0094-0143(05)70004-5
8. Nguyen HT, Benson CB, Bromley B, Campbell JB, Chow J, Coleman B, et al. Multidisciplinary consensus on the classification of prenatal and postnatal urinary tract dilation (UTD classification system). *J Pediatr Urol.* (2014) 10:982–98. doi: 10.1016/j.jpurol.2014.10.002
9. Faure A, London K, Smith GHH. Early mercaptoacetyltriglycine(MAG-3) diuretic renography results after pyeloplasty. *BJU Int.* (2016) 118:790–6. doi: 10.1111/bju.13512
10. Parikh K, Hammer M, Kraft K, Ivančić V, Smith EA, Dillman JR. Pediatric ureteropelvic junction obstruction: can magnetic resonance urography identify crossing vessels? *Pediatr Radiol.* (2015) 45:1788–95. doi: 10.1007/s00247-015-3412-y
11. Jiang X, Anderson C, Schnatz PF. The safety of direct trocar versus veress needle for laparoscopic entry: a meta-analysis of randomized clinical trials. *J Laparoendos Adv Surg Tech.* (2012) 22:362–70. doi: 10.1089/lap.2011.0432
12. Hong YH, DeFoor WR, Reddy PP, Schulte M, Minevich EA, VanderBrink BA, et al. Hidden incision endoscopic surgery (HIdES) trocar placement for pediatric robotic pyeloplasty: comparison to traditional port placement. *J Robot Surg.* (2018) 12:43–7. doi: 10.1007/s11701-017-0684-2
13. Iranmanesh P, Morel P, Buchs NC, Pugin F, Volonte F, Kreaden US, et al. Docking of the da vinci si surgical system® with single-site technology. *Int J Med Robot Comput Assist Surg MRCAS* (2013) 9:12–6. doi: 10.1002/rcs.1481
14. Cao H, Zhou H, Liu K, Ma L, Liu D, Tao T, et al. A modified technique of paraumbilical three-port laparoscopic dismembered pyeloplasty for infants and children. *Pediatr Surg Int.* (2016) 32:1037–45. doi: 10.1007/s00383-016-3958-2
15. Kutikov A, Resnick M, Casale P. Laparoscopic pyeloplasty in the infant younger than 6 months - Is it technically possible? *J Urol.* (2006) 175:1477–79. doi: 10.1016/S0022-5347(05)00673-7
16. Avery DI, Herbst KW, Lendvay TS, Noh PH, Dangle P, Gundeti MS, et al. Robot-assisted laparoscopic pyeloplasty: multi-institutional experience in infants. *J Pediatr Urol.* (2015) 11:139.e1-5. doi: 10.1016/j.jpurol.2014.11.025
17. Asensio M, Gander R, Royo GF, Lloret J. Failed pyeloplasty in children: Is robot-assisted laparoscopic reoperative repair feasible? *J Pediatr Urol.* (2015) 11:69.e1–6. doi: 10.1016/j.jpurol.2014.10.009
18. Olsen LH, Rawashdeh YF, Jorgensen TM. Pediatric robot assisted retroperitoneoscopic pyeloplasty: a 5-year experience. *J Urol.* (2007) 178:2137–41. doi: 10.1016/j.juro.2007.07.057
19. Minnillo BJ, Cruz JAS, Sayao RH, Passerotti CC, Houck CS, Meier PM, et al. Long-term experience and outcomes of robotic assisted laparoscopic pyeloplasty in children and young adults. *J Urol.* (2011) 185:1455–60. doi: 10.1016/j.juro.2010.11.056
20. Singh O, Gupta SS, Hastir A, Arvind NK. Laparoscopic dismembered pyeloplasty for ureteropelvic junction obstruction: experience with 142 cases in a highvolume center. *J Endourol.* (2010) 24:1431–34. doi: 10.1089/end.2010.0002
21. Atug F, Woods M, Burgess SV, Castle EP, Thomas R. Robotic assisted laparoscopic pyeloplasty in children. *J Urol.* (2005) 174(4 Pt 1):1440–42. doi: 10.1097/01.ju.0000173131.64558.c9
22. Franco I, Dyer LL, Zelkovic P. Laparoscopic pyeloplasty in the pediatric patient: hand sewn anastomosis versus robotic assisted anastomosis–is there a difference? *J Urol.* (2007) 178:1483–6. doi: 10.1016/j.juro.2007.06.012
23. Barbosa JA, Kowal A, Onal B, Gouveia E, Walters M, Newcomer J, et al. Comparative evaluation of the resolution of hydronephrosis in children who underwent open and robotic-assisted laparoscopic pyeloplasty. *J Pediatr Urol.* (2013) 9:199–205. doi: 10.1016/j.jpurol.2012.02.002
24. Yee DS, Shanberg AM, Duel BP, Rodriguez E, Eichel L, Rajpoot D. Initial comparison of robotic-assisted laparoscopic versus open pyeloplasty in children. *Urology* (2006) 67:599–602. doi: 10.1016/j.urology.2005.09.021
25. Subotic U, Rohard I, Weber DM, Gobet R, Moehrlen U, Gonzalez R. A minimal invasive surgical approach for children of all ages with ureteropelvic junction obstruction. *J Pediatr Urol.* (2012) 8:354–8. doi: 10.1016/j.jpurol.2011.07.004
26. Lee RS, Retik AB, Borer JG, Peters CA. Pediatric robot assisted laparoscopic dismembered pyeloplasty: comparison with a cohort of open surgery. *J Urol.* (2006) 175:683–7. doi: 10.1016/S0022-5347(05)00183-7
27. Song SH, Lee C, Jung J, Kim SJ, Park S, Park H, et al. A comparative study of pediatric open pyeloplasty, laparoscopy-assisted extracorporeal pyeloplasty, and robot-assisted laparoscopic pyeloplasty. *PLoS ONE* (2017) 12:e0175026. doi: 10.1371/journal.pone.0175026
28. Cundy T, Harling L, Hughes-Hallett A, Mayer EK, Najmaldin AS, Athanasiou T, et al. Meta-analysis of robot-assisted vs conventional laparoscopic and open pyeloplasty in children. *BJU Int.* (2014) 114:582–94. doi: 10.1111/bju.12683
29. Salö M, Sjöberg Altemani T, Anderberg M, Salö M, Sjöberg Altemani T. Pyeloplasty in children: perioperative results and long-term outcomes of robotic-assisted laparoscopic surgery compared to open surgery. *Pediatr Surg Int* (2016). 32:599–607. doi: 10.1007/s00383-016-3869-2
30. Link RE, Bhayani SB, Kavoussi LR. A prospective comparison of robotic andlaparoscopic pyeloplasty. *Ann Surg.* (2006) 243:486–91. doi: 10.1097/01.sla.0000205626.71982.32
31. Jacobs BL, Seelam R, Lai JC, Hanley JM, Wolf JS, Hollenbeck BK, et al. Cost analysis of treatments for ureteropelvic junction obstruction. *J Endourol.* (2017) 31:204–9. doi: 10.1089/end.2016.0722

32. Varda BK, Johnson EK, Clark C, Chung BI, Nelson CP, Chang SL. National trends of perioperative outcomes and costs for open, laparoscopic and robotic pediatric pyeloplasty. *J Urol.* (2014) 191:1090–5. doi: 10.1016/j.juro.2013.10.077
33. Varda BK, Wang Y, Chung BI, 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 pediatric pyeloplasty in the United State from 2003 to 2015. *J Pediatric Urol.* (2018) 14:336.e1–336.e8. doi: 10.1016/j.jpurol.2017.12.010
34. Palmer KJ, Lowe GJ, Coughlin GD, Patil N, Patel VR. Launching a successful robotic surgery program. *J Endourol.* (2008) 22:819–24. doi: 10.1089/end.2007.9824
35. Behan JW, Kim SS, Dorey F, De Filippo RE, Chang AY, Hardy BE, et al. Human capital gains associated with robotic assisted laparoscopic pyeloplasty in children compared to open pyeloplasty. *J Urol.* (2011) 186:1663–7. doi: 10.1016/j.juro.2011.04.019
36. Freilich DA, Penna FJ, Nelson CP, Retik AB, Nguyen HT. Parental satisfaction after open versus robot assisted laparoscopic pyeloplasty: results from modified glasgow children's benefit inventory survey. *J Urol.* (2010) 183:704–8. doi: 10.1016/j.juro.2009.10.040
37. Gargollo PC. Hidden incision endoscopic surgery: description of technique, parental satisfaction and applications. *J Urol.* (2011) 185:1425–32. doi: 10.1016/j.juro.2010.11.054
38. Peters CA. Complications in pediatric urological laparoscopy: results of a survey. *J Urol.* (1996) 155:1070–3. doi: 10.1016/S0022-5347(01)66394-8
39. Braga LH, Pace K, DeMaria J, Lorenzo AJ. Systematic review and meta-analysis of robotic-assisted versus conventional laparoscopic pyeloplasty for patients with ureteropelvic junction obstruction: effect on operative time, length of hospital stay, postoperative complications, and success rate. *Eur Urol.* (2009) 56:848–57. doi: 10.1016/j.eururo.2009.03.063
40. Reddy MN, Nerli RB. The laparoscopic pyeloplasty: is there a role in the age of robotics? *Urol Clin North Am.* (2015) 42:43–52. doi: 10.1016/j.ucl.2014.09.004
41. Baek M, Silay M, Au Jk, Huang GO, Elizondo RA, Puttmann KT, et al. Does the use of 5 mm instruments affect the outcomes of robot-assisted laparoscopic pyeloplasty in smaller working spaces? A comparative analysis of infants and older children. *J Pediatr Urol.* (2018) 14:537.e1–537.e6. doi: 10.1016/j.jpurol.2018.06.010

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Surgery

SYSTEMATIC REVIEW
published: 12 March 2019
doi: 10.3389/fsurg.2019.00009

A Comprehensive Analysis of Robot-Assisted Surgery Uptake in the Pediatric Surgical Discipline

Nicolas Fernandez[1,2,3]* and *Walid A. Farhat*[1]

[1] *Division of Urology, Hospital for SickKids, University of Toronto, Toronto, ON, Canada,* [2] *Department of Urology, Fundación Santa Fe de Bogota, Bogota, Colombia,* [3] *Division of Urology, Hospital Universitario San Ignacio, Pontificia Universidad Javeriana, Bogota, Colombia*

Introduction: Robotic assisted surgery (RAS) is one of the most recent surgical approaches that has quickly been adopted by the pediatric urology community. Over the last decade, a vast amount of manuscripts has been published, supporting the safety and applicability of RAS in the pediatric population. The quality of published literature about this innovative technology remains supported by case-reports and retrospective case-series. Historical behavior of literature productivity and implementation of laparoscopy followed a similar trend. We present the historical publication uptake of RAS in pediatric urology and other surgical disciplines using a bibliometric comparison of the most cited manuscripts.

Materials and Methods: A systematic search and review of the literature was undertaken by the authors. Literature search was performed in OVID, PubMed, EMBASE, Scopus, Web of Science, and Google Scholar. The search period included all publications between 1985 and June 2018. All languages were included. Data analysis for graphical representation was performed using VOSviewer® version 1.6.8 and Impact Index Analysis was used to adjust the citations by the time since publication.

Results: A total of 1,014 titles were identified. After applying exclusion criteria, 200 papers were included for the RAS arm and 402 for the laparoscopic one. Case-series was the most common type of publication. Average citations for laparoscopic manuscripts was 23 (*SD* ± 31) and for RAS was 20 (*SD* ± 31.5). The impact index analysis showed an average of 95 (*SD* ± 167) for laparoscopic manuscripts vs. 66 (*SD* ± 101) for RAS. The laparoscopic manuscript with the highest citation count had 199 citations with an impact index of 12.1. And the RAS manuscript with the highest citation count had 280 citations and an impact index of 4.3.

Conclusion: Literature productivity in pediatric laparoscopic and RAS has quickly grown. Pediatric Urologists play a key role in the introduction of this innovative tool. Literature supporting its implementation and future consolidation requires to focus on increasing the level of evidence.

Keywords: robot-assisted surgery, laparoscopy, pediatrics, urology, minimally invasive surgery, bibliometric analysis

Edited by:
Miguel Alfedo Castellan,
University of Miami, United States

Reviewed by:
Francisco Javier Reed,
Hospital Exequiel González Cortés, Chile
Juan Ignacio Bortagaray,
Monash Children's Hospital, Australia

***Correspondence:**
Nicolas Fernandez
nicolas.fernandez@sickkids.ca

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Surgery

Received: *11 September 2018*
Accepted: *15 February 2019*
Published: *12 March 2019*

Citation:
Fernandez N and Farhat WA (2019) A Comprehensive Analysis of Robot-Assisted Surgery Uptake in the Pediatric Surgical Discipline. Front. Surg. 6:9. doi: 10.3389/fsurg.2019.00009

INTRODUCTION

Robotic surgery is one of the most recent surgical approaches that has quickly been adopted by the pediatric urology community. Since the first reported cases of laparoscopic surgery in the early 1990's and Peter's et al. first robot-assisted laparoscopic procedure on a pediatric patient in 2002, a vast amount of experience has been gained in the pediatric urological RAS field (1–3). By 2006, the application of RAS in children remained largely unexplored and the perspective of pediatric urologists was polarized (4, 5). Over the last decade, a vast amount of manuscripts have been published, supporting the safety and applicability of RAS in the pediatric population with an increase of 236.6% per year by 2016 (6).

Pediatric Urology has been the specialty that continue to lead this field with pyeloplasty being the most frequently performed procedure to date (7). More recent data support that more than 80% of pediatric urologists see a clear role for RAS in the pediatric population (5). The quick growth of RAS has been supported by the fact that surgeons can perform complex reconstructive procedures with much shorter learning curves compared to regular laparoscopy (8–10). In fact it has been seen that RAS-naïve surgeons who are performing suturing for the first time, they do it much faster than with laparoscopy (11). More recent studies are now supporting shorter lengths of stay and fewer complications for RAS cases compared to laparoscopic ones (12). Nonetheless, the quality of published literature about this innovative technology remains supported by case-reports and retrospective case-series. Historical behavior of literature productivity and implementation of laparoscopy followed a similar trend. Previous bibliometric analysis studies have shown how literature productivity and consumption (citations) cannot be interpreted the same way for all specialties in a universal way (13–15). For instance, topics like coronary artery disease, or cancer have more visibility and will be of more interest to more medical fields. This translates to higher citation counts for these publications, but specialties like pediatric RAS surgery where the amount of specialists interested in this field is smaller a proportional smaller citation count is seen. This proportion needs to be kept in mind when it comes to interpreting the citation counts based on the specialty "size".

Based on a Progressive Scholarly Acceptance analysis, RAS has not passed the transition point yet and remains un-accepted by the scientific community (16). Innovative technologies are rarely implemented universally and RAS is not the exception (6). Limitations for RAS and laparoscopy, as innovations, in the surgical field have gone through similar paths, both technologies have had to overcome critics and prove to be safe and replicable. We hypothesize that RAS has taken off in a much faster way compared to laparoscopy, considering that RAS enables surgeons the possibility of performing complex procedures with a shorter learning curve. For these reasons, we hereby present a mathematical analysis (need to consider statistical analysis) of a literature review to show the results of a historical bibliometric comparison of the most cited manuscripts since laparoscopy and RAS were implemented.

METHODS

A systematic search and review of the literature was undertaken by the authors following the PRISMA concepts. Literature search was performed in OVID, PubMed, EMBASE, Scopus, Web of Science, and Google Scholar. A comprehensive search included the MeSh terms: Pediatrics, minimally invasive surgical procedures, laparoscopy, urology, and robotics. The search period included all publications between 1985 and June 2018. Citation count per manuscript was taken from Scopus, Web of Science and Google Scholar. A secondary search was performed following the same methodology to include pediatric surgical procedures with the MeSh terms: Pediatric Surgery, robotics. No citation analysis was performed on this secondary analysis. Otolaryngologic and Neurosurgical publications were excluded. For manuscripts with different citation counts on each database, we used the highest citation count out of the three databases. Citation data extraction was performed in a 2-day period between June 20th and 21st of 2018. Impact index analysis (IIA) was initially developed as a way to adjust the citation count interpretation based on the time since publication. For this reason, we used the IIA in the present study to interpret our results. We followed the formula reported by Fernandez et al. considering influential manuscripts with low scores (13).

All extracted titles and abstracts were screened for relevance and disagreements were resolved by consensus. Duplicated titles and abstracts that did not disclose any information about pediatric urological robot-assisted or laparoscopic surgery were excluded. For manuscripts comparing regular laparoscopy with robot-assisted surgery, the title was included in the robot-assisted analysis. All languages were included. Data analysis for graphical representation was performed using VOSviewer® version 1.6.8 (http://www.vosviewer.com).

Comparisons of continuous variables was carried out with *t*-tests and ANOVA when more than two set of groups were compared. Statistical analyses were analyzed using SPSS v. 25.0 (SPSS 25.0—SPSS Inc., Chicago, Illinois). $P < 0.05$ were considered statistically significant.

RESULTS

A total of 1,014 titles were identified. After duplicated titles were excluded, 667 titles were screened and after applying exclusion criteria, 602 titles were included for analysis; 200 for the robot-assisted arm and 402 for the laparoscopic one. Case-series was the most common type of publication for both arms followed by review articles and case reports (**Figure 1**). There was only one experiment with an animal model and another with an inanimate one in the RAS analysis and 4 and 6, respectively, in the laparoscopic manuscripts. There are only 8 publications that were prospective studies. In the RAS analysis there were no randomized clinical trials as oppose to laparoscopic publications where we identified 4 manuscripts. There were more cost analysis studies in the RAS arm than laparoscopy. We looked for geographical distributions of the most cited manuscripts in order to compare centers' and their

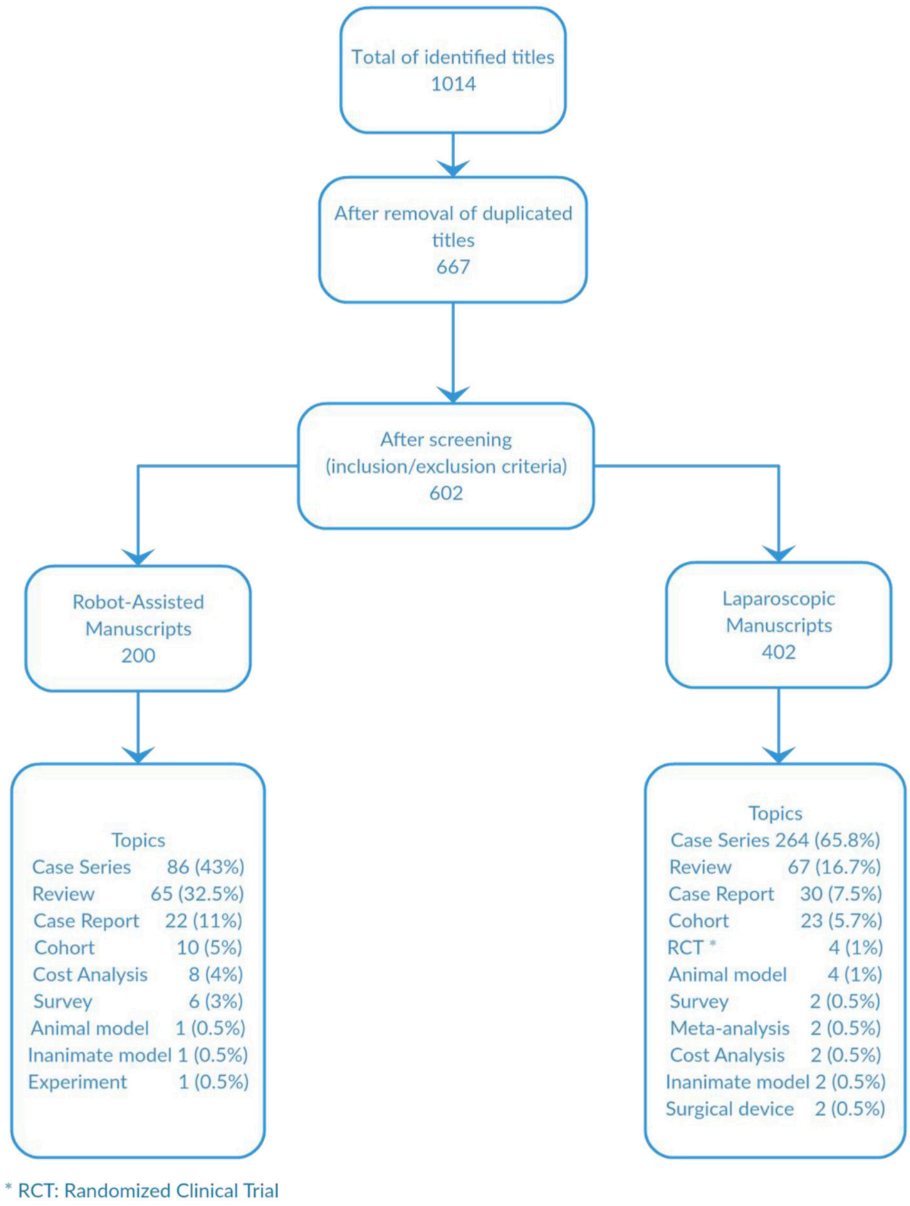

FIGURE 1 | Manuscript selection and distribution of types of studies.

citation counts and how they transitioned from laparoscopy into RAS. We found that the majority of authors and centers that were on the top ten positions of the most cited manuscripts were different for laparoscopy and RAS. The only author who remained at the top 10 for laparoscopy and RAS was Dr. Craig Peters.

When comparing the amount of publications per year between laparoscopic manuscripts and RAS, a higher and quicker proportional increase in the publication count for RAS manuscripts was noted (**Figure 2**). When comparing the amount of manuscripts published since 2,000 for pediatric urological laparoscopy, RAS urology and pediatric general surgery, the mean publication counts for this 18-year period was 20.78, 11.11, and 6.56, respectively ($p < 0.0000$) (**Figure 2**). When the same comparison is made for RAS in pediatric urology, pediatric general surgery and pediatric ENT there is a statistically significant difference favoring a higher productivity for pediatric urology ($p = 0.041$) (**Figure 2**).

In the first decade after either technique was introduced, there were less publications for laparoscopy (58 publications) than RAS (103 publications).

Average citations for laparoscopic manuscripts was 23 (*SD* ± 31) and for RAS was 20 (*SD* ± 31.5). The impact index analysis showed an average of 95 (*SD* ± 167) for laparoscopic manuscripts vs. 66 (*SD* ± 101) for RAS. When comparing average citation counts for publications before and after the year

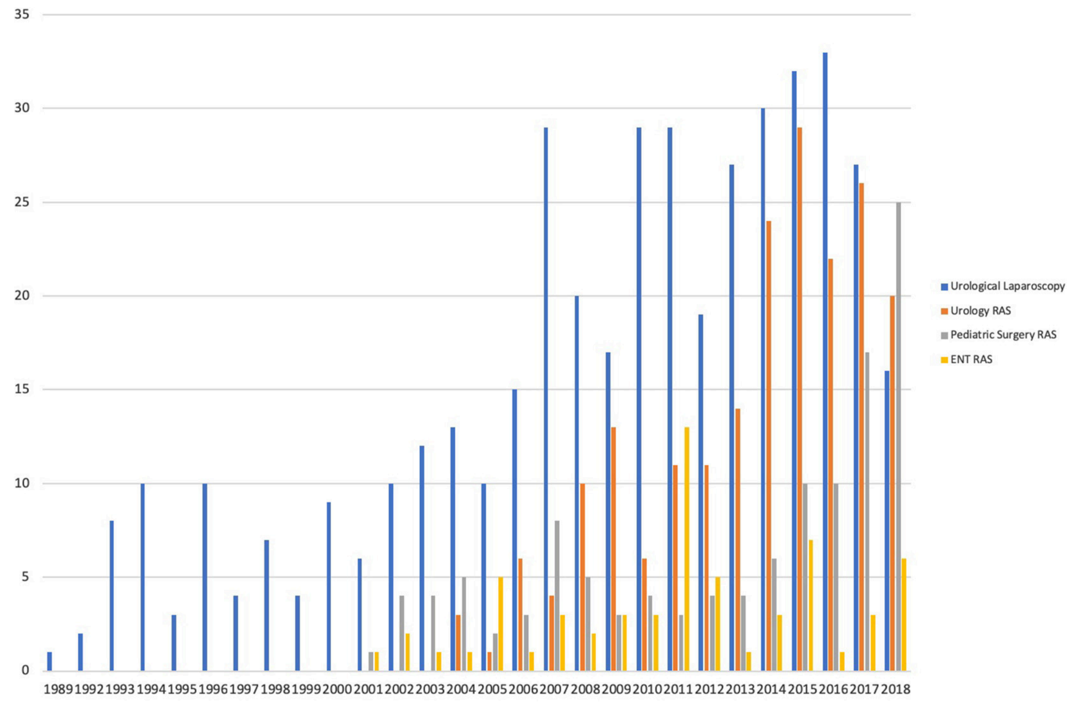

FIGURE 2 | Historical count of publications for laparoscopic and robot-assisted publications.

2000 for laparoscopic procedures, the average citation counts for publications after 2000 was 20 and before 47 (CI = 17.20–35.44) ($p <$ 0.0001). We also did the same comparison using the impact index scores and found an average impact index of 86 for publications after the year 2000 and 157 for those published before ($p = 0.01$).

The laparoscopic manuscript with the highest citation count had 199 citations with an impact index of 12.1. And the RAS manuscript with the highest citation count had 280 citations and an impact index of 4.3.

Our impact index analysis showed low scores for landmark papers that have remained as highly influential since their publication time in the early 2000's. Historical impact index trends show that most recent papers have more impact (**Figures 4A,B**).

Almost all publications came from North-America (81%) followed by Europe (15%) and the remaining from Asian and Middle-East countries. The Journal where most of the RAS manuscripts were published was the Journal of Pediatric Urology with 26.5% of the publications followed by Journal of Urology with 10.5%. For regular laparoscopy, the journal with most manuscripts was Journal of Urology with 19.2% followed by Journal of Pediatric Urology with 13.6%. By the time laparoscopy was initially introduced, the Journal of Pediatric Urology was not yet indexed.

Secondary search identified a total of 118 publications in pediatric surgery. RAS and laparoscopy have steadily increased, but pediatric surgery has not had the same proportion of increase over time as in the pediatric urology subspecialty (**Figure 2**).

Most discussed topics were pyeloplasty followed by ureteral re-implantation (**Figure 3**). For Pediatric Surgery, the most common discussed topic was fundoplication. There has been a most recent increase in cost analysis publications over time for RAS. During the second decade after implementation of pediatric laparoscopy, a significant amount of manuscripts focused on the use of single port surgery. RAS literature was mainly about the presentation of applicability and safety of this technology. All publications were published exclusively in urology journals with Journal of Urology and Journal of Pediatric Urology being the ones with the most published and most cited manuscripts.

DISCUSSION

Minimally invasive surgery (MIS) has been a significant landmark in pediatric surgery discipline but robotic approach is evidently impacted pediatric urology evolution and practice far more than any other pediatric surgical disciplines. Our results show similar historical trends when comparing laparoscopy to RAS when looking at citation counts and level of evidence of supporting manuscripts. The main difference has been noticed on much quicker and higher manuscript productivity. Also, when adjusting by time since publication using our novel developed Impact index, we notice that RAS has had a better impact on the scientific community compared to laparoscopy. Implementation of innovative technologies depends on multiple factors and research with publications do enhance uptake of new technologies. RAS has had a quick take-off and one of the reasons for this trend is that literature acted as a catalyst for adopting it. At

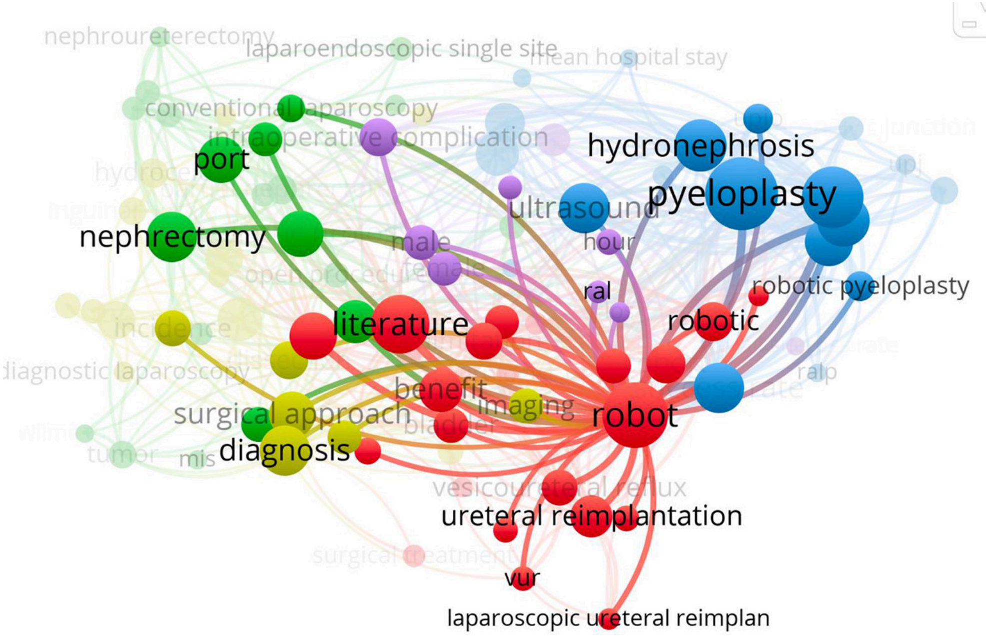

FIGURE 3 | Most discussed topics for manuscripts published in laparoscopy and robot-assisted pediatric urology.

some degree, this supports how new technologies are accepted by the surgical community. The urge to publicize and the pressure of community for recognition, may affect the quality of scientific productivity. Our results along with other authors like Cundy et al. show that 90% of published manuscripts in this topic are level IV (3, 17). Nevertheless, careful interpretation of literature is needed when new technologies are being implemented. (18, 19). Interestingly despite finding that there are 4 randomized studies and 2 meta-analysis in the laparoscopic literature, these have not been highly cited.

In the early 1990's, the implementation of laparoscopy as a novel technology, showed to be safe and reproducible when compared to open surgery for most of the procedures (20). The possibility of internet influencing the amount of citations is plausible when analyzing the impact index for publications before and after the year 2000. A similar trend has been seen for RAS. Nonetheless, none of either technology has enabled the creation of a novel surgical technique. Surgeons are the door of entrance for many innovative technologies. Our results support how such tool has evolved and is now broadly implemented (21).

Our results do not show the same evolution for pediatric surgery, similar to what has seen by other authors (3). Our results show that most publications focused on the applicability and safety of robotic surgery when compared to regular laparoscopy or open surgery. If considering open surgery as a "gold standard" the use of laparoscopy and RAS have shown to be comparable for procedures like pyeloplasty (22, 23). This explains why it is the most reported procedure in literature. For other procedures like nephrectomy, MIS has shown to be superior with less morbidity and shorter hospital stay (24). In the case of the management of vesicoureteral reflux, ureteral reimplantation performed laparoscopically and by RAS has now shown debatable results when compared to those of open surgery (25–27).

Bibliometrics and impact factor for published literature cannot be analyzed based only on the amount of citations. It is important to consider the specialty and discussed topic amongst other variables like time since publication at the moment of interpreting this data. Our results show how MIS in pediatric urology is a very specialized topic that is read and cited by a very selective group sub-specialists. This is proven by the fact that all manuscripts are published in urological journals for both, laparoscopy and RAS. The amount of literature produced per year has never been above 50 publications and average citation counts of 20 on our analysis compared to other topics. For instance vesicoureteral reflux, which is of more interest to other specialties besides pediatric urology, the average citation counts were 101, this confirms how selective this topic can be (13). Our impact index analysis also showed that despite having similar citation averages between laparoscopic surgery and RAS, the latter has had more impact in the community and is quickly growing with more publications in 2018 than regular laparoscopy. Trends for better impact index for more recent manuscripts might be due to the preference of readers for the most recent publications.

With the ongoing debate on the cost-effective of RAS in the pediatric population (28), we noted higher number of manuscripts that tackle this particular issue (cost analysis between RAS and regular laparoscopy). This reflects the common and significant need to justify and rationalize the use of such an expensive technology (7, 23, 25, 29).

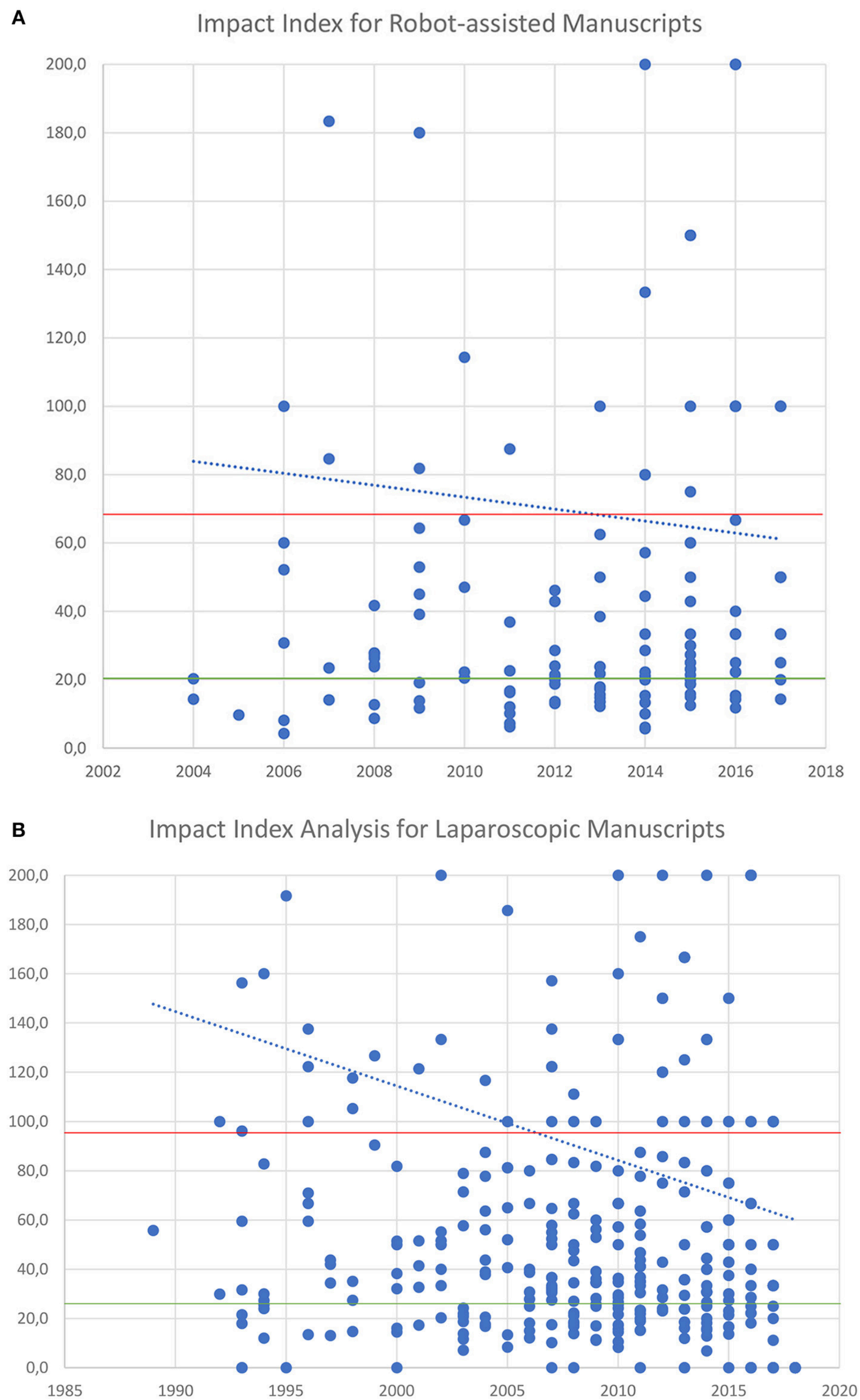

FIGURE 4 | (A) Impact Index analysis per manuscript over time for RAS. **(B)** Impact Index analysis per manuscript over time for Laparoscopy. In red average Impact Index and green average citations per manuscript. In blue the trend of Impact index over time.

Considering that MIS has been introduced as a new technology, its implementation was never supported by research based in basic science studies or experiments. Can we say that the implementation of novel technologies may not be necessarily supported by high quality type of studies to show its efficacy. It is our opinion that the adoption of new technology in surgery may not be because of the high quality studies *per se* but rather because it is doable and can be broadly adopted then some will adopt

Our results show that about 1% of the manuscripts describe results of experiments in animal or inanimate models. One reason for this might be the interest of authors to present information on how MIS can be clinically implemented. Nonetheless, the lack of this kind of experimental research misses the opportunity for innovation and probably for higher evidence-based literature that consolidates a safer path for the safe and efficient use of this novel tool. It is interesting to see that early adopters of RAS had the highest risk of litigation (30). But after the amount of procedures performed increased, the risks dropped. Most of the claims were due to surgical complications instead device failures from the DaVinci platform. This probably supports that novel technologies may not introduce a risk for legal actions if implemented and used in a responsible way. Good quality published literature may protect surgeons from legal actions against them.

Current efforts need to focus on the development of predictable inanimate models to help support the development of instruments that respond to the high technical demands of pediatric surgery. RAS instruments have been developed to be used on adults and pediatric surgeons have adopted these instruments into pediatric patients. The small working space is a challenge that few manuscripts have addressed and there is a need for scientific evidence to answer this question to help improve the usage of RAS in small patients (31). Literature productivity on this topic has tried to answer this question. The minimal effective volume that allows the performance of different surgical tasks without arm collision is between 125 and 130 cm^3 (31, 32). Abdominal characteristics for a suitable abdomen have been estimated to be a pubic-xyphoid length of 15 cm and an anterior superior iliac spine of 13 cm. Patient's weight has been defined as 10 kg. Considering all this variables, appropriate age range is around the 3 years of life. Considering this, many of upper tract reconstructive cases are performed earlier in life. For this reason, it is critical to focus our research on how to improve these technical limitations. Our group is currently working on developing a predictable 3-D inanimate model that simulates our results on small animal models reducing instrument collision and abdominal wall tension and traction (data presented at the NARUS conference 2018). This kind of results will allow the development of smaller instruments and improve the usage of current robot platforms in a better way.

CONCLUSIONS

Literature productivity in pediatric laparoscopic and robot-assisted surgery topic has quickly grown. Level of evidence literature productivity has been similar for both technologies with more impact for RAS in the community, exponentially growing at a faster pace than how laparoscopy was introduced. Current graduating generations have had a significant exposure to RAS during their adult training and for this reason we believe RAS has remained a leading topic in the pediatric urology specialty (33, 34). Future directives need to focus on increasing the level of evidence to support innovation and development of pediatric instruments.

AUTHOR CONTRIBUTIONS

NF proposed the idea of manuscript and did the data search and analysis. WF supervised the process of the entire manuscript and made the final corrections and elaborated the discussion.

REFERENCES

1. Koyle M, Woo H, Kavoussi L. Laparoscopic nephrectomy in the first year of life. *J Pediatr Sug.* (1993) 28:693e35.
2. Peters CA. Robotically assisted surgery in pediatric urology. *Urol Clin N Am.* (2004) 31:743–52. doi: 10.1016/j.ucl.2004.06.007
3. Cundy TP, Shetty K, Clark J, Chang TP, Sriskandarajah K, Gattas NE, et al. The first decade of robotic surgery in children. *J Pediatr Surg.* (2013) 48:858–65. doi: 10.1016/j.jpedsurg.2013.01.031
4. Lee RS, Retik AB, Borer JG, Peters CA. Pediatric robot assisted laparoscopic dismembered pyeloplasty: comparison with a cohort of open surgery. *J Urol.* (2006) 175:683–7. doi: 10.1016/S0022-5347(05)00183-7
5. Cundy TP, Marcus HJ, Hughes-Hallett A, Najmaldin AS, Yang GZ, Darzi A. International attitudes of early adopters to current and future robotic technologies in pediatric surgery. *J Pediatr Surg.* (2014) 49:1522–6. doi: 10.1016/j.jpedsurg.2014.05.017
6. Cundy TP, Harley SJD, Marcus HJ, Hughes-Hallett A, Khurana S. Global trends in paediatric robot-assisted urological surgery: a bibliometric and progressive scholarly acceptance analysis. *J Robot Surg.* (2018) 12:109–15. doi: 10.1007/s11701-017-0703-3
7. Bennett WE, Whittam BM, Szymanski KM, Rink RC, Cain MP, Carroll AE. Validated cost comparison of open vs. robotic pyeloplasty in American children's hospitals. *J Robot Surg.* (2017) 11:201–6. doi: 10.1007/s11701-016-0645-1
8. Nguyen HT, Passerotti CC, Penna FJ, Retik AB, Peters CA. Robotic assisted laparoscopic mitrofanoff appendicovesicostomy: preliminary experience in a pediatric population. *J Urol.* (2009) 182 (Suppl 4):1528–34. doi: 10.1016/j.juro.2009.06.055
9. Barashi NS, Rodriguez MV, Packiam VT, Gundeti MS. Bladder Reconstruction with bowel: robot-assisted laparoscopic ileocystoplasty with mitrofanoff appendicovesicostomy in pediatric patients. *J Endourol.* (2018) 32:119–26. doi: 10.1089/end.2017.0720
10. Passerotti C, Peters CA. Robotic-assisted laparoscopy applied to reconstructive surgeries in children. *World J Urol.* (2006) 24:193–7. doi: 10.1007/s00345-006-0084-0
11. Murthy PB, Schadler ED, Orvieto M, Zagaja G, Shalhav AL, Gundeti MS. Setting up a pediatric robotic urology program: a USA institution experience. *Int J Urol.* (2018) 25:86–93. doi: 10.1111/iju.13415
12. Silay M, Spinoit A, Undre S. Global minimally invasive pyeloplasty study in children: results from the pediatric urology expert group of the european association of urology young academic urologists working party. *J Pediatr Urol.* (2016) 12:229.e1-7. doi: 10.1016/j.jpurol.2016.04.007
13. Fernandez N, Puerto A, Azuero A, O'Kelly F, Hannick J, Rickard M, et al. Historical bibliometric analysis of the top cited articles on vesicoureteral reflux 1950-2016, and incorporation of a novel impact index. *J Pediatr Urol.* (2018) 14:446.e1-446.e9. doi: 10.1016/j.jpurol.2018.04.004
14. O'Kelly F, Nason GJ, McLoughlin LC, Flood HD, Thornhill JA. A comparative bibliometric analysis of the top 150 cited papers in hypospadiology (1945–2013). *J Pediatr Urol.* (2015) 11:85.e1-85.e11. doi: 10.1016/j.jpurol.2014.11.022

15. Rousseau R. Library science: forgotten founder of bibliometrics. *Nature.* (2014) 510:218. doi: 10.1038/510218e
16. Schnurman Z, Kondziolka D. Evaluating innovation. part 1: the concept of progressive scholarly acceptance. *J Neurosurg*. (2016) 124:207–11. doi: 10.3171/2015.1.JNS142661
17. Sackett D. Rules of evidence and clinical recommendations on the use of antithrombotic agents. *Chest.* (1989) 95:2s—4s. doi: 10.1378/chest.95.2_Supplement.2S
18. Jimbo M, Granberg CF, Osumah TS, Bandari J, Cannon GM, Routh JC, et al. Discrepancies in self-reported and actual conflicts of interest in pediatric urology robotic surgery. *J Urol*. (2018) 201:393–99. doi: 10.1016/j.juro.2018.07.043
19. Criss CN, Gadepalli SK. Sponsoring surgeons: an investigation on the influence of the da Vinci robot. *Am J Surg.* (2018) 216:84–7. doi: 10.1016/j.amjsurg.2017.08.017
20. Bansal D, Cost NG, Bean CM, Vanderbrink BA, Schulte M, Noh PH. Infant robot-assisted laparoscopic upper urinary tract reconstructive surgery. *J Pediatr Urol*. (2014) 10:869–74. doi: 10.1016/j.jpurol.2014.01.029
21. Senagore AJ. Adoption of laparoscopic colorectal surgery : it was quite a journey. *Clin Colon Rectal Surg.* (2015) 28:131–4. doi: 10.1055/s-0035-1560040
22. Varda BK, Johnson EK, Clark C, Chung BI, Nelson CP, Chang SL. National trends of perioperative outcomes and costs for open, laparoscopic and robotic pediatric pyeloplasty. *J Urol*. (2014) 191:1090–5. doi: 10.1016/j.juro.2013.10.077
23. Varda BK, Wang Y, Chung BI, 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 pediatric pyeloplasty in the United States from 2003 to 2015. *J Pediatr Urol*. (2018) 14:336.e1-336.e8. doi: 10.1016/j.jpurol.2017.12.010
24. Bowlin PR, Farhat WA. Laparoscopic nephrectomy and partial nephrectomy: intraperitoneal, retroperitoneal, single site. *Uro Clin North Am*. (2015) 42:31-42. doi: 10.1016/j.ucl.2014.09.012
25. Kurtz MP, Leow JJ, Varda BK, Logvinenko T, Yu RN, Nelson CP, et al. Robotic versus open pediatric ureteral reimplantation: costs and complications from a nationwide sample. *J Pediatr Urol*. (2016) 12:408.e1-408.e6. doi: 10.1016/j.jpurol.2016.06.016
26. De Lambert G, Fourcade L, Centi J, Fredon F, Braik K, Szwarc C, et al. How to successfully implement a robotic pediatric surgery program: Lessons learned after 96 procedures. *Surg Endosc Other Interv Tech*. (2013) 27:2137–44. doi: 10.1007/s00464-012-2729-y
27. Baek M, Koh CJ. Lessons learned over a decade of pediatric robotic ureteral reimplantation. *Investig Clin Urol*. (2017) 58:3–11. doi: 10.4111/icu.2017.58.1.3
28. Casella DP, Fox JA, Schneck FX, Cannon GM, Ost MC. Cost analysis of pediatric robot-assisted and laparoscopic pyeloplasty. *J Urol*. (2013) 189:1083–6. doi: 10.1016/j.juro.2012.08.259
29. Mahida JB, Cooper JN, Herz D, Diefenbach KA, Deans KJ, Minneci PC, et al. Utilization and costs associated with robotic surgery in children. *J Surg Res*. (2015) 199:169–76. doi: 10.1016/j.jss.2015.04.087
30. Nik-Ahd F, Souders CP, Zhao H, Houman J, McClelland L, Chughtai B, et al. Robotic urologic surgery: trends in litigation over the last decade. *J Robot Surg*. (2019). doi: 10.1007/s11701-018-00905-y
31. Thakre AA, Bailly Y, Sun LW, Van Meer F, Yeung CK. Is smaller workspace a limitation for robot performance in laparoscopy? *J Urol*. (2008) 179:1138–43. doi: 10.1016/j.juro.2007.10.091
32. Kutikov A, Guzzo TJ, Canter DJ, Casale P. Initial experience with laparoscopic transvesical ureteral reimplantation at the Children's Hospital of Philadelphia. *J Urol*. (2006) 176:2222–6. doi: 10.1016/j.juro.2006.07.082
33. Menhadji A, Abdelshehid C, Osann K, Alipanah R, Lusch A, Graversen J, et al. Tracking and assessment of technical skills acquisition among urology residents for open, laparoscopic, and robotic skills Over 4 years: is there a trend? *J Endourol*. (2013) 27:783–9. doi: 10.1089/end.2012.0633
34. Wang L, Diaz M, Stricker H, Peabody JO, Menon M, Rogers CG. Adding a newly trained surgeon into a high-volume robotic prostatectomy group: are outcomes compromised? *J Robot Surg*. (2017) 11:69–74. doi: 10.1007/s11701-016-0615-7

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

MINI REVIEW
published: 22 March 2019
doi: 10.3389/fped.2019.00085

Robotic Ureteral Reconstruction in the Pediatric Population

Aylin N. Bilgutay[1] and Andrew J. Kirsch[1,2]*

[1] Department of Pediatric Urology, Children's Healthcare of Atlanta, Atlanta, GA, United States, [2] Department of Urology, Emory University School of Medicine, Atlanta, GA, United States

Robot-assisted laparoscopic (RAL) surgery is a safe, minimally invasive technique that has become more widely used in pediatric urology over recent decades. With several advantages over standard laparoscopy, robotic surgery is particularly well-suited to reconstructive surgery involving delicate structures like the ureter. A robotic approach provides excellent access to and visualization of the ureter at all levels. Common applications include upper ureteral reconstruction (e.g., pyeloplasty, ureteropelvic junction polypectomy, ureterocalicostomy, and high uretero-ureterostomy in duplex systems), mid-ureteral reconstruction (e.g., mid uretero-ureterostomy for stricture or polyp), and lower ureteral reconstruction (e.g., ureteral reimplantation and lower ureter-ureterostomy in duplex systems). Herein, we describe each of these robotic procedures in detail.

Keywords: robotic surgery, pediatric urology, pyeloplasty, ureteroureterostomy, vesicoureteral reflux, ureteropelvic junction obstruction, ureterovesical junction obstruction, megaureter

Edited by:
Mohan S. Gundeti,
University of Chicago, United States

Reviewed by:
Yuval Bar-Yosef,
Dana-Dwek Children's Hospital, Israel
Jorge Correia-Pinto,
University of Minho, Portugal

****Correspondence:***
Aylin N. Bilgutay
aylin.bilgutay@gmail.com

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *29 November 2018*
Accepted: *27 February 2019*
Published: *22 March 2019*

Citation:
Bilgutay AN and Kirsch AJ (2019) Robotic Ureteral Reconstruction in the Pediatric Population. Front. Pediatr. 7:85. doi: 10.3389/fped.2019.00085

INTRODUCTION

Many considerations are involved in choosing surgical approach. Compared to open surgery, roboticsoffer several advantages including smaller incisions and more rapid convalescence. Robot-assisted laparoscopic (RAL) surgery may, however, be difficult or even impossible in very small patients, in whom pure laparoscopic intervention may be preferred. Pure laparoscopy allows for even smaller incisions than robotic surgery, with ports as small as 2–3 mm available. Another disadvantage of robotic surgery is increased cost compared to pure laparoscopic or open approaches. Benefits of robotic surgery include wristed movements and magnified vision, making it the ideal approach for delicate reconstructive procedures. Robotics continue to enjoy expanding applications and growing popularity among urologists and patient families alike.

UPPER URETERAL RECONSTRUCTION

Pyeloplasty

Pyeloplasty for ureteropelvic junction (UPJ) obstruction is the most common robotic surgery in pediatric urology (1). RAL retroperitoneoscopic pyeloplasty has been described in children (2); however, the transabdominal approach is more frequently utilized, providing a larger working space that facilitates dissection and anastomosis. Transabdominal robotic approach may involve transmesenteric UPJ exposure for left-sided cases to decrease operative time, as previously described for traditional laparoscopic pyeloplasty (3). However, reflecting the colon is usually rapid, and one should not risk limited exposure for potential time savings, particularly in complex cases.

Prior to positioning for the robotic portion of the case, we prefer starting with cystoscopy and retrograde pyelogram to delineate anatomy unless adequately assessed preoperatively with magnetic resonance urogram. A ureteral stent may be placed retrograde if desired. We prefer placing a ureteral stent antegrade during the robotic portion of the case.

Typical patient positioning for transabdominal robotic pyeloplasty is the modified flank/lateral decubitus position with affected side elevated ∼45° over a roll, contralateral arm extended on an arm board, and ipsilateral arm straight against the patient's ipsilateral side or extended parallel to the contralateral arm using an elevated armrest or pillows. Alternatively, the patient may be positioned supine with table rotation to elevate the pathologic side (1). One must ensure that all pressure points are adequately padded and the patient is appropriately secured to the table.

The patient is flattened for port placement. The camera port is placed first, usually at the umbilicus, using either open Hasson or Veress needle technique. Some surgeons recommend against the use of Veress needle in children (4). However, we believe that this technique can be applied safely in pediatric cases and have successfully used it for several years at our high volume robotic institution with no complications. For the Si, we use the 8.5 mm robotic camera port. A 10 or 12 mm port (e.g., the Autosuture® balloon trocar) may also be used as the Si robot camera port (5). For the Xi, the camera and working ports are identical, allowing placement of the camera through any port. Robotic working ports are then placed under direct vision. For the Si, 8 and 5 mm robotic ports and instruments are available, while only 8 mm ports/instruments are available for the Xi. We prefer 8 mm robotic ports even with the Si because of the greater variety of instrumentation available. Another advantage of the 8 mm instruments is a shorter intracorporeal length of the wristed segment, with decreased required intracorporeal working distance (5).

For the Si, ideal port placement results in a triangular working field. One working port is placed cephalad to the camera port in the midline or midclavicular line, and the other is placed inferiorly at an ∼30° angle rotated from midline toward the kidney of interest (**Figure 1A**). Ports are ideally spaced ∼1 hand's breadth apart, but this may be impossible in smaller children and infants. All ports are instead placed in the midline to maximize the limited working space in infants, as close as 3 cm if necessary (5).

Optimal port placement for the Xi robot is in a line rather than triangulated. A third robotic port and/or assistant port(s) may be placed if desired. We usually do not find additional ports necessary. With our typical three-port setup, a robotic instrument must be removed to allow the assistant to suction or pass sutures. This positioning and port placement may be used for any renal or upper ureteral procedure.

The hidden incision endoscopic surgery (HIdES) port placement technique was developed to eliminate visible scarring (6). This involves placing the camera port and one robotic working port below the level of a Pfannenstiel incision and placing the second robotic working port infraumbilically (**Figure 1B**). Incisions are thus hidden beneath the underwear line, which has been shown to be preferable to patients and parents (6, 7).

After port placement, the next step is docking. The bed is rotated to raise the ipsilateral side, and the height of the bed is adjusted as desired. These changes must be made prior to robot docking unless using the Xi system with Trumpf Medical's TruSystem® 7000 dV OR table, which allows "integrated table motion" (OR table movement after docking). With the Si, docking is typically over the ispilateral shoulder at a slight angle or straight in from the side. Docking trajectory is more forgiving with the Xi system, as the robotic arms rotate on the boom into the optimal position when you perform anatomic targeting.

Next, the white line of Toldt is incised, and the colon is reflected medially to expose the retroperitoneum. One may alternatively utilize a transmesenteric approach for left-sided cases. The renal pelvis, UPJ, and ureter are then identified and dissected with limited, low-power cautery use. We routinely use a hitch stitch for traction to facilitate this dissection in the absence of an assistant port. We use a 4–0 Vicryl on an SH needle, which is manually straightened and passed directly through the abdominal wall by the assistant, through-and-through the renal pelvis, then back out the abdominal wall. The assistant may then adjust the tension as desired by the surgeon and snap the stitch in place at the level of the skin. A hitch stitch may not be necessary if the renal pelvis is not too floppy.

Dismemberment is the next step. Depending on UPJ configuration, one may choose an appropriate location and trajectory for renal pelvis transection in order to create an adequately wide pyelotomy for eventual anastomosis. If the UPJ insertion is high, an alternative is to ligate it, transect the proximal ureter, and create a new dependent pyelotomy for anastomosis. Non-dismembered techniques (e.g., Foley Y-V plasty or flap pyeloplasties) are preferred by some authors (8–10). Use of these methods has even been described in the setting of a crossing vessel, with concomitant cephalad translocation of the crossing vessel or Hellström technique (8, 9). Flaps can be particularly useful for long segments of UPJ/ureteral stricture, whereas a Heineke-Mikulicz type pelvotomy (Fenger-plasty) may be sufficient for short strictures (8, 11). We favor the classic Anderson-Hynes dismembered pyeloplasty technique in the majority of cases. Pelvic reduction may be performed if desired; however, this is rarely necessary in our experience.

The proximal ureter is then spatulated. Traditional descriptions favor spatulation along the lateral aspect because the proximal ureteral blood supply arises medially. Spatulation must be continued for an adequate length to ensure a wide anastomosis incorporating healthy ureter. A portion of the proximal ureter may ultimately be excised if it appears unsuitable for reconstruction; however, we recommend leaving such a segment attached for use as a handle until anastomosis is nearly complete. The anastomosis may be performed with running or interrupted fine absorbable suture. Typically, we perform half of the anastomosis with one running 5–0 Vicryl, then place a ureteral stent in antegrade fashion over a wire passed through an angiocatheter advanced directly through the abdominal wall. To confirm appropriate stent positioning, one may have the circulator instill dilute methylene blue solution into the bladder

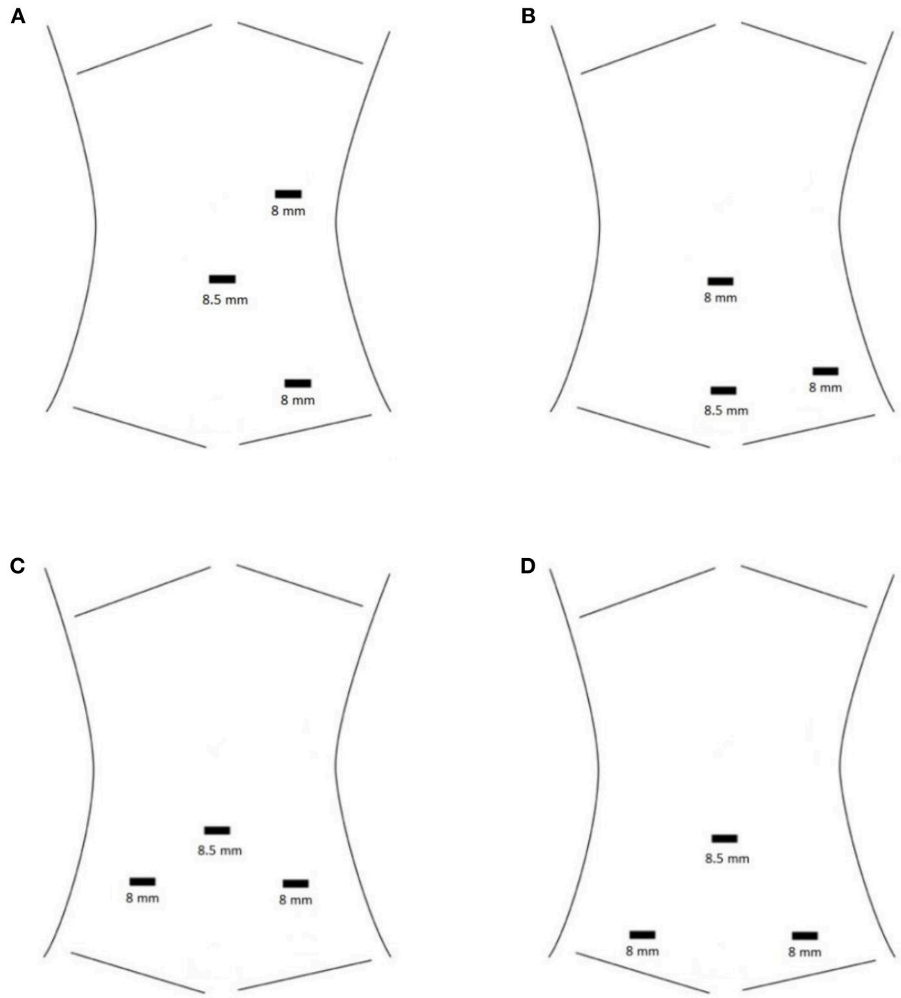

FIGURE 1 | (A) Standard port placement for RAL left pyeloplasty with the Si robot. The camera port is at the umbilicus. **(B)** HIdES port placement for RAL left pyeloplasty with the Si robot. The camera port is the inferior-most port. The camera port and one working port are hidden at or below the level of a Pfannenstiel incision, while the other working port is hidden in the umbilicus. **(C)** Standard port placement for RAL ureteral reimplantation with the Si robot. The camera port is at the umbilicus. **(D)** HIdES port placement for RAL ureteral reimplantation with the Si robot. The camera port is at the umbilicus. Skin incisions for the working ports are lower than in the standard port placement (at or below the level of a Pfannenstiel incision). Fascial entry sites for the working ports may be placed higher than the skin incisions in order to increase working space within the pelvis. This is achieved by applying cephalad traction during port placement.

through the Foley catheter, which should reflux up through the stent if the distal coil is in the bladder. The proximal stent coil is then placed within the pelvis, and the anastomosis is completed with a second running suture. Alternative approaches include placing a stent in retrograde fashion or leaving a percutaneous nephrostomy/nephroureterostomy tube or Penrose drain instead of an internal stent. Tubeless procedures have also been described with no short-term complications (12). Long-term success rates of tubeless robotic pyeloplasty have yet to be determined.

Robotic pyeloplasty is effective, with multiple series including $\geq$50 patients reporting success rates of 94–100% utilizing a transperitoneal or retroperitoneal approach (2, 13–20). A recent retrospective long-term study reported an 8-year failure-free rate of 91.5% after robotic pyeloplasty (21). A meta-analysis from 2014 showed comparable success and complication rates in pediatric patients after minimally invasive or open pyeloplasty (22). A recent retrospective cohort study using the national Premier database revealed that while the total number of pyeloplasties decreased by 7% annually between 2003 and 2015, robotic cases increased by 29% annually, accounting for 40% of all cases in 2015 (23). Increased robot utilization was greatest in the pediatric population. Complication rates were similarly low in open and robotic cases.

UPJ Reconstruction, Special/Complex Cases

Stones and/or UPJ polyps, if present, may be addressed concomitantly with retroperitoneoscopic or transperitoneal robotic pyeloplasty (24–27). Concurrent pyelolithotomy and pyeloplasty is safe and effective, with acceptable stone-free rates

(94, 83, and 72% at 1, 3, and 6 months, respectively) (25). Operative time was longer for pyeloplasty with pyelolithotomy (median 151 min) vs. pyeloplasty alone (120 min, $p < 0.0001$), with no difference in length of hospital stay.

Ureteral fibroepithelial polyps are an uncommon but important source of obstructive hydronephrosis in children and can be challenging to diagnose preoperatively (24). If a polyp is suspected, endoscopy may be the preferred approach. However, in cases of large or multifocal lesions, or if a concurrent UPJ stenosis is thought to be present, robotics provide superior definitive management (26).

Redo (salvage) pyeloplasties present a special challenge. Dense peripelvic fibrosis, longer strictures, and compromised vascularity may all contribute to the increased difficulty in such cases. One recent study looking at laparoscopic redo pyeloplasties found that operative times were longer compared to primary cases (191 vs. 145 min, $p = 0.0001$), but success rates were comparable at 93.3% (28). Other groups have reported success rates from 77.8 to 100% for small cohorts undergoing redo pyeloplasty (29–32). Use of buccal mucosal onlay grafts for robotic salvage pyeloplasty (33, 34) and complex ureteral stricture repairs (35–37) has been shown to be safe and effective with short-term follow up.

Ureterocalicostomy is an option for renal salvage in cases where pyeloplasty is not feasible. The open procedure was originally described by Neuwirt (38). Indications for ureterocalicostomy are relative and may include UPJ obstruction in with an intrarenal pelvis or recurrent UPJ obstruction with dense scarring making redo pyeloplasty difficult or impossible. It has been considered a last resort for kidney preservation, as an alternative to nephrectomy (39). Robotic ureterocalicostomy was first reported in the pediatric population by Casale et al. with steps based on the open procedure (40). These authors retrospectively studied 9 pediatric patients who underwent transperitoneal robotic ureterocalicostomy in the setting of recurrent UPJ obstruction or intrarenal UPJ. Two patients underwent concomitant ureteroscopic stone treatment. The hilum was mobilized to allow for rapid vascular control; however, hilar clamping was not required in any case. Diuretic renogram confirmed unobstructed systems in all patients 12 months postoperatively (40).

MID URETERAL RECONSTRUCTION

UU for mid Ureteral Stricture

RAL end-to-end UU may be indicated in the setting of mid ureteral stricture. Port placement for mid ureteral reconstruction can be achieved in a fashion similar to that described above for proximal ureteral reconstruction, with the ports shifted slightly inferiorly if needed. The diseased segment may be excised, and both ends spatulated at opposite aspects to achieve a wide anastomosis. For a relatively short stricture, a Heineke-Mikulicz repair may be adequate (41).

For long or multiple mid ureteral strictures, tension-free end-to-end anastomosis may not be possible. In such cases, the use of a graft may obviate the need for more morbid procedures such as ileal ureter, transureteroureterostomy, or autotransplantation. Buccal mucosal grafts may be used for complex pyeloplasties (33, 34) or complex ureteral stricture repairs (35–37). Use of the appendix as a ureteral substitute or as an onlay flap has also been described for complex right mid or upper ureteral stricture repair, initially in the open (42–44) or laparoscopic (45, 46) settings. Recently, Yarlagadda et al published a case report of robotic appendiceal interposition for right-sided ureteral stricture disease (47). In this case, a 5 cm obliterative ureteral stricture secondary to recurrent ureterolithiasis and pyelonephritis was repaired with interposition of the appendix between the proximal and distal healthy ureter. Resolution of hydronephrosis and flank pain was demonstrated at 10 months. Long-term results using this technique are needed.

LOWER URETERAL RECONSTRUCTION

Extravesical Reimplantation for VUR

The most common RAL distal ureteral surgery is extravesical ureteral reimplantation for VUR, following steps of the open Lich-Gregoir technique originally described in the 1960s (48, 49) VUR may also be treated endoscopically or with open or laparoscopic transvesical reimplantation. Open ureteral reimplantation has a reported success of 93.5–98% (50–52). Endoscopic VUR treatment is the least invasive option, but is associated with variable radiographic cure rates of 67–93% (53–57). Success is likely dependent on technique, surgeon experience, and patient factors. The hydrodistention implantation technique (HIT) provides better outcomes than the older subureteric transurethral injection (STING) procedure, and several authors have reported radiographic success rates ≥80% (58–60). The Double HIT has emerged as the most common injection technique in the United States (61), affording the highest endoscopic success rates (57, 62).

Patient positioning for RAL distal ureteral procedures is typically lithotomy for the Si, allowing for cystoscopy (if desired) and robotic surgery in a single prep and drape. The robot is docked between the legs in this scenario. Side-docking is also possible, especially with the Xi, allowing the patient to remain supine. Port placement at our institution involves an 8.5 mm Si robotic camera port at the umbilicus with open Hasson or Veress technique. One may also use a 10 or 12 mm port (e.g., the Autosuture® balloon trocar) for the Si robot (5). Xi camera and working ports are identical, allowing the camera to go through any of the ports.

After camera port placement, working ports are placed on either side of the umbilicus. These are placed inferiorly to the camera port to create a triangular working field for Si (**Figure 1C**), or in a line for the Xi. One may use 8 or 5 mm working ports for the Si, whereas only 8 mm instruments are available for the Xi. The HIdES port placement technique for lower urinary tract reconstruction involves placing the working ports at or below the level of a typical Pfannenstiel incision (**Figure 1D**) (6). Assistant port(s) and/or 3rd robotic port may be placed; however, we generally find this unnecessary. Unless the Xi and proprietary OR table are being used, one must adjust table height and position prior to docking.

Once docked, the first steps are opening the peritoneum (**Figure 2**) and mobilizing the ureter with judicious cautery use. The ureter is then followed distally to the ureterovesical junction (UVJ), taking care to preserve vas or uterine arteries in a boy or girl, respectively. A bladder hitch stitch may be utilized if the bladder is floppy and UVJ not clearly seen. A detrusor tunnel is created in the appropriate trajectory. The ideal location for detrusor tunnel may be more apparent in the absence of a hitch stitch, which may distort the anatomy. Ideal detrusor tunnel length has been described as 5:1 in comparison with the ureteral diameter (10). Flaps are developed on either side of the tunnel in order to prevent obstruction. Lastly, the tunnel is closed over the ureter. We use a running 3–0 V-loc for this, starting at the distal-most aspect and running proximally. Others may use different suture types, interrupted instead of running, and/or may start proximally, according to surgeon preference.

VUR resolution rates after extravesical RAL ureteral reimplantation (RALUR) reported in the literature range from 66.7 to 100% in multiple relatively small series (63–73). Overall success upon pooling these series is 91% (74). A multi-institutional retrospective study reported radiographic resolution in 87.9% of 280 ureters (75). More recently, a large prospective multi-institutional study reported 93.8% resolution in 199 ureters (76).

RALUR may be performed bilaterally; however, there is concern that bilateral dissection of the posterior bladder may disrupt the pelvic nerve plexus, resulting in higher rates of postoperative urinary retention. Nerve-sparing dissection has been proposed to reduce this complication (77). In 2008, Casale et al. reported a 97.6% success rate following bilateral nerve-sparing RALUR in 41 patients (65). There were no complications or instances of urinary retention. Herz et al. reported a 91.7% success rate for unilateral RALUR but a success rate of only 77.8% of ureters (72.2% of children) for bilateral cases (78). In this study, complication rates (including ureteral obstruction, readmission, and urinary retention) were higher for bilateral cases. A nerve-sparing technique was not utilized.

Peri-ureteral diverticula (if present) may be reduced/excised during reimplantation (79). In duplex systems, common sheath reimplantation with or without tapering has been described with good outcomes (80). Ureteral tapering may be performed while maintaining the native UVJ in the

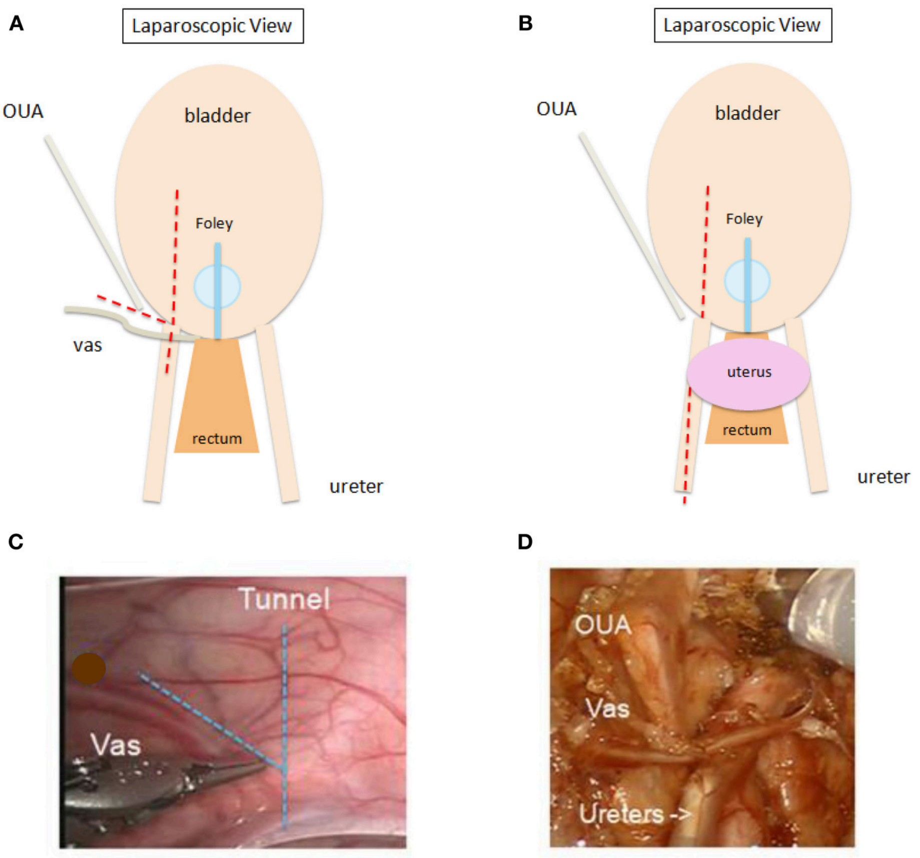

FIGURE 2 | (A,B) Schematic showing sites for opening peritoneum (- - -) during RAL ureteral reimplantation. Peritoneum may be opened in line with proposed detrusor tunnel or transversely for wider exposure. "V" flap **(A)** recommended for adequately exposing vas deferens in boys. One may open peritoneum further cephalad along the ureter to allow for additional ureteral mobilization **(B)**, especially in peri- or post-pubertal girls or in otherwise complex cases. OUA, obliterated umbilical artery. **(C,D)** Intraoperative view prior to **(C)** and after **(D)** opening peritoneum in a male patient. OUA, obliterated umbilical artery.

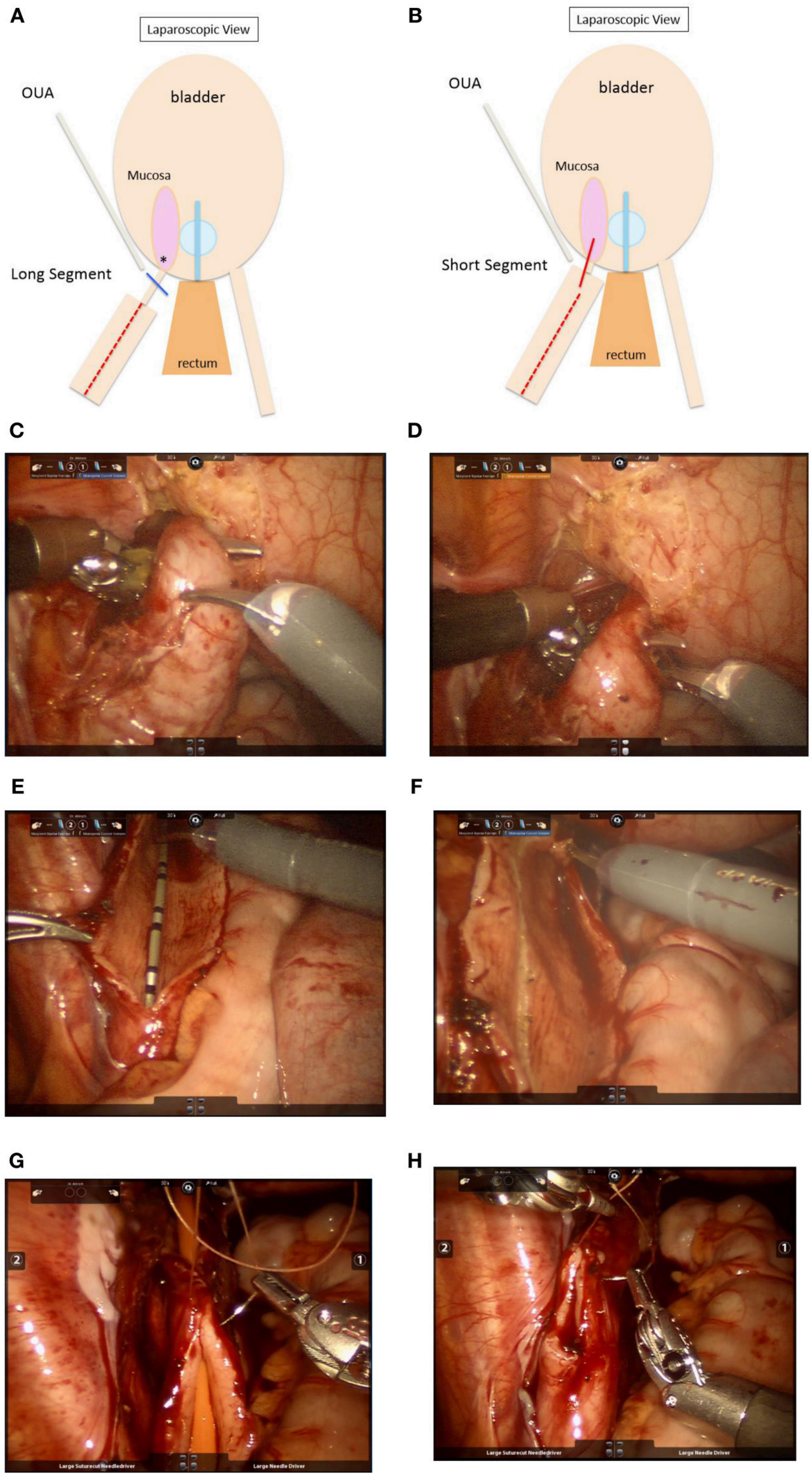

FIGURE 3 | (A) Schematic showing repair of obstructed megaureter with a long segment of stenotic UVJ. Steps: i. Keep ureter attached. ii. Taper megaureter (- - -) iii. Ligate UVJ (—). iv. Dismember ureter. v. Anastomosis at new site (*). Stent ± peritoneal closure. OUA, obliterated umbilical artery. **(B)** Repair of obstructed megaureter with a short stenotic UVJ segment. Steps: i. Keep ureter attached. ii. Taper megaureter (- - -) iii. Partially dismember (—). iv. *In situ* Heineke-Mikulicz anastomosis. Stent ± peritoneal closure. OUA, obliterated umbilical artery. **(C)** Intraoperative view during robotic repair of a left obstructed megaureter. The ureter has been mobilized circumferentially without devascularizing it. **(D)** The distally narrowed and obstructed segment is apparent in the view above. **(E)** A longitudinal

(Continued)

FIGURE 3 | ureterotomy has been created to allow for tapering. In this view, the ureter is still attached at the UVJ in order to maintain traction during tapering. **(F)** The ureter is scored to demarcate excess tissue for excisional tapering. **(G,H)** After excision of excess tissue, the ureter is closed/tapered using fine absorbable suture (5–0 Vicryl in the case above) over a 10 Fr catheter. The next steps include dismemberment at the UVJ, creation of ureteroneocystostomy, and creation of a detrusor tunnel to achieve a nonobstructed, nonrefluxing reimplantation.

setting of a non-obstructed, refluxing megaureter (81). For complex reimplants (i.e., those with history of prior anti-reflux surgery, requiring tapering and/or dismembering, or associated duplication or diverticulum), Arlen et al. found comparable success and complication rates for RAL vs. open cases, with shorter hospitalization in the RAL group (82). Older children were more likely to undergo RALUR.

Extravesical Reimplantation for UVJ Obstruction/Obstructed Megaureter

RAL dismembered extravesical ureteral reimplantation with or without tapering may be used for repair of obstructed megaureters (**Figures 3A,C–H**) (83, 84). The obstructed UVJ is divided, and a new ureteroneocystostomy anastomosis is created. A non-refluxing detrusor tunnel is created as described above. When tapering, we prefer to leave the ureter connected to the bladder during this process to provide retraction. Dismemberment is then performed after tapering is complete, similar to the process described by Khan et al. (85). A non-dismembered technique may also be used to repair obstructed megaureters, using the Heineke-Mikulicz principle (**Figure 3B**) (86).

UU in Duplex Systems

In appropriate duplex systems, end-to-side ureteroureterostomy (UU) can be performed proximally or distally depending on surgeon preference. We favor a distal approach, eliminating risk of hilar vessel injury, and allowing for intraoperative decision-making regarding performance of UU vs. ureteral reimplantation (vs. both concurrently in select settings). In some cases, it may be safer and more efficacious to perform UU in the mid ureter, thus avoiding both pelvic structures and renal hilar anatomy. Upper-to-lower UU may be performed for obstructed and/or ectopic upper moiety when there is no vesicoureteral reflux (VUR) into the lower moiety. Lower-to-upper UU may be performed in the setting of lower moiety VUR and unobstructed non-ectopic upper moiety (80).

Robot-assisted UU is a safe and effective alternative to open UU in children, with similar operative times and complication rates, and slightly shorter hospitalizations (87). UU has been shown to be safe and effective even in the setting of a minimally functioning/non-functioning moiety (as an alternative to upper moiety heminephrectomy) and irrespective of ureteral size difference (88).

When performing RAL UU, it is imperative to correctly identify each ureter. This can be facilitated with cystourethroscopy and passage of a temporary ureteral stent into one of the ureters. It is our practice to leave a double-J ureteral stent across the anastomosis, which is removed 4–6 weeks postoperatively. A renal-bladder ultrasound is performed ∼4 weeks after stent removal, with additional imaging as clinically indicated.

CONCLUSION

RAL surgery is a safe, minimally invasive technique with various applications in pediatric ureteric reconstruction. A robotic approach allows access to the ureter at all levels. Multiple aspects of robotic surgery, including magnified three-dimensional view and wristed movements with multiple degrees of freedom, are particularly well-suited to these delicate reconstructive procedures. Robotic surgery continues to enjoy growing popularity among urologists and patient families alike.

AUTHOR CONTRIBUTIONS

AB and AK both contributed to deciding the structure, content of the manuscript and to writing, editing the manuscript.

REFERENCES

1. Van Batavia JP, Casale P. Robotic surgery in pediatric urology. *Curr Urol Rep.* (2014) 15:402. doi: 10.1007/s11934-014-0402-9
2. Olsen LH, Rawashdeh YF, Jorgensen TM. Pediatric robot assisted retroperitoneoscopic pyeloplasty: a 5-year experience. *J Urol.* (2007) 178:2137–2141. Discussion 2141. doi: 10.1016/j.juro.2007.07.057
3. Romero FR, Wagner AA, Trapp C, Permpongkosol S, Muntener M, Link RE, et al. Transmesenteric laparoscopic pyeloplasty. *J Urol.* (2006) 176(6 Pt 1):2526–9. doi: 10.1016/j.juro.2006.07.155
4. Spinoit AF, Nguyen H, Subramaniam R. Role of robotics in children: a brave New World! *Eur Urol Focus.* (2017) 3:172–80. doi: 10.1016/j.euf.2017.08.011
5. Chang C, Steinberg Z, Shah A, Gundeti MS. Patient positioning and port placement for robot-assisted surgery. *J Endourol.* (2014) 28:631–8. doi: 10.1089/end.2013.0733
6. Gargollo PC. Hidden incision endoscopic surgery: description of technique, parental satisfaction and applications. *J Urol.* (2011) 185:1425–31. doi: 10.1016/j.juro.2010.11.054
7. Garcia-Roig ML, Travers C, McCracken C, Cerwinka W, Kirsch JM, Kirsch AJ. Surgical scar location preference for pediatric kidney and pelvic surgery: a crowdsourced survey. *J Urol.* (2017) 197(3 Pt 2):911–9. doi: 10.1016/j.juro.2016.11.033
8. Amon Sesmero JH, Delgado MC, de la Cruz Martin B, Serrano MR, Mainez Rodriguez JA, Tapia Herrero AM. Laparoscopic pyeloplasty: always dismembered? *J Endourol.* (2016) 30:778–82. doi: 10.1089/end.2015.0800
9. Szydelko T, Apoznanski W, Koleda P, Rusiecki L, Janczak D. Laparoscopic pyeloplasty with cephalad translocation of the crossing vessel-a new approach to the Hellstrom technique. *Wideochir Inne Tech Maloinwazyjne.* (2015) 10:25–9. doi: 10.5114/wiitm.2015.48695
10. Wein AJ, Kavoussi LR, Campbell MF. Chapter 41: Management of upper urinary tract obstruction. In: Wein AJ, Kavoussi LR, et al, editors. *Campbell-Walsh Urology*. 10th ed. Philadelphia, PA: Elsevier Saunders (2012). p. 1122–68.

11. Janetschek G, Peschel R, Bartsch G. Laparoscopic fenger plasty. *J Endourol.* (2000) 14:889–93. doi: 10.1089/end.2000.14.889
12. Fichtenbaum EJ, Strine AC, Concodora CW, Schulte M, Noh PH. Tubeless outpatient robotic upper urinary tract reconstruction in the pediatric population: short-term assessment of safety. *J Robot Surg.* (2018) 12:257–60. doi: 10.1007/s11701-017-0722-0
13. Minnillo BJ, Cruz JA, Sayao RH, Passerotti CC, Houck CS, Meier PM, et al. Long-term experience and outcomes of robotic assisted laparoscopic pyeloplasty in children and young adults. *J Urol.* (2011) 185:1455–60. doi: 10.1016/j.juro.2010.11.056
14. Mufarrij PW, Woods M, Shah OD, Palese MA, Berger AD, Thomas R, et al. Robotic dismembered pyeloplasty: a 6-year, multi-institutional experience. *J Urol.* (2008) 180:1391–6. doi: 10.1016/j.juro.2008.06.024
15. Singh P, Dogra PN, Kumar R, Gupta NP, Nayak B, Seth A. Outcomes of robot-assisted laparoscopic pyeloplasty in children: a single center experience. *J Endourol.* (2012) 26:249–53. doi: 10.1089/end.2011.0350
16. Patel V. Robotic-assisted laparoscopic dismembered pyeloplasty. *Urology.* (2005) 66:45–9. doi: 10.1016/j.urology.2005.01.053
17. Schwentner C, Pelzer A, Neururer R, Springer B, Horninger W, Bartsch G, et al. Robotic Anderson-Hynes pyeloplasty: 5-year experience of one centre. *BJU Int.* (2007) 100:880–5. doi: 10.1111/j.1464-410X.2007.07032.x
18. 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. doi: 10.1111/j.1464-410X.2009.08983.x
19. Cestari A, Buffi NM, Lista G, Sangalli M, Scapaticci E, Fabbri F, et al. Retroperitoneal and transperitoneal robot-assisted pyeloplasty in adults: techniques and results. *Eur Urol.* (2010) 58:711–8. doi: 10.1016/j.eururo.2010.07.020
20. Sivaraman A, Leveillee RJ, Patel MB, Chauhan S, Bracho JE II, Moore CR, et al. Robot-assisted laparoscopic dismembered pyeloplasty for ureteropelvic junction obstruction: a multi-institutional experience. *Urology.* (2012) 79:351–5. doi: 10.1016/j.urology.2011.10.019
21. Hopf HL, Bahler CD, Sundaram CP. Long-term outcomes of robot-assisted laparoscopic pyeloplasty for ureteropelvic junction obstruction. *Urology.* (2016) 90:106–10. doi: 10.1016/j.urology.2015.12.050
22. 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. doi: 10.1016/j.eururo.2013.06.053
23. Varda BK, Wang Y, Chung BI, 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 pediatric pyeloplasty in the United States from 2003 to 2015. *J Pediatr Urol.* (2018) 14:336.e1–8. doi: 10.1016/j.jpurol.2017.12.010
24. Dai LN, Chen CD, Lin XK, Wang YB, Xia LG, Liu, Pet al. Retroperitoneal laparoscopy management for ureteral fibroepithelial polyps causing hydronephrosis in children: a report of five cases. *J Pediatr Urol.* (2015) 11:257 e251–5. doi: 10.1016/j.jpurol.2015.02.019
25. Jensen PH, Berg KD, Azawi NH. Robot-assisted pyeloplasty and pyelolithotomy in patients with ureteropelvic junction stenosis. *Scand J Urol.* (2017) 51:323–8. doi: 10.1080/21681805.2017.1300188
26. Osbun N, Ellison JS, Lendvay TS. Robot-Assisted Laparoscopic Excision of ureteral and ureteropelvic junction fibroepithelial polyps in children. *J Endourol.* (2016) 30:896–900. doi: 10.1089/end.2016.0006
27. Skolarikos A, Dellis A, Knoll T. Ureteropelvic obstruction and renal stones: etiology and treatment. *Urolithiasis.* (2015) 43:5–12. doi: 10.1007/s00240-014-0736-2
28. Abraham GP, Siddaiah AT, Ramaswami K, George D, Das K. Laparoscopic management of recurrent ureteropelvic junction obstruction following pyeloplasty. *Urol Ann.* (2015) 7:183–7. doi: 10.4103/0974-7796.150489
29. Powell C, Gatti JM, Juang D, Murphy JP. Laparoscopic pyeloplasty for ureteropelvic junction obstruction following open pyeloplasty in children. *J Laparoendosc Adv Surg Tech A.* (2015) 25:858–63. doi: 10.1089/lap.2015.0074
30. Basiri A, Behjati S, Zand S, Moghaddam SM. Laparoscopic pyeloplasty in secondary ureteropelvic junction obstruction after failed open surgery. *J Endourol.* (2007) 21:1045–51. Discussion 1051. doi: 10.1089/end.2006.0414
31. Braga LH, Lorenzo AJ, Skeldon S, Dave S, Bagli DJ, Khoury AE, et al. Failed pyeloplasty in children: comparative analysis of retrograde endopyelotomy versus redo pyeloplasty. *J Urol.* (2007) 178:2571–5. Discussion 2575. doi: 10.1016/j.juro.2007.08.050
32. Thomas JC, DeMarco RT, Donohoe JM, Adams MC, Pope JCt, Brock JW III. Management of the failed pyeloplasty: a contemporary review. *J Urol.* (2005) 174:2363–6. doi: 10.1097/01.ju.0000180420.11915.31
33. Zampini AM, Nelson R, Zhang JJH, Reese J, Angermeier KW, Haber GP. Robotic salvage pyeloplasty with buccal mucosal onlay graft: video demonstration of technique and outcomes. *Urology.* (2017) 110:253–6. doi: 10.1016/j.urology.2017.07.023
34. Ahn JJ, Shapiro ME, Ellison JS, Lendvay TS. Pediatric robot-assisted redo pyeloplasty with buccal mucosa graft: a novel technique. *Urology.* (2017) 101:56–9. doi: 10.1016/j.urology.2016.12.036
35. Arora S, Campbell L, Tourojman M, Pucheril D, Jones LR, Rogers C. Robotic buccal mucosal graft ureteroplasty for complex ureteral stricture. *Urology.* (2017) 110:257–8. doi: 10.1016/j.urology.2017.06.037
36. Lee Z, Waldorf BT, Cho EY, Liu JC, Metro MJ, Eun DD. Robotic ureteroplasty with buccal mucosa graft for the management of complex ureteral strictures. *J Urol.* (2017) 198:1430–5. doi: 10.1016/j.juro.2017.06.097
37. Zhao LC, Yamaguchi Y, Bryk DJ, Adelstein SA, Stifelman MD. Robot-assisted ureteral reconstruction using buccal mucosa. *Urology.* (2015) 86:634–8. doi: 10.1016/j.urology.2015.06.006
38. Neuwirt K. Implantation of the ureter into the lower calyx of the renal pelvis. *Urol Cutaneous Rev.* (1948) 52:351.
39. Gite VA, Siddiqui AK, Bote SM, Patil SR, Kandi AJ, Nikose JV. Ureterocalycostomy - final resort in the management of secondary pelvi-ureteric junction obstruction: our experience. *Int Braz J Urol.* (2016) 42:501–6. doi: 10.1590/S1677-5538.IBJU.2015.0368
40. Casale P, Mucksavage P, Resnick M, Kim SS. Robotic ureterocalicostomy in the pediatric population. *J Urol.* (2008) 180:2643–8. doi: 10.1016/j.juro.2008.08.052
41. Goel A, Singh D, Sengottayan VK, Sankhwar S. Nondismembered ureteroplasty for congenital midureteral stenosis: a new application of an old technique. *Urology.* (2010) 76:1004–6. doi: 10.1016/j.urology.2010.03.093
42. Adani GL, Pravisani R, Baccarani U, Bolgeri M, Lorenzin D, Terrosu G, et al. Extended ureteral stricture corrected with appendiceal replacement in a kidney transplant recipient. *Urology.* (2015) 86:840–3. doi: 10.1016/j.urology.2015.06.010
43. Murai R, Ushida H, Osafune T, Johnin K, Kageyama S, Okada Y. [Repair of right ureteral stenosis by traumatic injury with appendiceal interposition: a case report]. *Nihon Hinyokika Gakkai Zasshi.* (2013) 104:667–70. doi: 10.5980/jpnjurol.104.667
44. Dagash H, Sen S, Chacko J, Karl S, Ghosh D, Parag P, et al. The appendix as ureteral substitute: a report of 10 cases. *J Pediatr Urol.* (2008) 4:14–9. doi: 10.1016/j.jpurol.2007.08.004
45. Duty BD, Kreshover JE, Richstone L, Kavoussi LR. Review of appendiceal onlay flap in the management of complex ureteric strictures in six patients. *BJU Int.* (2015) 115:282–7. doi: 10.1111/bju.12651
46. Reggio E, Richstone L, Okeke Z, Kavoussi LR. Laparoscopic ureteroplasty using on-lay appendix graft. *Urology.* (2009) 73:928 e927–10. doi: 10.1016/j.urology.2008.06.034
47. Yarlagadda VK, Nix JW, Benson DG, Selph JP. Feasibility of intracorporeal robotic-assisted laparoscopic appendiceal interposition for ureteral stricture disease: a case report. *Urology.* (2017) 109:201–5. . doi: 10.1016/j.urology.2017.08.017
48. Gregoir W. [The Surgical Treatment of Congenital Vesico-Ureteral Reflux]. *Acta Chir Belg.* (1964) 63:431–9.
49. Robert Lich Jr., Lonnie WH, and Lawrence AD. Recurrent urosepsis in children. *J Urol.* (1961) 86:554–8. doi: 10.1016/S0022-5347(17)65219-4
50. Nelson CP, Hubert KC, Kokorowski PJ, Huang L, Prasad MM, Rosoklija I, et al. Long-term incidence of urinary tract infection after ureteral reimplantation for primary vesicoureteral reflux. *J Pediatr Urol.* (2013) 9:92–8. doi: 10.1016/j.jpurol.2011.12.009

51. Elder JS, Peters CA, Arant BS Jr, Ewalt DH, Hawtrey CE, Hurwitz RS, et al. Pediatric Vesicoureteral Reflux Guidelines Panel summary report on the management of primary vesicoureteral reflux in children. *J Urol.* (1997) 157:1846–51. doi: 10.1016/S0022-5347(01)64882-1
52. Barrieras D, Lapointe S, Reddy PP, Williot P, McLorie GA, Bigli D, et al. Are postoperative studies justified after extravescial ureteral reimplantation? *J Urol.* (2000) 164(3 Pt 2):1064–6. doi: 10.1016/S0022-5347(05)67251-5
53. Hacker FM, Frech-Dorfler M, von Rotz M, Rudin C. Endoscopic hyaluronic acid/dextranomer gel implantation is effective as first-line treatment of vesicoureteral reflux (VUR) in children: a single centre experience. *Eur J Pediatr Surg.* (2011) 21:299–303. doi: 10.1055/s-0031-1279700
54. Elder JS, Diaz M, Caldamone AA, Cendron M, Greenfield S, Hurwitz R, et al. Endoscopic therapy for vesicoureteral reflux: a meta-analysis. I. Reflux resolution and urinary tract infection. *J Urol.* (2006) 175:716–22. doi: 10.1016/S0022-5347(05)00210-7
55. Friedmacher F, Colhoun E, Puri P. Endoscopic injection of dextranomer/hyaluronic acid as first line treatment in 851 consecutive children with high grade vesicoureteral reflux: efficacy and long-term results. *J Urol.* (2018) 200:650–5. doi: 10.1016/j.juro.2018.03.074
56. Kaye JD, Srinivasan AK, Delaney C, Cerwinka WH, Elmore JM, Scherz HC, et al. Clinical and radiographic results of endoscopic injection for vesicoureteral reflux: defining measures of success. *J Pediatr Urol.* (2012) 8:297–303. doi: 10.1016/j.jpurol.2011.02.006
57. Kalisvaart JF, Scherz HC, Cuda S, Kaye JD, Kirsch AJ. Intermediate to long-term follow-up indicates low risk of recurrence after Double HIT endoscopic treatment for primary vesico-ureteral reflux. *J Pediatr Urol.* (2012) 8:359–65. doi: 10.1016/j.jpurol.2011.07.006
58. Lee EK, Gatti JM, Demarco RT, Murphy JP. Long-term followup of dextranomer/hyaluronic acid injection for vesicoureteral reflux: late failure warrants continued followup. *J Urol.* (2009) 181:1869–74. Discussion 1874–65. doi: 10.1016/j.juro.2008.12.005
59. Gupta A, Snodgrass W. Intra-orifice versus hydrodistention implantation technique in dextranomer/hyaluronic acid injection for vesicoureteral reflux. *J Urol.* (2008) 180(4 Suppl.):1589–92. Discussion 1592–83. doi: 10.1016/j.juro.2008.04.073
60. Shim JS, Kim JW, Oh MM, Moon du G. Efficacy of hydrodistention implantation technique in treating high-grade vesicoureteral reflux. *Korean J Urol.* (2012) 53:194–9. doi: 10.4111/kju.2012.53.3.194
61. Kirsch AJ, Arlen AM, Lackgren G. Current trends in dextranomer hyaluronic acid copolymer (Deflux) injection technique for endoscopic treatment of vesicoureteral reflux. *Urology.* (2014) 84:462–8. doi: 10.1016/j.urology.2014.04.032
62. Molitierno JA, Scherz HC, Kirsch AJ. Endoscopic treatment of vesicoureteral reflux using dextranomer hyaluronic acid copolymer. *J Pediatr Urol.* (2008) 4:221–8. doi: 10.1016/j.jpurol.2007.11.015
63. Chan KW, Lee KH, Tam YH, Sihoe JD. Early experience of robotic-assisted reconstructive operations in pediatric urology. *J Laparoendosc Adv Surg Tech A.* (2010) 20:379–82. doi: 10.1089/lap.2009.0340
64. Lee RS, Sethi AS, Passerotti CC, Peters CA. Robot-assisted laparoscopic nephrectomy and contralateral ureteral reimplantation in children. *J Endourol.* (2010) 24:123–8. doi: 10.1089/end.2009.0271
65. Casale P, Patel RP, Kolon TF. Nerve sparing robotic extravesical ureteral reimplantation. *J Urol.* (2008) 179:1987–9. Discussion 1990. doi: 10.1016/j.juro.2008.01.062
66. Marchini GS, Hong YK, Minnillo BJ, Diamond DA, Houck CS, Meier PM, et al. Robotic assisted laparoscopic ureteral reimplantation in children: case matched comparative study with open surgical approach. *J Urol.* (2011) 185:1870–5. doi: 10.1016/j.juro.2010.12.069
67. Smith RP, Oliver JL, Peters CA. Pediatric robotic extravesical ureteral reimplantation: comparison with open surgery. *J Urol.* (2011) 185:1876–81. doi: 10.1016/j.juro.2010.12.072
68. Chalmers D, Herbst K, Kim C. Robotic-assisted laparoscopic extravesical ureteral reimplantation: an initial experience. *J Pediatr Urol.* (2012) 8:268–71. doi: 10.1016/j.jpurol.2011.04.006
69. Kasturi S, Sehgal SS, Christman MS, Lambert SM, Casale P. Prospective long-term analysis of nerve-sparing extravesical robotic-assisted laparoscopic ureteral reimplantation. *Urology.* (2012) 79:680–3. doi: 10.1016/j.urology.2011.10.052
70. Callewaert PR, Biallosterski BT, Rahnama'i MS, Van Kerrebroeck PE. Robotic extravesical anti-reflux operations in complex cases: technical considerations and preliminary results. *Urol Int.* (2012) 88:6–11. doi: 10.1159/000332953
71. Gundeti MS, Kojima Y, Haga N, Kiriluk K. Robotic-assisted laparoscopic reconstructive surgery in the lower urinary tract. *Curr Urol Rep.* (2013) 14:333–41. doi: 10.1007/s11934-013-0328-7
72. Schomburg JL, Haberman K, Willihnganz-Lawson KH, Shukla AR. Robot-assisted laparoscopic ureteral reimplantation: a single surgeon comparison to open surgery. *J Pediatr Urol.* (2014) 10:875–9. doi: 10.1016/j.jpurol.2014.02.013
73. Akhavan A, Avery D, Lendvay TS. Robot-assisted extravesical ureteral reimplantation: outcomes and conclusions from 78 ureters. *J Pediatr Urol.* (2014) 10:864–8. doi: 10.1016/j.jpurol.2014.01.028
74. Grimsby GM, Dwyer ME, Jacobs MA, Ost MC, Schneck FX, Cannon GM, et al. Multi-institutional review of outcomes of robot-assisted laparoscopic extravesical ureteral reimplantation. *J Urol.* (2015) 193(5 Suppl.):1791–5. doi: 10.1016/j.juro.2014.07.128
75. Boysen WR, Ellison JS, Kim C, Koh CJ, Noh P, Whittam B, et al. Multi-institutional review of outcomes and complications of robot-assisted laparoscopic extravesical ureteral reimplantation for treatment of primary vesicoureteral reflux in children. *J Urol.* (2017) 197:1555–61. doi: 10.1016/j.juro.2017.01.062
76. Boysen WR, Akhavan A, Ko J, Ellison JS, Lendvay TS, Huang J, et al. Prospective multicenter study on robot-assisted laparoscopic extravesical ureteral reimplantation (RALUR-EV): Outcomes and complications. *J Pediatr Urol.* (2018) 14:262 e261–6. doi: 10.1016/j.jpurol.2018.01.020
77. David S, Kelly C, Poppas DP. Nerve sparing extravesical repair of bilateral vesicoureteral reflux: description of technique and evaluation of urinary retention. *J Urol.* (2004) 172(4 Pt 2):1617–20. Discussion 1620. doi: 10.1097/01.ju.0000139951.37492.91
78. Herz D, Fuchs M, Todd A, McLeod D, Smith J. Robot-assisted laparoscopic extravesical ureteral reimplant: a critical look at surgical outcomes. *J Pediatr Urol.* (2016) 12:402 e401–9. doi: 10.1016/j.jpurol.2016.05.042
79. Noh PH, Bansal D. Pediatric robotic assisted laparoscopy for paraureteral bladder diverticulum excision with ureteral reimplantation. *J Pediatr Urol.* (2013) 9:e28–30. doi: 10.1016/j.jpurol.2012.06.011
80. Herz D, Smith J, McLeod D, Schober M, Preece J, Merguerian P. Robot-assisted laparoscopic management of duplex renal anomaly: comparison of surgical outcomes to traditional pure laparoscopic and open surgery. *J Pediatr Urol.* (2016) 12:44 e41–7. doi: 10.1016/j.jpurol.2015.04.046
81. Faasse MA, Lindgren BW, Gong EM. Robot-assisted laparoscopic ureteral reimplantation with excisional tailoring for refluxing megaureter. *J Pediatr Urol.* (2014) 10:773 e771–2. doi: 10.1016/j.jpurol.2014.01.023
82. Arlen AM, Broderick KM, Travers C, Smith EA, Elmore JM, Kirsch AJ. Outcomes of complex robot-assisted extravesical ureteral reimplantation in the pediatric population. *J Pediatr Urol.* (2016) 12:169 e161–6. doi: 10.1016/j.jpurol.2015.11.007
83. Fu W, Zhang X, Zhang X, Zhang P, Gao J, Dong J, et al. Pure laparoscopic and robot-assisted laparoscopic reconstructive surgery in congenital megaureter: a single institution experience. *PLoS ONE.* (2014) 9:e99777. doi: 10.1371/journal.pone.0099777
84. Hemal AK, Nayyar R, Rao R. Robotic repair of primary symptomatic obstructive megaureter with intracorporeal or extracorporeal ureteric tapering and ureteroneocystostomy. *J Endourol.* (2009) 23:2041–6. doi: 10.1089/end.2009.0103
85. Khan A, Rahiman M, Verma A, Bhargava R. Novel technique of laparoscopic extravesical ureteric reimplantation in primary obstructive megaureter. *Urol Ann.* (2017) 9:150–2. doi: 10.4103/0974-7796.204182
86. Landa-Juarez S, Guerra-Rivas A, Salgado-Sangri R, Castillo-Fernandez AM, de la Cruz-Yanez H, Garcia-Hernandez C. [Laparoscopic

ureterovesical repair for megaureter treatment]. *Cir Cir.* (2017) 85:196–200. doi: 10.1016/j.circir.2016.08.003

87. 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. doi: 10.1089/end.2015.0223
88. McLeod DJ, Alpert SA, Ural Z, Jayanthi VR. Ureteroureterostomy irrespective of ureteral size or upper pole function: a single center experience. *J Pediatr Urol.* (2014) 10:616–9. doi: 10.1016/j.jpurol.2014.05.003

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

MINI REVIEW
published: 26 March 2019
doi: 10.3389/fped.2019.00090

Robotic Assisted Surgery in Pediatric Urology: Current Status and Future Directions

*Catherine J. Chen and Craig A. Peters**

Pediatric Urology, Children's Health System Texas, University of Texas Southwestern, Dallas, TX, United States

The evolution of robotic surgical technology and its application in Pediatric Urology have been rapid and essentially successful. Further development remains limited in three key areas: procedural inefficiencies, cost and integration of surgical and clinical information. By addressing these challenges through technology and novel surgical paradigms, the real potential of surgical robotics in pediatric, as well as adult applications, may ultimately be realized. With this evolution, a continued focus on patient-centered outcomes will be essential to provide optimal guidance to technical innovations.

Keywords: robotic surgery, pyeloplasty, ureteral reimplantation, pediatric, minimally invasive surgery

OPEN ACCESS

Edited by:
Miguel Alfedo Castellan, University of Miami, United States

Reviewed by:
Tiago Elias Rosito, Universidade Federal do Rio Grande do Sul (UFRGS), Brazil
Roberto Iglesias Lopes, Hospital for Sick Children, Canada

Correspondence:
Craig A. Peters
craig.peters@utsouthwestern.edu

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *11 January 2019*
Accepted: *01 March 2019*
Published: *26 March 2019*

Citation:
Chen CJ and Peters CA (2019) Robotic Assisted Surgery in Pediatric Urology: Current Status and Future Directions. Front. Pediatr. 7:90. doi: 10.3389/fped.2019.00090

BACKGROUND

Robot assisted surgical systems have revolutionized minimally invasive surgery, providing many advancements, including three-dimensional visualization, elimination of surgeon tremor, wristed instruments, and improved surgeon ergonomics. Since the first Intuitive Surgical da Vinci® surgical system was approved by the Food and Drug Administration in 2000, robot assisted surgery has been embraced by surgeons worldwide. As of September 30, 2017, 4,271 da Vinci® units have been installed, with 65% of these units installed in the United States, 17% in Europe, 15% in Asia, and 3% in the rest of the world (1).

The initial application of robot assisted surgery in the field of urology began with adult robot assisted prostatectomies and was soon applied to the pediatric population with robot assisted pyeloplasties (2). In pediatric urology, robot assisted surgery has subsequently been reported for ureteral reimplant, ureteroureterostomy, appendicovesicostomy creation, bladder neck reconstruction, and augmentation ileocystoplasty (3–8). In addition, robot assisted procedures have been reported in infants and as well as with 5 mm robotic instruments (9, 10).

Over the past 20 years, there has been continued improvement in robot assisted surgical systems with Intuitive Surgical releasing several upgrades and several other companies developing competing robotic platforms (11). As with all technological advances in medicine, patient-centered outcomes must be critically assessed and limitations identified so that technology can be continuously improved. Current limitations in robot assisted surgery can be distilled into three major categories: procedural inefficiencies, cost, and integration of surgical information.

PATIENT-CENTERED OUTCOMES

As the most common robot assisted surgery performed in children, robot assisted pyeloplasty has a more robust literature compared to that of other procedures; however, published studies are case series and not randomized controlled trials (12). Furthermore, these different studies used different criteria of outcomes such as resolution of pain, decrease in hydronephrosis on ultrasound, improved MAG3 lasix scans, duration of surgical procedure, duration of hospitalization, or use of postoperative pain medications, making meta-analysis difficult.

While the number of robot assisted ureteral reimplants is increasing in the United States, the literature demonstrates mixed results, with some groups reporting similar reflux resolution rates and other groups reporting inferior resolution rates compared to known open reimplant reflux resolution rates (3, 13–16). The variation of outcomes likely is secondary to variation in surgical technique, grades of reflux, and criteria used to evaluate resolution.

In order to truly assess patient outcomes, such as disease resolution, pain, and recovery, as well as compare results to that of open procedures, it is paramount for future research to clearly delineate all potential factors that can affect outcomes in order to accurately evaluate the efficacy of robot assisted pediatric urological surgery. As research consortia develop, it is critical for study protocols to be clearly defined so that data from different institutions can be combined. Current limitations in the literature center on the lack of consistency in terms of preoperative pathology grading as well as postoperative follow-up and definition of resolution.

In addition to disease resolution, there has been a small focus on scar location and robotic trocar placement to minimize visible scars. In many open procedures in pediatric urology, the incision site can often be placed in a location that can be easily hidden. The hidden incision endoscopic surgery (HIDES) trocar placement allows for the incision site of the trocar to be placed in a similar easily to conceal location on the abdomen while skiving in the subcutaneous fat and entering through the fascia at a higher more optimal location for robotic assisted surgery (17). In a recent survey of the general population regarding incision location for pediatric urologic surgery, many preferred incisions that could be covered by undergarments; however, this study fails to address that surgical incisions especially in children tend to heal well and fade over time (18). We have noticed in our patients who underwent laparoscopic surgery, that their port site incision scars are barely noticeable at follow-up appointments. While outcomes have been shown to be similar with the HIDES trocar placement, we recommend for surgeons especially at the beginning of their learning curve to use trocar placement locations that decrease the level of procedural difficulty (19).

LIMITATIONS: PROCEDURAL INEFFICIENCIES

A major roadblock in the implementation of robot assisted surgery to a wider spectrum of pediatric reconstructive urologic procedures centers on procedural inefficiencies. After demonstration of feasibility, any robot assisted surgical procedure is subsequently compared to the same procedure performed in an open fashion. While robot assisted pyeloplasties and less so, robot assisted ureteral reimplants have been well-integrated into the pediatric urology practice, other applications of robot assisted surgery fail to be adapted into routine practice mainly due to the extended time required to complete the procedure with robot assistance compared to the traditional open approach. This extended time can be attributed to procedural inefficiencies with robotic technology.

A key difference between open and robot assisted surgery is that in open surgery, the surgical assistant, either a trainee or a surgical first assist, actively facilitates the procedure, to allow the surgeon to perform the operation. This facilitation can range from staying still, retracting and stabilizing tissue, to active movement such as suture management, cutting, and suctioning. The key to this type of facilitation is that it is dynamic and involves an additional person working in tandem with the primary surgeon.

Our current use of the robot limits the use of an assistant and eliminates the ability for **dynamic facilitation**. While the use of the robotic fourth arm provides some facilitation in retraction, it is a static assist. If any changes need to be made, the surgeon must pause what they are currently doing to move the fourth arm, decreasing surgical efficiency.

In adult urology, the placement of additional laparoscopic ports allows for an active bedside assistant which has allowed for improved outcomes in complex procedures such as robot assisted partial nephrectomies. However, the reluctance to place additional ports due to cosmetic considerations in the pediatric population eliminates the role of a dynamic surgical facilitator. In an attempt to circumvent this limitation, many surgeons will use a hitch stitch to act as a retractor. While this technique is sufficient in simpler reconstructive procedures, the hitch stitch is static with limited ability to change positioning once it is placed.

One of the challenges of robot assisted surgical procedures is the inefficiency of suturing. Given the amount of limited working space, significant time can be spent pulling suture through as well as making sure that the suture does not tangle. While the impact is minimal in procedures with limited suturing, it can increase the surgical time significantly in cases that require large amounts of sewing, such as in robot assisted bladder augmentations.

Currently, robot assisted bladder augmentation has yet to be incorporated into routine practice due to the significant operative time needed to sew the bowel patch onto the bladder. When this procedure is performed in an open fashion, the dynamic facilitator assists the surgeon by ensuring the bowel segments are lined up to enable efficient throws as well as managing the suture and cinching down each throw so that the surgeon can focus on loading the needle and throwing the next stitch. The use of a dynamic surgical facilitator could potentially decrease operative time for this procedure robotically. Megaureter tapering is another procedure that requires increased suturing length as well as increased complexity.

There are many different approaches to improve sewing inefficiencies in robot assisted bladder augmentations. From a procedural approach, an immediate solution would be to place additional laparoscopic ports and have a bedside dynamic facilitator to assist with suture management. This does require a very skilled assistant who is completely familiar with the procedure. From a technological standpoint, development of a multi-arm surgical platform that allows for two surgeons to be operating robotically at the same time would enable robotic technology to incorporate dynamic facilitation. Currently, the

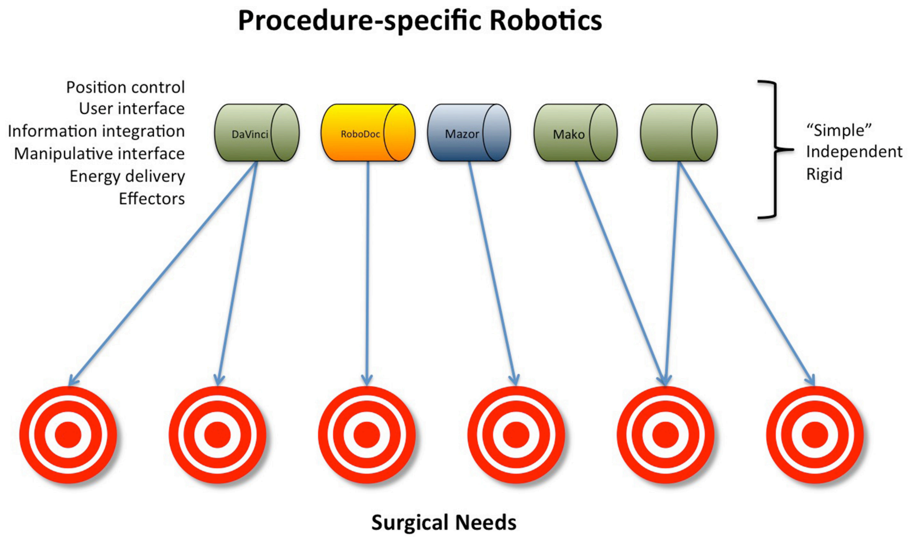

FIGURE 1 | Procedure-specific robotics.

operator sitting on the second console in a dual console system is only able to make changes in camera position while the primary surgeon console retains control over the working arms. The surgical assistant's role is significantly minimized and the assistant is often times more a spectator than a dynamic facilitator. Another technological solution might be development of a tool that could facilitate sewing and suture management.

Currently, there are two types of robotic instruments available: 5 and 8 mm instruments. In addition to the size difference, there are differences in the design of the instrument. While the 5 mm instruments are smaller, they have a different type of articulation mechanism, necessitating a larger radius of curve in order to make the similar movements compared to 8 mm instruments. This makes them suboptimal in smaller spaces such as in pediatric cases. Also, there are limited instrument options in the 5 mm size and the mechanical motion is less precise. The development of robotic instruments designed specifically for pediatric robot assisted surgery and small working spaces would be distinctly helpful. While there are studies demonstrating feasibility of 5 mm instruments in pediatric cases, many surgeons do not notice a significant difference in skin incision size and thus, use the 8 mm instruments because of more instrument options as well as increase ease of movement (10, 20). Although the first impression might be that such instruments would represent a small market, it is likely that they would find significant application in the evolving areas of adult oncological practice and reconstruction, such as trans-oral robotic procedures or endocrine surgery.

LIMITATIONS: COST

With healthcare costs increasing, we must evaluate the cost of surgical advancement. It is well-established that a robot assisted procedure costs more than its equivalent open procedure (12, 21). The majority of this is due to the high cost to purchase and maintain a robotic system and its disposable supplies. While the number of robot assisted cases are increasing, we are far from offsetting the significant cost of the robot platform.

With the da Vinci® system being the sole FDA-approved robot platform for urological surgery, it has had a monopoly on the market. There are also other robotic platforms that have been approved by the FDA; however, they are specialty and procedure specific and cannot be generally applied. The Flex® Robotic System is used and developed for transoral surgery and the Senhance™ Surgical Robotic System is designed for colorectal, transabdominal, and transthoracic procedures (11, 22–24). The inability to apply these robotic systems across specialties only increases the overall cost of healthcare. The ideal robot platform would be universal for all surgical and procedural specialties.

A potential solution to these challenges that push costs upward might be the development of robust modular robotic surgical systems. All current robotic systems involve two basic elements: positional control and end effectors (**Figure 1**). A modular robotic surgical system would integrate positional control with end-effectors that are designed to interact with specific anatomy, eliminating the need for procedure specific surgical systems (**Figure 2**). Such a design would be more cost-effective than the current designs that are limited to specific anatomy sites and procedures.

Furthermore, potentially lower value technological research and development also contributes to increased costs. While some have focused on haptics, ultimately, it is not the absence of haptics that is contributing to the ultimate problem of complex reconstructive cases taking significantly more time when performed with robot assistance compared to open surgery. There are many surrogates, such has visual cues of the tissue, that provide the same feedback to the surgeon.

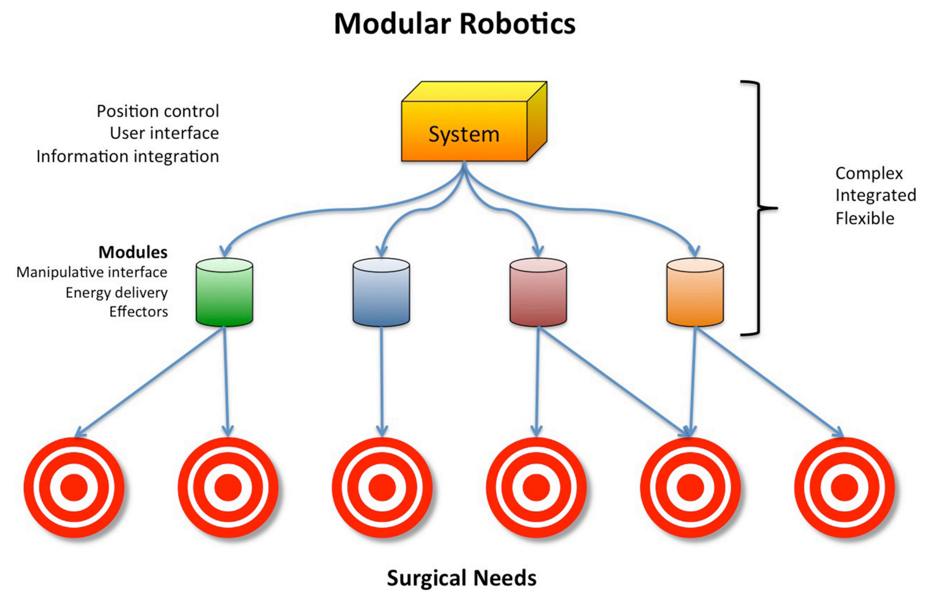

FIGURE 2 | Modular robotics.

Thus, it is crucial for surgeons to work with scientists and engineers to guide robotic advances. It is key for surgeons to step back and critically assess the barriers that we are encountering in procedures in order to better guide robotic research and development.

LIMITATIONS: INTEGRATION OF SURGICAL INFORMATION

Currently, the majority of surgeons use the robot as a surgical tool; however, there are adjunctive features that enhance the surgeon's ability to make surgical decisions, including Firefly™ and intraoperative ultrasound. The Firefly™ technology uses fluorescent aided imaging to help the surgeon identify vascular perfusion, which can help identify healthy tissue as well as normal vs. malignant tissue. The intraoperative ultrasound feature allows the surgeon to identify difficult to visualize structures. These technologies represent the simplest forms of informational integration in robotic surgery.

There is significant potential for the robot platform to become an information integration system, where digital imaging such as CT or MRI scans can be superimposed on the surgical field to allow for more precise surgical planning and mapping, as well as aid in difficult dissections. This allows the procedure to be personalized to the individual and the individual's pathology, and provides a more robust "view" of the surgical field. Even further informational integration may be feasible as well, with the fusion of anatomic and instrument positional data to facilitate surgical navigation. Autonomous or semi-autonomous actions of the robot have been explored and may further permit more efficient and effective interventions (25).

CONCLUSION

While robot assisted surgery has greatly improved minimally invasive surgery, we are far from perfecting this technology. Going forward, teamwork is key. Given the small procedural numbers at single pediatric institutions, the application of research consortia can help identify specific needs for surgical techniques to optimize outcomes. It is also critical to have open communication between physicians and engineers to develop new technology that will truly increase the applicability of robot assisted surgical technology.

AUTHOR CONTRIBUTIONS

CC researched and wrote the review. CP conceived the theme and key elements, reviewed, and edited the article.

REFERENCES

1. FAQ. Available online at: https://isrg.gcs-web.com/investor-faqs
2. Atug F, Woods M, Burgess SV, Castle EP, Thomas R. Robotic assisted laparoscopic pyeloplasty in children. *J Urol.* (2005) 174(4 Pt 1):1440–2. doi: 10.1097/01.ju.0000173131.64558.c9
3. Akhavan A, Avery D, Lendvay TS. Robot-assisted extravesical ureteral reimplantation: outcomes and conclusions from 78 ureters. *J Pediatr Urol.* (2014) 10:864–8. doi: 10.1016/j.jpurol.2014.01.028
4. Biles MJ, Finkelstein JB, Silva MV, Lambert SM, Casale P. Innovation in robotics and pediatric urology: robotic ureteroureterostomy for

duplex systems with ureteral ectopia. *J Endourol.* (2016) 30:1041–8. doi: 10.1089/end.2015.0645
5. Gundeti MS, Eng MK, Reynolds WS, Zagaja GP. Pediatric robotic-assisted laparoscopic augmentation ileocystoplasty and Mitrofanoff appendicovesicostomy: complete intracorporeal–initial case report. *Urology.* (2008) 72:1144–7; discussion: 1147. doi: 10.1016/j.urology.2008.06.070
6. Gundeti MS, Petravick ME, Pariser JJ, Pearce SM, Anderson BB, Grimsby GM, et al. A multi-institutional study of perioperative and functional outcomes for pediatric robotic-assisted laparoscopic Mitrofanoff appendicovesicostomy. *J Pediatr Urol.* (2016) 12:386.e1–e5. doi: 10.1016/j.jpurol.2016.05.031
7. Nguyen HT, Passerotti CC, Penna FJ, Retik AB, Peters CA. Robotic assisted laparoscopic Mitrofanoff appendicovesicostomy: preliminary experience in a pediatric population. *J Urol.* (2009) 182:1528–34. doi: 10.1016/j.juro.2009.06.055
8. Bagrodia A, Gargollo P. Robot-assisted bladder neck reconstruction, bladder neck sling, and appendicovesicostomy in children: description of technique and initial results. *J Endourol.* (2011) 25:1299–305. doi: 10.1089/end.2011.0031
9. Avery DI, Herbst KW, Lendvay TS, Noh PH, Dangle P, Gundeti MS, et al. Robot-assisted laparoscopic pyeloplasty: multi-institutional experience in infants. *J Pediatr Urol.* (2015) 11:139.e1–5. doi: 10.1016/j.jpurol.2014.11.025
10. Paradise HJ, Huang GO, Elizondo Sáenz RA, Baek M, Koh CJ. Robot-assisted laparoscopic pyeloplasty in infants using 5-mm instruments. *J Pediatr Urol.* (2017) 13:221–2. doi: 10.1016/j.jpurol.2016.12.011
11. Sheth KR, Van Batavia JP, Bowen DK, Koh CJ, Srinivasan AK. Minimally invasive surgery in pediatric urology: adaptations and new frontiers. *Urol Clin North Am.* (2018) 45:611–21. doi: 10.1016/j.ucl.2018.06.008
12. Mahida JB, Cooper JN, Herz D, Diefenbach KA, Deans KJ, Minneci PC, et al. Utilization and costs associated with robotic surgery in children. *J Surg Res.* (2015) 199:169–76. doi: 10.1016/j.jss.2015.04.087
13. Arlen AM, Broderick KM, Travers C, Smith EA, Elmore JM, Kirsch AJ. Outcomes of complex robot-assisted extravesical ureteral reimplantation in the pediatric population. *J Pediatr Urol.* (2016) 12:169.e1–6. doi: 10.1016/j.jpurol.2015.11.007
14. Timberlake MD, Peters CA. Current status of robotic-assisted surgery for the treatment of vesicoureteral reflux in children. *Curr Opin Urol.* (2017) 27:20–6. doi: 10.1097/MOU.0000000000000357
15. Grimsby GM, Dwyer ME, Jacobs MA, Ost MC, Schneck FX, Cannon GM, et al. Multi-institutional review of outcomes of robot-assisted laparoscopic extravesical ureteral reimplantation. *J Urol.* (2015) 193(5 Suppl.):1791–5. doi: 10.1016/j.juro.2014.07.128
16. Bowen DK, Faasse MA, Liu DB, Gong EM, Lindgren BW, Johnson EK. Use of Pediatric Open, Laparoscopic and Robot-Assisted Laparoscopic Ureteral Reimplantation in the United States: 2000 to 2012. *J Urol.* (2016) 196:207–12. doi: 10.1016/j.juro.2016.02.065
17. Gargollo PC. Hidden incision endoscopic surgery: description of technique, parental satisfaction and applications. *J Urol.* (2011) 185:1425–31. doi: 10.1016/j.juro.2010.11.054
18. Garcia-Roig ML, Travers C, McCracken C, Cerwinka W, Kirsch JM, Kirsch AJ. Surgical scar location preference for pediatric kidney and pelvic surgery: a crowdsourced survey. *J Urol.* (2017) 197(3 Pt 2):911–9. doi: 10.1016/j.juro.2016.11.033
19. Hong YH, DeFoor WR, Reddy PP, Schulte M, Minevich EA, VanderBrink BA, et al. Hidden incision endoscopic surgery (HIdES) trocar placement for pediatric robotic pyeloplasty: comparison to traditional port placement. *J Robot Surg.* (2018) 12:43–7. doi: 10.1007/s11701-017-0684-2
20. Baek M, Silay MS, Au JK, Huang GO, Elizondo RA, Puttmann KT, et al. Does the use of 5 mm instruments affect the outcomes of robot-assisted laparoscopic pyeloplasty in smaller working spaces? A comparative analysis of infants and older children. *J Pediatr Urol.* (2018) 14:537.e1–6. doi: 10.1016/j.jpurol.2018.06.010
21. Behan JW, Kim SS, Dorey F, De Filippo RE, Chang AY, Hardy BE, et al. Human capital gains associated with robotic assisted laparoscopic pyeloplasty in children compared to open pyeloplasty. *J Urol.* (2011) 186(4 Suppl):1663–7. doi: 10.1016/j.juro.2011.04.019
22. U.S. Food & Drug Administration. *FDA Clears New Robotically-Assisted Surgical Device for Adult Patients.* (2017). Available online at: http://news.doximity.com/entries/9699292?authenticated=false
23. Medrobotics. *Medrobotics® Corporation Receives FDA Clearance for Flex® Robotic System for Scarfree® Colorectal Procedures.* (2017).
24. Medrobotics. *Medrobotics® Corporation Receives FDA Clearance for World's First and Only Flexible Transabdominal and Transthoracic Robotic Scope.* (2018).
25. Shademan A, Decker RS, Opfermann JD, Leonard S, Krieger A, Kim PC. Supervised autonomous robotic soft tissue surgery. *Sci Transl Med.* (2016) 8:337ra64. doi: 10.1126/scitranslmed.aad9398

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

PERSPECTIVE
published: 28 March 2019
doi: 10.3389/fped.2019.00094

Pediatric Robotic Surgery in South America: Advantages and Difficulties in Program Implementation

Juan M. Moldes[1]*, *Francisco Ignacio de Badiola*[1], *Roberto Luis Vagni*[1], *Pedro Mercado*[1], *Virginia Tuchbaum*[1], *Marcos G. Machado*[2] *and Pedro José López*[3]

[1] Department Pediatric Surgery, Hospital Italiano de Buenos Aires, Buenos Aires, Argentina, [2] Department of Urology, Faculdade de Medicina, Universidade de São Paulo, Hospital das Clínicas, São Paulo, Brazil, [3] Department Pediatric Urology, Hospital Exequiel Gonzalez Cortés y Clínica Alemana, Santiago, Chile

Robotic assisted laparoscopic surgery is gaining popularity around the world due to its vast benefits. Although it has been established mainly in developed countries, in South America the robotic programs have become more popular, but its growth is clearly slower. Information about robotic pediatric surgery program in Brazil, Chile, Uruguay, and Argentina was collected through e-mail surveys. Results were analyzed and compared to worldwide information about robotic surgery. Due to the wide social, economical, and technological gap between hospitals in South America, it is hard to develop a proper pediatric robotic surgery program. The main obstacles in those four countries appear to be a combination of high purchase costs and equipment maintenance, lack of financial coverage of the procedure by insurance companies and the absence of significant benefits proved in pediatrics in relation to laparoscopic surgery. The pediatric specialties are in the process of making and implementing robotic programs supported by the evident development in adult specialties. However, pediatric robotic surgery in Brazil, Chile, Uruguay and Argentina do not seems to share that growth.

Keywords: robotic surgery, pediatric, minimally invasive surgery, pediatric urology, South America

OPEN ACCESS

Edited by:
Miguel Alfedo Castellan,
University of Miami, United States

Reviewed by:
Andres Gomez Fraile,
Hospital Universitario 12 De Octubre, Spain
Santiago Vallasciani,
Sidra Medical and Research Center, Qatar

Correspondence:
Juan M. Moldes
juan.moldes@hospitalitaliano.org.ar

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *14 December 2018*
Accepted: *04 March 2019*
Published: *28 March 2019*

Citation:
Moldes JM, de Badiola FI, Vagni RL, Mercado P, Tuchbaum V, Machado MG and López PJ (2019) Pediatric Robotic Surgery in South America: Advantages and Difficulties in Program Implementation. Front. Pediatr. 7:94. doi: 10.3389/fped.2019.00094

INTRODUCTION

Robotic assisted surgery is one of the most advanced forms of Minimally Invasive Surgery. It has been used worldwide on a broad range of medical specialties since the 1990s, evolving rapidly evolved since then (1). In the pediatric surgery field, it has been mainly adopted on urologic procedures, where more complex surgeries which require extreme precision are performed. However, there are few reports of pediatric urology procedures done with this technology compared to what is published related to adult's surgery.

Pediatric robotic surgery has undergone significant growth since its first application in 2002 (2, 3). The first pediatric robotic procedure performed at most centers was the robotic assisted laparoscopic pyeloplasty. The relatively high incidence of ureteropelvic junction obstruction combined with surgeon familiarity with laparoscopic pyeloplasty made it a natural first robotic procedure. Since then, it has become more commonly performed accounting for 11–12.6% of pyeloplasties performed in the USA by 2009 (4), and it accounts for about 40% of cases nowadays (5–7).

Ureteral reimplantation, both intra or extravesical approach, robotic assisted ureteroureterostomy for the treatment of ectopic ureter and ureterocele have become more

TABLE 1 | Number of Robots related to the country population.

Country/region	Robots	Population (million)	Robot/people (million)
Brazil	40	207	1/5.1
Argentina	3	44	1/14.6
Chile	8	17	1/2.1
Uruguay	1	3	1/3.1
USA	2,862	323	1/0.11
Europe	742	741	1/0.99
Asia	579	4,463	1/7.7

frequently performed according to recent publications. On the other hand there are an increasing number of reports of complex reconstructive procedures, such as urinary incontinence treatment with procedures on the bladder neck, bladder augmentation, and continent urinary stoma (5, 8, 9).

While extirpative procedures were described, they are not becoming popular with a robotic approach, likely due to that they are relatively easy to master with a pure laparoscopic approach, making it less cost—effective (2). The progress of robotic assisted surgery is predominant in developed countries, however, in Latin America, regardless of its limitations, it is growing.

Our objective is to describe the current situation of robotic pediatric surgery in four countries of South America, describing the limitations and difficulties that have been faced on the implementation of a long term pediatric robotic program.

METHODS

Information about robotic pediatric surgery program were collected in Brazil, Chile, Uruguay, and Argentina. The following data was collected: number of active programs in each country, year the program started working, number of surgeons and pediatric surgeons trained in robotics, the estimated number of surgeries performed during the program and costs of the surgery and entity responsible for the payment.

Data through a survey regarding pitfalls of the pediatric robotic surgery program was also requested among centers and surgeons performing pediatric robotic surgery.

RESULTS

In the region where the survey was conducted, we found a total of 52 active robotic equipment. Brazil, with 40 robots, is the country that has experienced the major progress in the area. In relation to its general population and the number of robots, it appears that Chile is the country with the best coverage of its population with 1 robot every 2.1 million people, followed by Uruguay with 1 every 3.4, Brazil with 1 every 5.1 million people and Argentina with 1 robot every 14.6 million people (**Table 1**). In relation to the pediatric population younger than 14 years old, the proportion is similar to the adults (**Table 2**).

The location of the robots is similar in the four countries where the systems are mostly gathered in one or two big cities. In Chile and Uruguay, 100% of the equipment's are in the capital cities (Santiago de Chile and Montevideo, respectively), while in Argentina the 66% are in Buenos Aires. In Brazil, 75% are located in the two major cities which are Sao Paulo and Rio de Janeiro.

TABLE 2 | Population under 14 years old in year 2017.

	Population 2017	% kids under 14	Total
Brazil	207,660,929	22.79	46,899,407
Argentina	44,098,971	24.7	10,892,445
Chile	17,373,831	20.27	3,577,092
Uruguay	3,456,750	20.44	684,982

TABLE 3 | Description of Robot programs in South America.

	Active robots	Program started	Trained adult surgeons	Trained pediatric surgeons	Trained pediatric urologist
Brazil	40	2008	400	2	2
Chile	8	2010	106	13	6
Argentina	3	2008	24	1	1
Uruguay	1	2011	3	0	0

Regarding the surgeons and pediatric urologists accredited in robotic surgery by Intuitive® company, it has been difficult to obtain the accurate information related to Brazil because the enormous geographic area that covers that country. A total around 400 surgeons are accredited by the company, most of them trained overseas. A local training center is planned to start to work in 2019 in Rio de Janeiro. Among them, we were only able to collect information from four pediatric surgeons active in robotic surgery.

In the rest of the three countries, it is clear that Chile has the largest number of pediatric surgeons trained with 2.5 doctors per robot, followed by Argentina with 0.3 and Uruguay without any accredited one. The relationship between accredited adult and pediatric surgeons, in Chile the proportion is from 106 to 19, in Argentina from 24 to 1 and in Uruguay from 3 to 0.

It is interesting to note that the vast majority of accreditations were made in the first years after the acquisition of robotic systems (**Table 3**).

In none of the four countries described are there any active training programs for pediatric surgeons and there are only two pediatric proctors accredited by Intuitive, one in Brazil and one in Chile.

The number of procedures varies a lot in the region, highlighting Brazil with more than 21,000 surgeries since the acquisition of the first robot in 2008. The average of surgeries performed by robot is between 525 and 625 procedures per system in Brazil, Chile, and Argentina. Within these described procedures the number of pediatric surgeries does not exceed 4% of the total in any country. We can also notice that the curve of use of the robot is upward in adult patients while in pediatric patients it seems to grow very slowly or even decrease (**Table 4**).

In the region, most robots are located in private health institutions. In Brazil, 6 of the 40 robotic systems and in Argentina 1 of 3 are in public health institutions while in Chile and Uruguay there are none.

TABLE 4 | Robot utilization by country.

	Approx. total procedures	Pediatric program started	Approx. pediatric Q procedures	Approx. pediatric urologic procedures
Brazil	21,700	2008	5	30
Chile	5,000	2010	146	50
Argentina	1,700	2008	6	12
Uruguay	50	2011	0	0

In the public hospitals of South America procedures are mainly paid through foundations or government coverage. With some exceptions in the private Health Organizations, the private insurances do not cover the costs, thus the usual way to achieve coverage for this surgery is to assimilate the cost to a laparoscopic procedure and the difference is pay by the patient out of his pocket.

The type of surgery performed in pediatrics was mainly urological where the pyeloplasty represented around 60% of all pediatric urology procedures in these four countries. Complex procedures such as Renal Oncological Resection, Radical Prostatectomy for rhabdomyosarcoma, Ureterocalicostomy, Vesicoureteral Reimplantation, Nephrectomy, Heminephrectomy, and excision of prostatic utricle have also been performed.

DISCUSSION

Despite the huge demographic and economic contrast of South America compared to North America and Europe, robotic surgery is slowly but constantly evolving and is no longer a fantasy. From the data collected in this survey it is clear that this growth is due to adult patients, and that the use in pediatric patients is very limited with not sings of increasing in the near future.

It is interesting to see the relationship of the number of robots with the population especially if we compare it with the United States and Europe where the differences are very marked. In the Region (four countries), the proportion is 1 for every 5.2 million people and in the United States it is 1 for every 112,000 people and in Europe 1 for every 998,000 people approximately. The comparison with Asia gives a similar result with our region with 1 robot every 7.7 million people. It is possible that these differences and similarities have to do with the economic realities experienced by each region.

Robotic surgery in pediatric patients is still not cost effective everywhere. Probably, the initial doubts about acquiring the robotic technology in all the countries were mainly related to the economic factor, the high cost of the acquisition of the equipment and, especially the high cost of its maintenance. This fact takes special relevance at the time of purchasing a robot system with private fund, a situation that represents the most frequent reality in South America.

Büter et al. suggests that, before initiating a robotic program, it is necessary to know that sufficient number of cases will be performed to cover and justify the equipment costs, a situation which has been difficult to assess in our countries (10). With some exceptions, in these four countries the health insurance companies do not cover such complex technologies, so it was difficult to assess the cost of the system before buying it.

As an example, the first robotic equipment that was acquired by the Hospital Italiano de Buenos Aires, had to be purchased with a bank loan that was initially paid with the medical doctor's own funds due to the lack of support from the institution. Once the robot started to work and demonstrated the system's financial self-sustainability, the hospital took full responsibility of the loan and costs related to the robot.

The usual way to achieve coverage for the insurance company is to take care of the costs as if the surgery was performed by laparoscopy and leave the patient to pay the robotic extra fee, that in the region is between USD $ 4,000 and 6,000 per procedure. Insurance companies justify this action arguing that there is no high-level scientific evidence that shows better results than laparoscopy (11).

Around 120 procedures per year are necessary to financially support the program in our countries, however there is still controversy on the number of cases per year needed to make the robotic platform cost-effective (12).

According to the number of surgeries surveyed, it is not possible for us to support the robotic system only with pediatric patients. Following the same line, Büter et al. indicates that, due to the type of cases and volume of patients who would benefit from the use of the robot in pediatric urology, it is more realistic to be a part of a multispecialty adult robotic program in order to share costs and maximize the use of robotic console (10, 12). Therefore, it will be very difficult that a pure pediatric hospital gets a robot in the future.

The public institutions that have acquired the system have faced a dilemma in the investment of economic resources in this high-cost technology with limited application for specific pathologies and without high-level results published in the literature vs. the use of those public funds in higher basic priorities with greater impact in the treated population. The surgeries are mainly paid through foundations or government coverage and many of them had their programs temporarily or definitively interrupted mainly due to high costs. As an example, in Argentina, the Federico Abete Hospital in the province of Buenos Aires, started with two robotic systems in 2009 had to definitively interrupt the program 3 years later due to the lack of economic resources awarded to sustain the program (13).

On the other hand it is interesting to note that in those public hospitals, pediatric surgery has not had any development so we can infer that it is not only an economic problem but there are a series of others factors perhaps related to the scarcity of trained pediatric surgeons, the little support of general institutions for pediatric development or to the fact that no pediatric hospital has an exclusive robotic program or to the absence of proven advantages in pediatric patients.

The number of certain surgical procedures needed to become an expert is not well established. There are no studies that have addressed the learning curve of robotic operations for surgeons-in-training (14). Prithvi et al. estimates that 100 performed surgeries are required to obtain consistent results in pediatric urology cases and one surgery per week is needed to maintain the surgical skills and to make progress in the development of new skills (15).

With this very low number of procedures performed in Latin American Pediatric Surgery Services, almost no one has managed to surpass the number of the 20 surgeries suggested in a given time to acquire the necessary skills to take full advantage of the robot's capabilities (16, 17). May be this is another reasons why many pediatric surgeons still feel more comfortable with laparoscopic surgery, where practically all of them have loosely completed the learning curve.

This low number of robotic surgeries also makes it nearly impossible to achieve the requirement to perform and/or to become a robotic surgeon according to the standards of accreditation suggested by the Society of Urologic Robotic Surgery or other consensus, such as the SAGES-MIRA Robotic Surgery Consensus Group (18, 19).

This is clearly displayed in the statistics of 52 programs available in Argentina, Brazil, Chile, and Uruguay where there are only 16 accredited pediatric surgeons and 9 pediatric urologists.

Based on what Orvieto published in 2012, that in the reduced field of pediatric surgery, simulation appears as a crucial tool for the development of robotic skills and shorten the learning curve (16, 20). Perhaps the way to accredit in the region in pediatric surgery should be based mainly on the acquisition of laparoscopic skills combined with a more complete and defined robotic simulation program. Regarding the necessary tutorship by proctors, we could consider the proctors to be from the same homonymous adult specialties as the pediatric specialties in the same hospital providing the tutoring in order to make the final stage more accessible and lowering costs, especially considering that between 4 and 10 proctoring procedures are suggested to complete the training (15).

Due to what was previously mentioned, it is and has been difficult to set training and simulation programs for pediatric surgeons, which is evident in the fact that there are no programs in execution in any countries. Only recently is there one proctor in Chile and one in Brazil to form resources in pediatrics.

Regarding the size of the instruments, the robotic surgery is not the most minimal invasive procedure we can perform on a child today. The latest development of the laparoscopic instruments give us 3 mm instruments that are delicate and precise enough to comfortably perform most of the surgeries.

In addition to the fact that we are part of an adult surgery program and that the robotic 5-mm instruments are not as good as the 8-mm instruments, due to the space that the robotic wrist needs, is why we may have to use those for pediatric surgeries resulting on an large caliber instruments especially for young children. On top of this, when we use the robot we may need to use a fourth auxiliary port, while in laparoscopic procedures we exceptionally need an extra fourth port. This instrumental issue also results in an obstacle at the time of suggesting a minimally invasive approach (16).

On the other hand a surgeon who performs a laparoscopic Pyeloplasty with 3-mm instruments in 1 h on a 1-year-old child will probably take longer with the robot, so we can consider the advantage of using it in expert hands.

It is easier to see the robotic advantages in complex procedures, especially in those where there is a lot of reconstruction suture or dissections in very complex and/or small spaces. Even with a low number of surgeries, the complex surgery is more accessible specially for senior surgeons, who know the technical issues of the surgery, but know very little of laparoscopy. So, if we sum up the previously developed items, the indication of this technology in pediatrics may be reserved for demanding surgeries in terms of the location or complexity of the reconstruction, such as pelvic floor. On the other hand, an advantage of the robotic system technology that has made available the minimal invasive surgery to all those senior pediatric surgeons who were not interested at some stage of their career to walk the "painful" early stages of the so developing laparoscopic surgery.

If we start from the evident concept that robotic instruments are superior to any other endoscopic instruments because of its advantages in the mobility and the 3D vision, maybe we should stop trying to demonstrate that the results are at least similar than laparoscopic or open approaches and assume the fact that for very complex patients the use of the latest technology makes the surgical act easier.

CONCLUSIONS

The high cost, the difficulty of obtain enough number of procedures to get a proper expertise and the difficulty in getting a proper robotic training in pediatrics, combined with the absence of high-level scientific evidence published in pediatric patients that demonstrates clear advantages in terms of results and complications over laparoscopy and open surgery, may be the reasons why robotic surgery cannot take off in this region. Hopefully with the new developments and broad implementation of the robotic technology it will reduce costs and increase the number of pediatric patients treated with robotic surgery.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the supplementary files.

AUTHOR CONTRIBUTIONS

JM and PJL conceived of the presented idea. JM developed the theory and performed the computations. RV and FdB verified the analytical methods. PM encouraged VT to investigate a specific aspect and supervised the findings of this work. All authors discussed the results and contributed to the final manuscript. JM wrote the manuscript with support from MM, FdB, and RV. PJL and MM helped supervise the project. Both PM and VT contributed to the final version of the manuscript. All authors provided critical feedback and helped shape the research, analysis and manuscript.

REFERENCES

1. Kalan S, Chauhan S, Coelho R, Orvieto M, Camacho I, Palmer K. et al. History of robotic surgery. *J Robotic Surg.* (2010) 4:141–7. doi: 10.1007/s11701-010-0202-2
2. Kearns J, Gundeti M. Pediatric robotic urologic surgery. *J Indian Assoc Pediatr Surg.* (2014) 19:123–8. doi: 10.4103/0971-9261.136456
3. Cundy T, Shetty K, Clark J, Chang T, Sriskandarajah K, Gattas N, et al. The first decade of robotic surgery in children. *J Pediatr Surg.* (2013) 48:858–65. doi: 10.1016/j.jpedsurg.2013.01.031
4. Sukumar S, Roghmann F, Sood A, Abdo A, Menon M, Sammon J, et al. Correction of ureteropelvic junction obstruction in children: national trends and comparative effectiveness in operative outcomes. *J Endourol.* (2014) 28:592–8. doi: 10.1089/end.2013.0618
5. Mizuno K, Kojima Y, Nishio H, Hoshi S, Sato Y, Hayashi Y. Robotic surgery in pediatric urology: current status. *Asian J Endosc Surg.* (2018) 11:308–17. doi: 10.1111/ases.12653
6. Cundy TP, Harling L, Hughes-Hallett A, Mayer EK, Najmaldin AS, Athanasiou T, et al. Meta-analysis of robot-assisted vs conventional laparoscopic and open pyeloplasty in children. *BJU Int.* (2014) 114:582–94. doi: 10.1111/bju.12683
7. Lucas SM, Sundaram CP, Wolf JS Jr, Leveillee RJ, Bird VG, Aziz M, et al. Factors that impact the outcome of minimally invasive pyeloplasty: results of the Multi-Institutional Laparoscopic and Robotic Pyeloplasty Collaborative Group. *J. Urol.* (2012) 187:522–7. doi: 10.1016/j.juro.2011.09.158
8. Howe A, Kozel Z, Palmer L. Robotic surgery in pediatric urology. *Asian J Urol.* (2017) 4:55–67. doi: 10.1016/j.ajur.2016.06.002
9. Spinoit A, Nguyen H, Subramaniam R. Role of robotics in children: a brave new world! *Eur Urol Focus.* (2017) 3:172–80. doi: 10.1016/j.euf.2017.08.011
10. Bütter A, Merritt N, Dave S. Establishing a pediatric robotic surgery program in Canada. *J Robot Surg.* (2017) 11:207–10. doi: 10.1007/s11701-016-0646-0
11. Varda BK, Wang Y, Chung BI, Lee RS, Kurtz MP, Nelson CP, el at. Has the robot caught up? National trends in utilization, perioperative outcomes, and cost for open, laparoscopic, and robotic pediatric pyeloplasty in the United States from 2003 to 2015. *J Pediatr Urol.* (2018) 14:336.e1–8. doi: 10.1016/j.jpurol.2017.12.010
12. Palmer KJ, Lowe GJ, Coughlin GD, Patil N, Patel VR. Launching a successful robotic surgery program. *J Endourol.* (2008) 22:819–24. doi: 10.1089/end.2007.9824
13. Secin FP, Coelho R, Monz Gardiner JI, Gad Campos Salcedo J, Puente R, Martnez L, et al. Robotic surgery in public hospitals of Latin-America: a castle of sand? *World J Urol.* (2018) 36:595–601. doi: 10.1007/s00345-018-2227-5
14. Tasian G, Wiebe D, Casale P. Learning curve of robotic assisted pyeloplasty for pediatric urology fellows. *J Urol.* (2013) 190:1622–27. doi: 10.1016/j.juro.2013.02.009
15. Murthy PB, Schadler ED, Orvieto M, Zagaja G, Shalhav AL, Gundeti MS. Setting up a pediatric robotic urology program: a USA institution experience. *Int J Urol.* (2017) 25:86–93. doi: 10.1111/iju.13415
16. Orvieto M, Large M, Gundeti M. Robotic paediatric urology. *BJU Int.* (2012) 110:2–13. doi: 10.1111/j.1464-410X.2011.10877.x
17. Sorensen M, Delostrinos C, Johnson M, Grady R, Lendvay T. Comparison of the learning curve and outcomes of robotic assisted pediatric pyeloplasty. *J Urol.* (2011) 185:2517–22. doi: 10.1016/j.juro.2011.01.021
18. Herron DM, Marohn M, SAGES-MIRA Robotic Surgery Consensus Group. A consensus document on robotic surgery. *Surg Endosc.* (2008) 22:313–25; discussion 311–2. doi: 10.1007/s00464-007-9727-5
19. Zorn KC, Gautam G, Shalhav AL, Clayman RV, Ahlering TE, Albala DM, et al. Training, credentialing, proctoring and medicolegal risks of robotic urological surgery: recommendations of the society of urologic robotic surgeons. *J Urol.* (2009) 182:1126–32. doi: 10.1016/j.juro.2009.05.042
20. Schlottmann F, Long J, Brown S, Patti M. Low confidence levels with the robotic platform among senior surgical residents: simulation training is needed. *J Robot Surg.* (2018) 13:155–8. doi: 10.1007/s11701-018-0853-y

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

REVIEW
published: 29 March 2019
doi: 10.3389/fped.2019.00093

The Robot-Assisted Extravesical Anti-reflux Surgery: How We Overcame the Learning Curve

*Ravindra Sahadev, Katelyn Spencer, Arun K. Srinivasan, Christopher J. Long and Aseem Ravindra Shukla**

Division of Pediatric Urology, Children's Hospital of Philadelphia, Philadelphia, PA, United States

OPEN ACCESS

Edited by:
Miguel Alfedo Castellan, University of Miami, United States

Reviewed by:
Andrew J. Kirsch, Children's Healthcare of Atlanta, United States
Yuval Bar-Yosef, Dana-Dwek Children's Hospital, Israel

***Correspondence:**
Aseem Ravindra Shukla
shuklaa@email.chop.edu

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *25 December 2018*
Accepted: *04 March 2019*
Published: *29 March 2019*

Citation:
Sahadev R, Spencer K, Srinivasan AK, Long CJ and Shukla AR (2019) The Robot-Assisted Extravesical Anti-reflux Surgery: How We Overcame the Learning Curve. Front. Pediatr. 7:93. doi: 10.3389/fped.2019.00093

Management of vesicoureteral reflux (VUR) has evolved over the past several decades, with a trend toward a decrease in surgical management. In spite of this, ureteral reimplantation remains a commonly performed procedure by pediatric urologists in selected cases. Although the basic tenets of the ureteral reimplant procedure remain the same, the extra- vs. intravesical approach, and the traditional open vs. minimally invasive approach remain the primary options to correct reflux. Considering the advantages conferred by the robotic surgery platform, many leading centers have preferentially adopted robot-assisted laparoscopic extravesical anti-reflux surgery, or in common surgical parlance, the robot-assisted laparoscopic ureteral reimplantation (RALUR), over pure laparoscopic or open approaches. Predicated on our experience of performing over 170 cases of RALUR, we have made technical modifications which we posit reduce the morbidity of the procedure while offering acceptable outcomes. This review highlights the evolution and establishment of RALUR as a standardization of care in the surgical management of VUR at our institution. In particular, we emphasize the technical nuances and specific challenges encountered through the learning curve in hopes of facilitating this process for others.

Keywords: robotic, ureteral reimplantation, RALUR, learning curve, extravesical approach

INTRODUCTION

Over the past two decades, both the evaluation and therapeutic interventions for vesicoureteral reflux (VUR) have undergone extensive evolutions, with a clear trend toward non-operative management and a focus on voiding dysfunction as the major risk factor for urinary tract infection (UTI) (1–3).

In spite of significant investigations aimed at identifying risk factors for the development of recurrent urinary tract infections and predicting the potential for VUR resolution and/or the development of renal scarring, our ability to do so remains limited. Still, when conservative management fails, and febrile UTIs or significant renal scarring occurs, children do require surgical management.

The surgical principles for the correction of VUR remain consistent, several years after its initial description (4). In order to prevent VUR the length of the anti-refluxing tunnel is extended, traditionally in a 5:1 ratio of tunnel length to width of the ureter. While the open ureteral reimplant has been the traditional gold standard repair for VUR, the minimally invasive approaches, such as sub-ureteral injections or laparoscopic and robotic assisted laparoscopic ureteral reimplant (RALUR), have been established as viable alternatives (3).

Although initial enthusiasm for RALUR has waned for some due to concerns about a steep learning curve which can potentially increase the risk of patient morbidity or persistent VUR (5, 6), the well-established benefits of the robotic approach encourage its use (7, 8). Benefits of the robotic vs. the open approach include an improved field of vision via magnification intraperitoneal visualization of the ureters and bladder, improved cosmesis for the patient, and a more rapid recovery in the immediate postoperative period due to an extravesical approach. In our experience several technical modifications mitigate the aforementioned risk of RALUR while maximizing patient outcomes.

In this review, we seek to explore the evolution of extravesical RALUR–as it is the most widely adapted robotic approach–and describe technical modifications that render this procedure reproducible across surgeons and lessen the learning curve trajectory.

EVOLUTION OF RALUR

Since its first description by Peters (9), the technical aspects of the RALUR have undergone several modifications. Along with the initial descriptions of robotic assisted pediatric urologic procedures, Peters highlighted the advantages of the robotic system, the need for evolution and evaluation (9). The surgical principles illustrated for both the robotic-assisted intravesical (RAIVUR) and extravesical techniques were adapted to the new platform while adhering to the principles of contemporary open surgical procedures. The intravesical techniques were favored in bilateral cases due the concerns of urinary retention with bilateral extravesical reimplantation (9).

Since then, while the RAIVUR confers advantages of decreased hematuria and bladder spasms compared to the open approach, it failed to gain widespread adaptation, largely due to technical challenges such as insufflation leaks through the larger trocar hiatus and limited working space of a small bladder (10, 11). Only three groups have reported their experience with RAIVUR, with modest success rates (83, 92, and 100% reflux resolution in 6, 19, and 3 patients, respectively) and highly variable complication rates (17, 52, and 0%) (10–12).

Meanwhile, the Lich-Gregoir technique has become popular for the robotic approach due to its ready adaptability to the technology. This trans-abdominal approach provides excellent visualization of the retrovesical space, particularly when compared to the open approach. The magnification of the robotic camera facilitates meticulous detrusor dissection, which combined with judicious use of energy devices limits the potential for collateral damage to the nerve bundles of the bladder (13).

As with other minimally invasive approaches, RALUR confers the significant benefits of minimally invasive surgery including a shorter convalescence, reduced hospital stay, and improved cosmesis. The realization of the potential improved experience for patients has led to more widespread acceptance for utilization of RALUR. This had led to more centers having a higher number of RALUR over open ureteral reimplants, including ours, and this is reflected in publication trends as well (**Figure 1**).

A negative postoperative voiding cystourethrogram (VCUG) remains the gold standard to declare surgical success after a ureteral reimplantation. But, traditionally high success rates of the open approach obviated a post-operative VCUG in practice. Similarly, with accumulating experience with the RALUR, and pilot studies have demonstrated that our technique delivers reliable VCUG proven success (14). Our institution now defines surgical success as a lack of postoperative febrile UTI and a negative VCUG, if obtained in the postoperative period (15). Potential short term complications reported after RALUR include minor self-limiting adverse events such as bladder spasms, hematuria, and GI disturbances. Other reported complications include urinary extravasation, UTIs, incisional hernia, ureteral obstruction resulting in anuria, and the rare complication of ureteral strictures.

Early reports for RALUR are typical for most new techniques: they are comprised of single institution experiences with small patient numbers. To compound this, there is a lack of uniformity in data reporting, including the age at the time of repair, the indication for ureteral reimplantation (VUR vs. obstruction), and the degree of reflux at the time of surgery. Bladder and bowel dysfunction has proven to be a significant risk factor for surgical failure yet remains under reported in the literature (16). Overview of the literature review (**Table 1**) suggests, in the first decade of utilization of RALUR, there were inconsistencies in reported success (66.7–100%) and complication (0–100%) rates (7–9, 11–15, 17–28). It is notable that higher Clavien grade complications occurred in reports following smaller patient cohorts. However, recent growing evidence in literature has been relatively consistent in proving the safety and efficacy of RALUR in prospective multi-institutional collaborative efforts (7, 8).

THE LEARNING CURVE

The learning curve refers to variations in the productivity of a new surgical procedure or surgeon over a specific time period that leads to achieving a consistent level of expertise to meet contemporary standards. Defining a learning curve is a challenging concept. Although some authors claim that proxies such as operative time, complication rates, and functional outcomes are inadequate measures to assess a true learning curve, most reports have defaulted to these as practical measures of surgical success (28, 29).

As outlined above, the heterogeneity of the published literature on RALUR on key variables such as patient demographics, grades of reflux, comorbidities, in addition to variable study catchment periods makes assessment of a true learning curve difficult.

In order to trace the influence of a learning curve to surgical parameters and outcomes for RALUR at our institution, we have compared the failure rates (need for secondary anti-reflux surgery), radiographic reflux resolution rate, operative time,

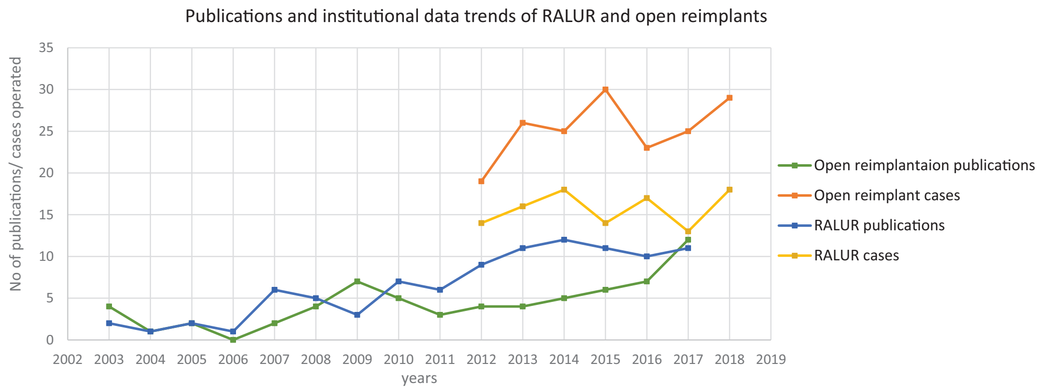

FIGURE 1 | Trends in publications and number of RALURs performed at our institute. Source: PubMed search report of terms "Open ureteral reimplantation" and "Robot-assisted ureteral reimplantation" as on 23 July 2018.

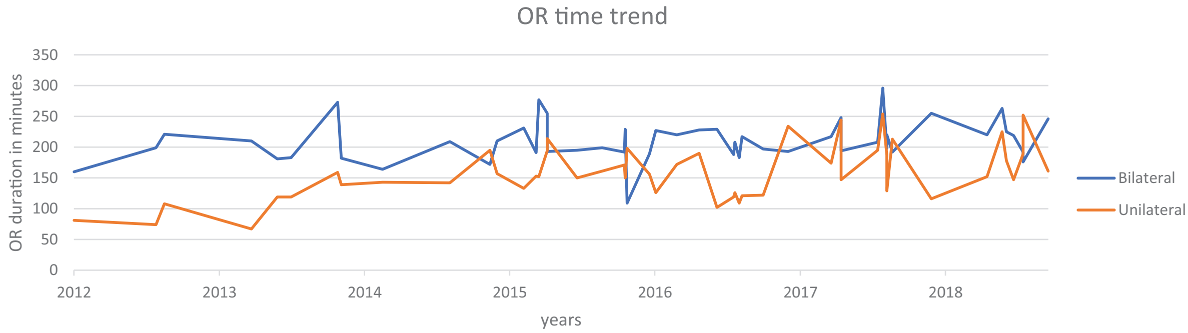

FIGURE 2 | Institutional- OR time trends over 2012 to 2018.

and/or complication rates over defined time frames (yearly trends) for a series of consecutive cases (**Table 2**). We feel as though a single institution center with a relatively high surgical volume as well as 5 different surgeons provides a unique opportunity to carry out this analysis.

A review of data from a prospectively maintained database from 2012 till October 2018, includes six surgeons performing RALUR on 170 patients, of which 60 were bilateral. One hundred twenty-seven were female patients. In our series, the average age at surgery was 5.9 years with a general trend toward higher age at surgery each year, contrary to the literature on national data (3). A Majority of RALUR were done for dilating VUR (Grade 3 or higher) with breakthrough UTIs or renal scarring (100 cases), 36 cases had a duplex anomaly, 23 obstructive megaureter and 10 bladder diverticula. Additionally, 18 cases had a prior history of failed sub-ureteric injection. Among VUR cases, 40% had high grade VUR (IV and V). The operative time varied depending on the number of ureters, need for cystoscopy, retrograde pyelography, placement of a suprapubic tube, and other concomitant procedures depending on the associated pathology (nephrectomy, heminephrectomy, etc.). For unilateral procedures without any concomitant procedure the mean operative time was 161 min (49 cases), and it was 208 min for bilateral cases (48 cases). Operative time includes time of first incision or procedure start, to procedure end time as recorded by the nursing staff. The operative time did not vary significantly between the first and last quarters of consecutive case series (**Figure 2**). Blood loss was minimal in most of the cases from the beginning.

Over the follow up period of 1 to 75 months (mean 23, median 20 months), six cases had transient urinary retention and four cases needed surgery for port site hernia (we now meticulously close fascia even for 5 mm port sites under direct vision). Four cases of ureteral obstruction were noted based on increased dilation of calyces on renal ultrasound with symptoms of flank pain with nausea; of which three cases resolved with cystoscopy and ureteral stenting for 6 weeks and, in another case, required open ureteral reimplantation. We previously reported our surgical outcomes on an initial cohort and found that postoperative febrile UTIs occurred in 15.8% of unilateral cases compared with 20% of bilateral cases ($p = 0.61$) (15). Surgical failure, denoted by postoperative febrile UTI and a positive VCUG was noted in five (8.7%) of the unilateral cases vs. three (8.6%) of the bilateral RALUR cases ($p = 0.98$). The updated demographic and clinical information is summarized in **Table 2**.

Although the intraoperative surgical time has remained consistent over the years, we note that the number and complexity of complications are decreasing over subsequent

TABLE 1 | A literature review of RALUR-EV.

References	Study year†	Baseline			Outcomes			
		No of patients	No of Ureters	OR time in min	Success rate#	Complications %*		
						Clavien grade 1	Clavien grade 2	Clavien grade 3
Peters (9)	2004	24	27	165	88		11	5
Chan et al. (12)	2005–2008	3	4	210	66.7	33	0	0
Boysen et al. (7)	2005–2014	260	363	177	87.9	5	1.9	2.7
Casale et al. (13)	2006–2007	41	82	139.8	97.6	0	4.87	0
Smith et al. (17)	2006–2009	25	33	185	95.6	16	0	4
Akhavan et al. (18)	2006–2013	50	78	–	92.3	4	14	4
Chalmers et al. (19)	2007–2010	16	22	152	90.9	0	0	0
Marchini et al. (11) (EV)	2007–2010	20	27	233.5	100	10	10	0
Schomburg et al. (14)	2008–2010	20	25	196	100	0	0	10
Gundeti et al. (20)	2008–2015	58	83	–	82	1.7	0	0
Silay et al. (21)	2008–2015	72	91	–	97.9	2.7	0	0
Katsturi et al. (22)	2009–2011	150	300	–	99.3	0	0.7	0
Dangle et al. (23)	2010–2013	29	40	–	80	–	–	–
Grimsby et al. (24)	2010–2013	61	93	–	72	1.6	1.6	8.2
Srinivasan et al. (15)	2012–2016	92	–	164	91.3	4.3	17	2.1
Hayashi et al. (25)	2013	9	15	268.78	93.3	100	0	0
Arlen et al. (26)	2013–2014	17	20	169.3	94.1	0	11.76	0
Herz et al. (27)	2013–2015	54	72	–	85.2	5.5	9.8	11
Boysen et al. (8)	2015–2017	143	199	194	93.8	4.9	0.7	5.6

† Approximate period.
 # Clinical or radiological success rates.
**Some reports did not report complications as per Clavien-Dindo grading directly; The reports were graded based on the description. Some authors included UTIs in the complications. There were no Grade-4 complications related to surgery reported in any of the studies. In many series, same patients have had complications of different grades, hence they cannot be summated.*

TABLE 2 | Summary of institutional RALUR data: patient characteristics and operative outcomes.

Year	No of pts.	Age in yrs.	No of renal units	VUR- I, II, III, IV, V, OMs	OR time in min	Need for subsequent anti-reflux surgery	Complications-Grade- 1, 2, 3,4	Mean follow up (months)
2012	15	4.53	18	0,3,3,7,1,1	132	1	3,1,1,0	23.36
2013	34	5.39	41	0,5,12,7,2,8	174	0	2,1,3,0	32.76
2014	25	5.18	30	3,2,9,5,3,3	165	1	0,1,1,0	33.43
2015	29	5.31	43	0,3,10,11,2,3	194	3	1,1,3,0	25.99
2016	24	7.62	38	0,4,8,7,2,3	206	0	1,0,1,0	20.35
2017	22	6.25	31	0,3,9,3,2,5	203	0	0,0,0,0	11.75
2018#	21	5.52	29	0,4,6,4,4,3	197	0	1,0,0,0	3.57

OM-Obstructive megaureter. # till October 2018.

years, concomitant to a reduced need for secondary interventions. Indeed, these results encouraged increasing use of RALUR at our institution with the increase in expertise and confidence level. Backed by comparable outcomes there has been an increase in the proportion of RALUR cases as compared to open ureteral reimplants (**Figure 1**). We expect, also, that being an academic teaching institute with many surgeons and trainees, inherent variations in the proficiency levels with atypical learning curve patterns would affect continued improvement in specific parameters.

TECHNICAL MODIFICATIONS TO ACHIEVE A SUCCESSFUL RALUR

Based on our experiences with RALUR, in addition to standard steps (**Table 3**), we have adopted several key technical modifications that we believe have improved our institutional outcomes (**Table 4**). Proper case selection is vital and must consider patient age, toilet training status, and the presence or absence of dysfunctional elimination. If there is a concern for secondary reflux due to a neurogenic bladder, this must be worked up prior to intervention. If significant bowel and/or bladder dysfunction persists in spite of adequate therapy, a suprapubic tube should be considered in order to ensure proper, low-pressure post-operative voiding prior to removing within a week.

In order to avoid collateral damage to the detrusor muscle and the nerve plexus, meticulous dissection and judicious use of electrocautery is vital (**Figure 3B**). We recommend that estimating tunnel length is inaccurate–and overestimated–when the bladder is even slightly distended, hence we now delineate the tunnel length–ensuring a measurement of tunnel length five times the diameter of the distal ureter–while the bladder is completely drained with a foley catheter (**Figure 3C**). We regularly utilize a hitch stitch not only to aid detrusor dissection but also to mark the direction of proposed tunnel (**Figure 3D**). We use only the tip of the hook to cauterize the identified bleeding spots and spread the muscles bluntly, rather than cutting those layers (**Figure 4B**).

Once the tunnel length of the detrusor is delineated, we begin dissecting the tunnel midway between the hitch stitch and ureterovesical junction until the bladder mucosal layer is defined (**Figure 4A**). Utilizing this window, we find that further progression proximally and distally proceeds more easily without the risk of inadvertent cystotomies (**Figure 4C**). We avoid medial and inferior dissection close to the VUJ, which poses damage to the nerve plexus and may increase the risk of detrusor injury and urinary retention. The ureters must be adequately mobilized in a cephalad direction in order to remove any proximal tension that may tease the ureter out of the tunnel.

Once the detrusorrhaphy begins, we prefer interrupted suturing with long term absorbable sutures (5–0 polydiaxone) in a "bottom up" approach, starting from uretero-vesical junction and then moving distally toward the hitch stitch (dome), as it allows for a tailored formation of the tunnel depending on the available ureter length and amount of tension. This technique can be confusing for the beginner and requires careful passing of suture underneath the ureter and back toward the initial bite

TABLE 3 | Standard steps of RALUR.

- Preoperative cystoscopy and retrograde pyelogram, if there is a suspicion of ectopic ureter, duplex systems, solitary system
- Patient position: Supine (younger patients) or modified lithotomy; Attention to pressure points and careful strapping to prevent shifting when patient put into lithotomy position.
- Port placement: 8.5 mm camera port at the umbilicus, 5 mm working instruments in midclavicular line on either side, or utilizing lower incisions with cephalad tunneling of the trocar.
- Cephalad ureteral mobilization to release tension
- Tunnel measurement and marking to achieve a 5:1 ratio
- Mild hydrodistension, hitch placement
- Detrusor tunnel creation
- Detrusorrhaphy-suturing
- Closure

TABLE 4 | Challenges and cautions/modifications.

Outcomes of concerns	Possible technical reasons	Modifications adopted
Urinary retention	Damage to nerve plexus	Precise dissection at VUJ between ureter and bladder, avoiding medial and caudal detrusor dissection (**Figure 4C**)
		Judicious use of electrocautery
Incomplete reflux resolution	Inadequate tunnel length	Standardized measurement of the tunnel length in the collapsed bladder (**Figure 3C**)
	Cephalad slippage of the ureter out of the tunnel	Including the ureter adventitia in the first few and last tunnel closure suture ("advancement stitches"). Proximal ureteral mobilization to release tension on tunnel closure
	Incomplete detrusor separation for the tunnel creation	Use of hitch stitch for adequate traction and bladder distension to facilitate dissection (**Figure 3D**)
Ureteral obstruction	Ureteral injury	Avoiding pre-stenting unless absolutely necessary (e.g., Duplex system), avoiding excessive traction and direct cautery usage on the ureter
	Excessive ureteral mobilization	Ureteral mobilization to the required length with frequent assessments
	Tight tunnel	"Bottom-up" approach starting at the UVJ with careful and stepwise closure of tunnel, raising adequate detrusor flaps to have a spacious tunnel
	Acute angulation of the ureter	Studying the course of the ureter and its angulation prior to hitch stitch and marking the corresponding tunnel line (**Figure 3C**)
Urinary leak	Cystotomy	Careful identification and repair prior to closure of detrussorotomy
	Leak from ureteral suture-line	Maximize urinary drainage with bladder catheter and/or suprapubic tube, and place ureteral stent if necessary.
	Refluxing stumps in cases of ectopic ureteral insertion	Adequate exposure, resection of residual, and closure of the stump.
Multiple post site scars	Multiple port site scars	HidES (Hidden incision for endoscopic surgery) groin ports, hide umbilical camera port within umbilical crease; only two working 5 mm ports; no assist port.
Injury to vas and vessels	Poor field of vision	Preservation of uterine vessels; Under-vision dissection distal to the vas deferens. Starting the distal ureteral dissection with good hemostasis to maintain optimum visibility (**Figure 3A**).

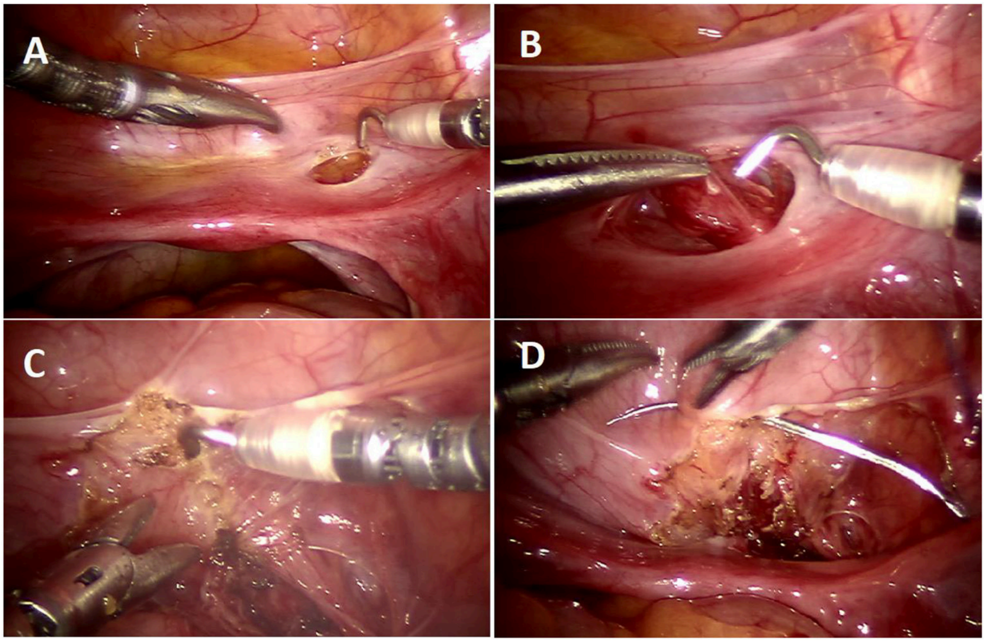

FIGURE 3 | Operative steps of RALUR. **(A)** Small window created in the broad ligament to access the ureter directly. **(B)** Ureteral mobilization: gentle handling by grasping only the ureteral adventitia. **(C)** Marking the detrusor tunnel in a collapsed bladder in line with the ureter. **(D)** Hitch stitch at the distal end of tunnel marking.

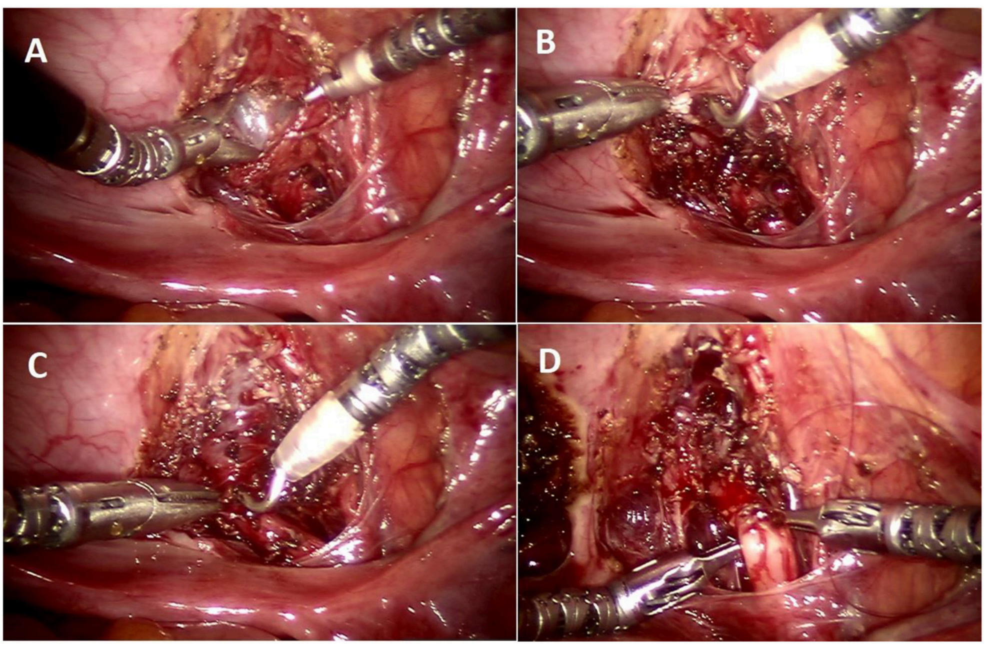

FIGURE 4 | Operative steps of RALUR. **(A)** Making a detrusor window till bluish bladder mucosa is delineated. **(B)** Detrusor muscle separated with direct pinpoint electrocautery tip combined with blunt spreading of the muscle fibers. **(C)** Detrusor tunnel opened proximally to ureterovesical junction. **(D)** Passing suture underneath the ureter to advance the ureter into the detrusor trough (left to right).

side (**Figure 4D**) to allow placement of the ureter deep in the tunnel with close approximation of the detrusor edges. It is important to include ureteral adventitia in the initial and ending detrusor closure stitch. In cases of dismembered reimplants, solitary kidney, tapered or complex reimplants we prefer to leave a double J stent, but we do not stent typical RALUR cases. We also do not routinely place a drain. We leave a urinary catheter overnight and discharge the patient once they are able to void, leaving residuals that are <25% of the expected bladder capacity.

Table 4 summarizes the common pitfalls and technical modification adopted to address those concerns.

CHALLENGES

In their recent review, Baek et al. analyzes the reasons for slower adoption of RALUR in comparison to the widespread and quickly adopted robotic prostatectomy among adult counterparts. The steeper learning curve and concerns about the efficacy compared to open reimplants were oft-cited reasons, and the authors suggested that the procedure be deferred to a later point in the robotic experience (30). However, from our learning curve experience, we deduce that careful adherence to outlined steps allows the RALUR to be safely and reproducibly performed. Standardization of salient steps with adequate training and judicious use of electrocautery will ensure the avoidance of common pitfalls.

Although there are debates regarding the efficacy of the RALUR in comparison to open ureteral reimplantation, we must be cautious while comparing the historical reports to the contemporary outcomes as the population characteristics (age group, voiding dysfunction, etc.) have been changing. Eventually, the trends suggest RALUR inexorably will be adopted more widely, and reports and ongoing multi-institutional consortiums will continue to provide further evidence regarding its safety and affirming its efficacy.

CONCLUSIONS

RALUR utilization has increased since its inception, but concerns over the procedure's technical difficulty, safety, risk of urinary retention and outcomes has limited its widespread use. Herein, we demonstrate that the learning curve of RALUR can be shortened with specific modifications predicated on experience, and that with technical adaptations, clinically significant improvements in surgical outcomes may be expected. In appropriately selected patients and with adequate preparation, we posit that the RALUR is a safe and effective technique that confers the well-described advantages of minimally invasive surgery to the treatment of VUR.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the supplementary files.

AUTHOR CONTRIBUTIONS

ARS conceived the idea, laid the platform for the review with substantial additions to the manuscript, along with proofreading. RS prepared the initial manuscript and collected the raw data. KS prepared the literature review and part of data abstraction. CL and AKS reviewed the manuscript and made significant corrections.

REFERENCES

1. Routh JC, Bogaert GA, Kaefer M, Manzoni G, Park JM, Retik AB, et al. Vesicoureteral reflux: current trends in diagnosis, screening, and treatment. *Eur Urol.* (2012) 61:773e82. doi: 10.1016/j.eururo.2012.01.002
2. Qureshi AH, Ajayi O, Schwaderer AL, Hains DS. Decreased Identification of vesicoureteral reflux: a cautionary tale. *Front Pediatr.* (2017) 5:175. doi: 10.3389/fped.2017.00175
3. Kurtz MP, Leow JJ, Varda BK, Logvinenko T, McQuaid JW, Yu RN, et al. The decline of the open ureteral reimplant in the United States: National data from 2003 to 2013. *Urology.* (2017) 100:193–7. doi: 10.1016/j.urology.2016.07.024
4. Paquin AJ. Ureterovesical anastomosis: the description and evaluation of a technique. *J Urol.* (1959) 82:573–83. doi: 10.1016/S0022-5347(17)65934-2
5. Cannon GM, Ost MC. Robot-assisted laparoscopic extravesical ureteral reimplantation for primary vesicoureteral reflux in children *J Urol.* (2017) 197:1379–81. doi: 10.1016/j.juro.2017.03.112
6. Gargollo PC. Editorial comment regarding: Prospective multicenter study on robot-assisted laparoscopic extravesical ureteral reimplantation (RALUR-EV): outcomes and complications. *J Ped Urol.* (2018) 14:263–4. doi: 10.1016/j.jpurol.2018.02.018
7. Boysen W, Ellison JS, Kim C, Koh CJ, Noh P, Whittam B, et al. Multi-institutional review of outcomes and complications of robot-assisted laparoscopic extravesical ureteral reimplantation for treatment of primary vesicoureteral reflux in children. *J Urol.* (2017) 197:1555–61. doi: 10.1016/j.juro.2017.01.062
8. Boysen WR, Akhavan A, Ko J, Ellison JS, Lendvay TS, Huang J, et al. Prospective multicenter study on robot-assisted laparoscopic extravesical ureteral reimplantation (RALUR-EV): Outcomes and complications. *J Pediatr Urol.* (2018) 14:262.e1–6. doi: 10.1016/j.jpurol.2018.01.020
9. Peters CA. Robotically assisted surgery in pediatric urology. *Urol Clin North Am.* (2004) 31:743–52. doi: 10.1016/j.ucl.2004.06.007
10. Peters CA, Woo R. Intravesical robotically assisted bilateral ureteral reimplantation. *J Endourol.* (2005) 19:618–21. doi: 10.1089/end.2005.19.618
11. Marchini GS, Hong YK, Minnillo BJ, Diamond DA, Houck CS, Meier PM, et al. Robotic assisted laparoscopic ureteral reimplantation in children: case matched comparative study with open surgical approach. *J Urol.* (2011) 185:1870–5. doi: 10.1016/j.juro.2010.12.069
12. Chan KW, Lee KH, Tam YH, Sihoe JD. Early experience in robotic-assisted laparoscopic bilateral intravesical ureteral reimplantation for vesicoureteral reflux in children. *J Robot Surg.* (2012) 6:259–62. doi: 10.1007/s11701-011-0288-1
13. Casale P, Patel RP, Kolon TF. Nerve sparing robotic extravesical ureteral reimplantation. *J Urol.* (2008) 179:1987–9; discussion 1990. doi: 10.1016/j.juro.2008.01.062
14. Schomburg JL, Haberman K, Willihnganz-Lawson KH, Shukla AR. Robot-assisted laparoscopic ureteral reimplantation: a single surgeon comparison to open surgery. *J Pediatr Urol.* (2014) 10:875–9. doi: 10.1016/j.jpurol.2014.02.013
15. Srinivasan AK, Maass D, Shrivastava D, Long CJ, Shukla AR. Is robot-assisted laparoscopic bilateral extravesical ureteral reimplantation associated with greater morbidity than unilateral surgery? A comparative analysis. *J Pediatr Urol.* (2017) 13:494.e1–7. doi: 10.1016/j.jpurol.2017.01.021
16. Sillén U. Bladder dysfunction and vesicoureteral reflux. *Adv Urol.* (2008) 8:815472. doi: 10.1155/2008/815472
17. Smith RP, Oliver JL, Peters CA. Pediatric robotic extravesical ureteral reimplantation: comparison with open surgery. *J Urol.* (2011) 185:1876–81. doi: 10.1016/j.juro.2010.12.072
18. Akhavan A, Avery D, Lendvay TS. Robot-assisted extravesical ureteral reimplantation: outcomes and conclusions from 78 ureters. *J Pediatr Urol.* (2014) 10:864–8. doi: 10.1016/j.jpurol.2014.01.028

19. Chalmers D, Herbst K, Kim C. Robotic-assisted laparoscopic extravesical ureteral reimplantation: an initial experience. *J Pediatr Urol.* (2012) 8:268–71. doi: 10.1016/j.jpurol.2011.04.006
20. Gundeti MS, Boysen WR, Shah A. Robot-assisted laparoscopic extravesical ureteral reimplantation: technique modifications contribute to optimized outcomes. *Eur Urol.* (2016) 70:818–23. doi: 10.1016/j.eururo.2016.02.065
21. Silay MS, Baek M, Koh CJ. Robot-assisted laparoscopic extravesical ureteral reimplantation in children: top-down suturing technique without stent placement. *J Endourol.* (2015) 29:864–6. doi: 10.1089/end.2014.0815
22. Kasturi S, Sehgal SS, Christman MS, Lambert SM, Casale P. Prospective long-term analysis of nerve-sparing extravesical robotic-assisted laparoscopic ureteral reimplantation. *Urology.* (2012) 79:680–3. doi: 10.1016/j.urology.2011.10.052
23. Dangle PP, Shah A, Gundeti MS. Robot-assisted laparoscopic ureteric reimplantation: extravesical technique. *BJU Int.* (2014) 114:630–2. doi: 10.1111/bju.12813
24. Grimsby GM, Dwyer ME, Jacobs MA, Ost MC, Schneck FX, Cannon GM, et al. Multi-institutional review of outcomes of robot-assisted laparoscopic extravesical ureteral reimplantation. *J Urol.* (2015) 193(5 Suppl.):1791–5. doi: 10.1016/j.juro.2014.07.128
25. Hayashi Y, Mizuno K, Kurokawa S, Nakane A, Kamisawa H, Nishio H, et al. Extravesical robot-assisted laparoscopic ureteral reimplantation for vesicoureteral reflux: initial experience in Japan with the ureteral advancement technique. *Int J Urol.* (2014) 21:1016–21. doi: 10.1111/iju.12483
26. Arlen AM, Broderick KM, Travers C, Smith EA, Elmore JM, Kirsch AJ. Outcomes of complex robot-assisted extravesical ureteral reimplantation in the pediatric population. *J Pediatr Urol.* (2016) 12:169.e1–6. doi: 10.1016/j.jpurol.2015.11.007
27. Herz D, Fuchs M, Todd A, McLeod D, Smith J. Robot-assisted laparoscopic extravesical ureteral reimplant: A critical look at surgical outcomes. *J Pediatr Urol*. (2016) 12:402.e1–402.e9. doi: 10.1016/j.jpurol.2016.05.042
28. Pruthi R, Smith A, Wallen E. Evaluating the learning curve for robot-assisted laparoscopic radical cystectomy. *J Endourol.* (2008) 22:2469–74. doi: 10.1089/end.2008.0320
29. Kaul S, Shah N, Menon M. Learning curve using robotic surgery. *Curr Urol Reports*. (2016) 7:125–29. doi: 10.1007/s11934-006-0071-4
30. Baek M, Koh CJ. Lessons learned over a decade of pediatric robotic ureteral reimplantation. *Investig Clin Urol*. (2017) 58:3–11. doi: 10.4111/icu.2017.58.1.3

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Surgery

ORIGINAL RESEARCH
published: 17 April 2019
doi: 10.3389/fsurg.2019.00022

Impact and Outcomes of a Pediatric Robotic Urology Mini-Fellowship

*Ciro Andolfi, Dev Patel, Veronica M. Rodriguez and Mohan S. Gundeti**

Pediatric Urology, Section of Urology, Department of Surgery, The University of Chicago Pritzker School of Medicine, Chicago, IL, United States

Introduction: In order to support practicing pediatric surgeons and urologists to safely and effectively incorporate robotic surgery into their practice, we established a 5-day mini-fellowship program with a mentor, preceptor and proctor at our institution. This study was designed to report our experience with the pediatric robotic mini-fellowship (PRM) and to evaluate the impact this course had on the participants' practice.

Methods: The mini-fellowship training at our institution is provided in two modules, including upper and lower urinary tract surgery, over a 5-day period. The one to one teacher-to-attendee experience included tutorial sessions, hands-on inanimate, and animate skills training, clinical case observations and video discussions. Participants were asked to complete a detailed questionnaire on their practice patterns before and after the PRM.

Results: Between 2012 and 2018, a total of 29 national and international pediatric surgeons and urologists underwent robotic renal and bladder surgery training. Twenty-six fellows (90%) completed the surveys, all of which were included for analysis. The median age at the time of fellowship was 43 years (32–63), and participants had practiced urology for a median of 76 months (3–372). All of them had a laparoscopic background, with a median experience of 120 months (12–372), and an average of 454 (± 703) laparoscopic procedures performed, including the years of training. The most common primary goals of participants were to understand the concept of robotic surgery and its applications (38.5%), and to practice in the wet lab to shorten their learning curve (38.5%). After PRM completion, 24 graduates (92%) felt likely to incorporate robotic surgery into their practice, of which 15 (58%) actually started a robotic program at their home institution. At 24 months after PRM completion, the overall number of surgeries performed with a robotic approach (RA) by these 15 participants was 478 with an average of 32 (± 44) procedures per fellow, of which 109 (23%) were extirpative (nephrectomy, partial nephrectomy, etc.), and 369 (77%) reconstructive procedures (pyeloplasty, ureteral reimplantation, etc.). Before PRM, the same 15 participants performed 844 procedures with a laparoscopic approach (LA), of which 527 (62.4%) were extirpative, and 317 (37.6%) were reconstructive surgeries. These data mark a significant switch in indications for minimally invasive surgery (MIS) in pediatric urology. The rise in the number of reconstructive procedures (37.6% LA vs. 77% RA) has shown that robotic surgery has undoubtedly facilitated the performance of more challenging procedures in a minimally invasive fashion.

OPEN ACCESS

Edited by:
Walid A. Farhat, Hospital for Sick Children, Canada

Reviewed by:
Massimo Garriboli, Guy's and St. Thomas' NHS Foundation Trust, United Kingdom
Yuval Bar-Yosef, Dana-Dwek Children's Hospital, Israel

***Correspondence:**
Mohan S. Gundeti
mgundeti@surgery.bsd.uchicago.edu

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Surgery

Received: *27 January 2019*
Accepted: *27 March 2019*
Published: *17 April 2019*

Citation:
Andolfi C, Patel D, Rodriguez VM and Gundeti MS (2019) Impact and Outcomes of a Pediatric Robotic Urology Mini-Fellowship. Front. Surg. 6:22. doi: 10.3389/fsurg.2019.00022

Conclusion: The success of a mini-fellowship program relies on the commitment of expert faculty to serve as tutorial instructors and proctors. In addition, a completely outfitted robotic laboratory with access to dry and wet lab is indispensable. A 5-day intensive PRM appears to enable postgraduate surgeons to successfully incorporate the robotic platform into their practice and to advance the complexity of minimally invasive procedures, allowing for more challenging surgeries, such as reconstructive urology.

Keywords: pediatric urology, robotic surgery, robotic-assisted laparoscopy, surgical simulation, surgical training

INTRODUCTION

After laparoscopy, robotics has revolutionized the minimally invasive approach in surgery. Many advanced and complex procedures have been reported to be feasible and safe by a robotic approach, whereas certain laparoscopic procedures were performed only by remarkably skilled surgeons. As the evidence for clinical safety and advantages of robotic surgery continues to grow, the demand for training will continue to increase. For urology, several groups (1–6) have reported their experience and the impact of structured courses on the participants' practice. However, for pediatric urology such training is not available and this approach has not been thoroughly evaluated so far. In addition, the manufacturers only provide one-day courses, such as the Intuitive Surgical da Vinci training program, which are administered by a technician, without considering human applications, especially for vulnerable populations such as pediatric patients.

At our institution, implementation of a pediatric urology activity with the robotic platform was achieved in October 2007. During our early adaptation, we found that there are a lot of nuances to be learnt for the safe application to the pediatric population. Taking into consideration the increasing success of this technology while also understanding these nuances to reduce the learning curve for colleagues around the world, our division proposed a course in the safe implementation of robotic urology, focused on upper, and lower urinary tract surgery in children. In 2012, we established a 5-day mini-fellowship with a mentor, preceptor and proctor in pediatric robotic urology, to assist practicing pediatric urologists incorporate robotic surgery into their practice. We made this available to those who want to learn as a CME-approved educational and introductory activity. Thus, this study was designed to report our experience with the PRM and to evaluate the impact this course had on the participants' practice.

MATERIALS AND METHODS

The mini-fellowship training at our institution is provided in two modules, including upper and lower urinary tract surgery, over a 5-day period. Participation is reserved to a maximum of three fully-trained pediatric surgeons or urologists, who are asked to go through online modules before training. The PRM embraces a mentor-preceptor-proctor experience and features one to one teacher-to-attendee instruction, including tutorial sessions, hands-on inanimate skills training, animal laboratory practice and operating room observation experience (**Figure 1**). One fellow would be in the animal lab while another would be in the simulation center doing dry lab, and the third attended the operating room to assist cases. All participants were required to complete a questionnaire before and immediately after completing the PRM to evaluate the various training components using a 5-point Likert scale (from 1—poor to 5—excellent). Program areas assessed were didactic tutorial sessions, skills training practice, animal laboratory training sessions, and operating room observation. As for follow-up, we sent questionnaires to all PRM participants, who were also asked to complete a survey on subsequent robotic operative experience after the PRM program. The study received IRB exemption because it includes interactions involving survey procedures.

All questionnaire results were reviewed, tabulated, and statistically analyzed. Pre-program vs. post-program skill and component ratings were analyzed with a paired sample *t*-test, after logarithmic transformation, and the χ^2 test was used to analyze data collected on non-continuous variables. A $P < 0.05$ was considered statistically significant.

RESULTS

Between 2012 and 2018, a total of 29 surgeons, from different Institutions around the world (USA, Canada, Brazil, Mexico, Chile, UK, Italy, Turkey, Saudi Arabia, Lebanon, India, Australia), underwent pediatric robotic renal and bladder surgery training. With a median follow-up of 24 (5–52) months, twenty-six fellows (90%) completed the surveys, all of which were included for analysis. The median age at the time of fellowship was 43 years (32–63), and participants had practiced urology for a median of 76 months (3–372). All of them had a laparoscopic background, with a median experience of 120 months (12–372) and an average of 454 (± 703) laparoscopic procedures performed, including the years of training. The primary goals of participants were to understand the concept of robotic surgery and its applications (38.5%), and to practice in the wet lab to shorten their learning curve (38.5%). After fellowship completion, 24 out of 26 graduates (92%) felt likely to incorporate robotic surgery into their practice, of which 15 (62.5%) actually started their robotic program. Among fellows who did not implement robotic surgery into their practice, financial constraints, and lack of proctorship were the main obstacles. Other impediments were found to be low caseload and absence of simulation training. The vast

FIGURE 1 | Mini-fellowship schedule flowchart.

majority of fellows who implemented robotic surgery into their practice were either academics (60%) or affiliated to an academic institution (33%). The overall number of surgeries performed with a robotic approach (RA) by these 15 PRM participants at 24 months after completion of our program was 478, with an average of 32 (± 44) per fellow, of which 109 (23%) were extirpative (nephrectomy, partial nephrectomy, etc.), and 369 (77%) reconstructive procedures (pyeloplasty, ureteral reimplantation, etc.). Before PRM, the same 15 participants performed a total of 844 procedures with a laparoscopic approach (LA), of which 527 (62.4%) were extirpative and 317 (37.6%) reconstructive surgeries. These data mark a significant switch in indication and use of minimally invasive surgery (MIS) in pediatric urology, with a rise of reconstructive procedures when a robotic platform is available (37.6% LA vs. 77% RA, $P < 0.01$). The number of high-grade complications reported was 14 (2.9%), all Clavien-Dindo grade III. The average number of operations needed to reach a subjective level of confidence was inversely proportional to the age of patients — from 4 for 5-year old patients to 10 for patients younger than 2 years of age. Seven (47%) out of 15 reported an independent level of performance, 3 (20%) required supervision, while the remaining 5 (33%) were able to perform only part of the procedure. In order of importance, the most anxiety-provoking components of surgery were: (1) suturing and tying; (2) accidental injury to surrounding structures; (3) ports positioning and handling; and (4) dissection. Overall, the PRM received an evaluation score of 4.5 (± 0.6) and, when fellows were questioned if they would recommend the PRM to other colleagues, the average score on a Likert scale was 4.7 (± 0.5). The two most useful elements of the PRM were found to be (1) wet lab training and (2) operative room observation. Among fellows who were able to embrace the robotic technology after the PRM a subjective improvement of the following skills was noted when compared to laparoscopy: ports management (3.9 vs. 4.5, $P = 0.045$); dissection (3.9 vs. 4.5, $P = 0.032$); clipping and stapling (3.8 vs. 4.5, $P = 0.019$); cutting tissue (3.9 vs. 4.6, $P = 0.025$); suturing and tying (3.1 vs. 4.4, $P = 0.002$).

DISCUSSION

Robotic surgery is increasingly gaining support from the surgical community. There has been a call from major governing bodies such as the Society of Urologic Robotic Surgeons, European Association of Urology, and the American Urological Association for development of training curricula increasing preclinical exposure to surgical techniques and validated assessment tools of proficiency (7). Several projects are currently underway to develop a robotic surgery curriculum and are in various stages of validation. Whilst the Fundamental Skills of Robotic Surgery (FSRS) is based on tasks on the Robotic Surgical Simulator (RoSS) virtual reality simulator; Fundamentals of Robotic Surgery (FRS) and Basic Skills Training Curriculum (BSTC) are designed for use on simulators and the robot itself (8–10). The European Association of Urology (EAU) Robotic Urology Section (ERUS) curricula benefits from a combination of dry lab, wet lab and virtual reality components, which may allow skills to be more transferable to the OR as tasks are completed in several formats. Finally, the ERUS curriculum includes the OR modular training program, as table assistant and console surgeon, and a post-training mentorship system which allows the trainees to assess their proficiency (11). However, the curriculum is in early stages of validation and more work is needed. In addition, there is no specific module tailored to pediatric patients.

Because of these limitations, pediatric surgeons have become increasingly eager to learn and adopt robotic techniques for the pediatric population despite having had little or no training during residency. Traditionally, for individuals not extensively exposed to robotic surgery during residency, robotic skills are learned by pursuing a post-residency fellowship in MIS or during brief one-day courses. For practicing urologists who seek training in robotic surgery, these short courses may not instill enough confidence or the necessary skill set to perform these procedures independently. At the same time the additional rigors of academic training imposed by dedicated fellowships preclude most urologists from obtaining appropriate training. To achieve better results than short courses in terms of take rates, while curtailing the time required for a formal MIS fellowship, we developed a dedicated five-day PRM program at our institution. As in the ERUS curriculum, we provided a non-formal post-training mentorship in order to help former fellows implement the robotic system into their daily routine. This is done remotely, through online networking and workshops, and at their home institution, through on-site training sessions, when feasible. The formalized implementation of such endeavors will need additional resources.

For this study, PRM participants were contacted 2 years after training and responded to a questionnaire specifically looking at practice patterns. Even if the vast majority of participants felt likely to incorporate robotic surgery into their practice, slightly over half of them had actually done so. Identifying ways to improve the take rate for robotic surgery is an important element in permitting PRM graduates to use these skills. Based on our data, financial constraints and lack of proctorship at the home institution were the biggest barrier for those who did not implement robotic surgery into their practice. Hopefully, the prohibitive costs of currently available robotic platforms will drop with the market inflow of new robotic technologies. However, proctorship will still be a challenge as, in the absence of a uniform training, credentialing and privileging remain institution-based processes.

After many years of exciting progress and refinements of laparoscopic instrumentations, the application of conventional MIS to the pediatric population has reached a plateau, particularly for reconstructive procedures. Intracorporeal suturing using the available laparoscopic tools is time consuming and requires vast experience. The robot, instead, has the potential to overcome these limitations by providing enhanced depth perception and improved dexterity with fine motions skills, and reducing the learning curve of intracorporeal tasks, such as dissection and suturing. As a result, surgeons are adopting this technology to assist in surgical procedures that were not feasible with conventional MIS. This observation is strongly supported by our study results, which show how our PRM program has dramatically changed indications to use an MIS approach. Among the 15 participants who established a robotic program in their home institutions, the rate of reconstructive procedures performed with an MIS approach, rose from 37.6 with laparoscopy to 77% with robot-assisted surgery. In addition, these fellows reported a subjective improvement with the robot in surgical skills, such as dissection, cutting, suturing, and tying.

To our knowledge the PRM in robotic pediatric urology remains unique to our institution. While regrettable, it is understandable, given the considerable commitment in personnel, space, equipment, and funds needed to equip and maintain a training facility of this nature. Because we value sharing skills that will unquestionably promote children's safety, we made a commitment to pursue this program to help educate practicing physicians on the benefits and usages of robotic surgical techniques. The success of a PRM program relies on the commitment of expert faculty to serve as tutorial instructors and proctors. In addition, a completely outfitted robotic laboratory with access to dry and wet lab is indispensable. A 5-day intensive robotic pediatric urology PRM appears to enable postgraduate surgeons to successfully increase their case volume and advance the complexity of minimally invasive procedures.

AUTHOR CONTRIBUTIONS

CA and MG: design of the work. CA, DP, VR, and MG: drafting the work and revising it critically. CA, DP, VR, and MG: final approval. All authors agree to all aspects of the work.

REFERENCES

1. Altunrende F, Autorino R, Haber GP, Laydner H, White MA, Khanna R, et al. Immediate impact of a robotic kidney surgery course on attendees practice patterns. *Int J Med Robot.* (2011) 7:165–9. doi: 10.1002/rcs.384
2. Gamboa AJ, Santos RT, Sargent ER, Louie MK, Box GN, Sohn KH, et al. Long-term impact of a robot assisted laparoscopic prostatectomy mini fellowship training program on postgraduate urological practice patterns. *J Urol.* (2009) 181:778–82. doi: 10.1016/j.juro.2008.10.018
3. Lucas SM, Gilley DA, Joshi SS, Gardner TA, Sundaram CP. Robotics training program: evaluation of the satisfaction and the factors that influence success of skills training in a resident robotics curriculum. *J Endourol.* (2011) 25:1669–74. doi: 10.1089/end.2010.0713
4. McDougall EM, Corica FA, Chou DS, Abdelshehid CS, Uribe CA, Stoliar G, et al. Short-term impact of a robot-assisted laparoscopic prostatectomy "mini-residency" experience on postgraduate urologists' practice patterns. *Int J Med Robot.* (2006) 2:70–4. doi: 10.1002/rcs.71
5. Mirheydar H, Jones M, Koeneman KS, Sweet RM. Robotic surgical education: a collaborative approach to training postgraduate urologists and endourology fellows. *JSLS.* (2009) 13:287–92.
6. Patel SR, Hedican SP, Bishoff JT, Shichman SJ, Link RE, Wolf JS Jr., et al. Skill based mentored laparoscopy course participation leads to laparoscopic practice expansion and assists in transition to robotic surgery. *J Urol.* (2011) 186:1997–2000. doi: 10.1016/j.juro.2011.07.007
7. Andolfi C, Umanskiy K. Mastering robotic surgery: where does the learning curve lead us? *J Laparoendosc Adv Surg Tech A.* (2017) 27:470–4. doi: 10.1089/lap.2016.0641
8. Chowriappa AJ, Shi Y, Raza SJ, Ahmed K, Stegemann A, Wilding G, et al. Development and validation of a composite scoring system for robot-assisted

surgical training–the Robotic Skills Assessment Score. *J Surg Res*. (2013) 185:561–9. doi: 10.1016/j.jss.2013.06.054

9. Foell K, Finelli A, Yasufuku K, Bernardini MQ, Waddell TK, Pace KT, et al. Robotic surgery basic skills training: evaluation of a pilot multidisciplinary simulation-based curriculum. *Can Urol Assoc J*. (2013) 7:430–4. doi: 10.5489/cuaj.222
10. Stegemann AP, Ahmed K, Syed JR, Rehman S, Ghani K, Autorino R, et al. Fundamental skills of robotic surgery: a multi-institutional randomized controlled trial for validation of a simulation-based curriculum. *Urology*. (2013) 81:767–74. doi: 10.1016/j.urology.2012.12.033
11. Volpe A, Ahmed K, Dasgupta P, Ficarra V, Novara G, van der Poel H, et al. Pilot validation study of the european association of urology robotic training curriculum. *Eur Urol*. (2015) 68:292–9. doi: 10.1016/j.eururo.2014.10.025

Conflict of Interest Statement: MG is co-director for the NARUS course.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

REVIEW
published: 07 May 2019
doi: 10.3389/fped.2019.00172

Check for updates

Robotic-Assisted Bladder Neck Procedures for Incontinence in Pediatric Patients

Patricio C. Gargollo [1] and Lindsay A. White [2]*

[1] *Division of Pediatric Urology, The Mayo Clinic and Mayo Medical School, Rochester, MN, United States,* [2] *The University of Washington School of Medicine, Seattle, WA, United States*

OPEN ACCESS

Edited by:
Miguel Alfedo Castellan, University of Miami, United States

Reviewed by:
Tiago Elias Rosito, Federal University of Rio Grande do Sul, Brazil
Juan Manuel Moldes, Hospital Italiano de Buenos Aires, Argentina

***Correspondence:**
Patricio C. Gargollo
gargollo.patricio@mayo.edu

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *05 February 2019*
Accepted: *12 April 2019*
Published: *07 May 2019*

Citation:
Gargollo PC and White LA (2019) Robotic-Assisted Bladder Neck Procedures for Incontinence in Pediatric Patients. Front. Pediatr. 7:172. doi: 10.3389/fped.2019.00172

Purpose: To review the current status of bladder neck procedures for incontinence in pediatric patients, focusing on the increasing role of robotic-assisted laparoscopic surgical techniques.

Methods: A comprehensive review of the literature on open and robotic-assisted bladder neck procedures was conducted, with a focus on articles published in the last 20 years. This data was subsequently compared with published results from robotic-assisted bladder neck reconstruction series completed at our institution.

Results: The principal bladder neck procedures for incontinence in pediatric patients include: Artificial Urinary Sphincter, Bladder Neck Sling, Bladder Neck Closure and Bladder Neck Reconstruction. Continence rates range from 60 to 100% with a lack of expert consensus on the preferred procedure (or combination of procedures). Robotic-assisted approaches are associated with longer operative times, especially early in the surgical experience, but demonstrate equivalent continence rates with potential benefits including: low intraoperative blood loss, improved cosmesis, and decreased intra-abdominal adhesion formation.

Conclusions: Robotic-assisted procedures of the bladder neck are safe, feasible, follow the same steps and principles as those of open surgery and produce equivalent continence rates. Robotic-assisted techniques can be adapted to a variety of bladder neck procedures and safely expanded to selected patients with previous open abdominal surgery.

Keywords: robotic surgery, urinary incontinence, bladder neck reconstruction, appendicovesicostomy, artificial urinary sphincter, bladder neck sling, bladder neck closure

INTRODUCTION

Minimally invasive techniques are at the forefront of urologic surgery. As advances in laparoscopic instrumentation and robotic technology continue, the use of these techniques in the pediatric population has expanded. Robotic-assisted procedures in the pediatric population are well established for nephrectomy, pyeloplasty, ureteral reimplantation, and bladder surgery, but the use of this technology remains limited in more complex reconstructive cases. Longer operative times are often cited as a barrier to the use of minimally invasive techniques in complex reconstruction, but it has been demonstrated that much of the difference in operative time can be mitigated with increased surgeon experience (1, 2). Even with longer operative times, advantages over open surgery may include lower intraoperative blood loss, decreased post-operative narcotic use, and superior cosmesis (3, 4). These benefits have the potential to be accentuated in the pediatric population due to the relatively confined working spaces and a heightened awareness of cosmesis. In addition, the potential for decreased intra-abdominal adhesion formation in laparoscopic and robotic procedures, as compared to open, cannot be discounted. In patient populations that are at high risk of undergoing multiple lifetime abdominal surgeries, the benefits of decreased adhesions could have significant implications in reducing both technical difficulty and operative time in re-operation (5, 6).

Furthermore, as the use of minimally invasive surgical techniques increases, so too does the pool of patients considered to be candidates for this approach. While previous open abdominal surgery (PAS) was traditionally considered a relative contraindication to a laparoscopic or robotic-assisted approach, emerging studies indicate safety and efficacy of complex robotic reconstructions in these populations (1). In this review, we will discuss the surgical interventions available for pediatric incontinence, the increasing role of robotic-assisted techniques, complex reconstruction of the bladder neck, and our cumulative experience and approach to treating these patients.

SURGICAL INTERVENTION FOR URINARY INCONTINENCE

Urine leakage in the absence of a detrusor contraction, regardless of the primary cause (exstrophy/epispadias, cloacal anomalies, or neurogenic bladder secondary to spinal cord injury or dysraphisms) is the definition of an incompetent urinary sphincter mechanism (7). The basic goal behind surgical procedures to address this incompetent sphincter mechanism is to tighten the bladder outlet. This can be achieved in many ways including: placement of an artificial urinary sphincter (AUS), placement of a bladder neck sling (BNS), bladder neck reconstruction (BNR), and bladder neck closure (BNC). We will review the current status of each of these surgical interventions for incontinence, and more specifically, how these procedures are being adapted for robotic-assisted laparoscopic surgery (RALS). Whether or not a concomitant bladder augmentation procedure should be performed with the procedures listed above is a highly contested topic and beyond the scope of this review, and thus will not be covered here.

ARTIFICIAL URINARY SPHINCTER

The AUS has been used for surgical intervention in pediatric incontinence for decades. The historical benefits of AUS placement include the ability to maintain the potential for spontaneous voiding, decreasing the percentage of patients required to complete obligatory clean intermittent catheterization (CIC), and the potential to delay, or avoid, fixed resistance procedures such as BNS, BNR, or BNC. Continence rates following AUS placement in the pediatric population have remained similar across decades with Simeoni et al. reporting overall success rates of 77% in 1996 (8) and Catti et al. demonstrating similar results with 73% of patients achieving continence in 2008 (9). Despite good continence, both studies also demonstrated relatively high complication rates, with device removal required in 19 and 20% of patients, respectively (8, 9). In addition, post-operative changes in detrusor dynamics following AUS placement are concerning as they have been shown to lead to renal failure in 16% of patients and the need for augmentation cystoplasty in 31% of patients (10).

In patients with previous surgery of the bladder neck or proximal urethra success rates of AUS placement become extremely variable. Castera et al. evaluated AUS placement in 49 patients with 67% of all patients achieving continence, but further comparison demonstrated that of patients with no previous surgery ($n = 25$), 86% achieved urinary continence, whereas only 37.5% of patients who had undergone prior bladder neck surgical procedures ($n = 8$) achieved continence (11). Ruiz et al. followed this study with examination of AUS placement in 23 patients without spina bifida, but with previous surgery of the bladder neck or proximal urethra and achieved continence in 87% of the 19 sphincters that remained in place (86.3% survival rate) (12). Levesque et al. looked beyond efficacy to evaluate long-term survival of the AUS in the pediatric population and found that the mean survival time of the prostheses was 12.5 years (95% CI, 10.3–14.6), and was independent of patient sex or incontinence etiology (13). In addition, Bauer conducted a meta-analysis encompassing 585 pediatric patients from reported series of AUS placement between 1996 and 2006 and found that 32% of patients voided spontaneously to completion without the aid of CIC, demonstrating that AUS may provide large advantages over other bladder outlet procedures for patients in which spontaneous voiding is a priority (10).

Recently, Moscardi et al. reported the first described case of robotic-assisted laparoscopic (RAL)-AUS placement in the pediatric population. The procedure was safely accomplished, and the patient remained continent between volitional voids at

Abbreviations: APV, Appendicovesicostomy; AUS, Artificial Urinary Sphincter; BNC, Bladder Neck Closure; BNR, Bladder Neck Reconstruction; BNS, Bladder Neck Sling; CIC, Clean Intermittent Catheterization; LM, Leadbetter/Mitchell; PAS, Previous open abdominal surgery; RAL-AUS, Robotic-assisted laparoscopic artificial urinary sphincter; RALS, Robotic-assisted laparoscopic surgery.

3-month follow-up (14). This report demonstrates that RAL-AUS placement is feasible in the pediatric population, which may be advantageous in facilitating concomitant intra-abdominal procedures, but further experience will be required to compare the safety, efficacy, and long-term outcomes, as it remains unclear if robotic-assistance will affect previously reported continence or complication rates.

BLADDER NECK SLING

Comparison of published data regarding the effectiveness of BNS for pediatric incontinence is challenging because most published series include patients with previous or concurrent procedures. In a review article from 2000, Kryger et al. reported overall continence for fascial sling placement varying from 40 to 100%, but with very limited follow-up (15). Snodgrass and colleagues completed BNS placement with appendicovesicostomy (APV) in 30 children with satisfactory continence (defined as 2 or fewer damp pads daily) achieved in 83% of patients (16). In addition, Snodgrass and Barber compared success rates of 34 consecutive patients with neurogenic incontinence receiving BNS alone and 37 patients receiving BNS plus Leadbetter-Mitchell (LM) BNR. They found that 46% of BNS alone cases did not require pads post-operatively whereas 82% of BNS plus LM BNR did not require pads (17). In addition, 6-month follow-up demonstrated that no patients had hydronephrosis and only 2 patients (BNS plus LM BNR) had transient low-grade reflux (grade I or II) on postoperative urodynamics, which resolved on subsequent studies 2 and 4 months later (17). It was initially believed that this may represent BNS superiority for preservation of the upper tracts, but this idea was later called into question by Grimsby et al. when they found that upon long-term assessment, 30% of these patients had postoperative vesicoureteral reflux (VUR)/hydronephrosis and 17% required ureteral reimplantation or subureteral injection of bulking agent (18). This further demonstrates the effects of limited clinical series and limited follow-up when comparing the success and long-term safety of BNS placement to alternative bladder outlet procedures.

These same confounders and limitations exist when comparing open vs. robotic-assisted BNS placement. Rare reports of BNS placement without concurrent BNR or APV exist, again making it difficult to compare to the open series described above. This author has extensive experience with RAL-BNS placement, but as this procedure is performed concurrently with BNR and APV, results will be discussed in subsequent sections. Finally, due to the superior continence rates now being achieved with BNS placement plus concurrent procedures, it is unlikely that the success of BNS alone will be able to be evaluated without these confounding factors.

BLADDER NECK CLOSURE

Closure of the bladder neck is perhaps the most radical option for achieving continence, as it is irreversible and requires compliance with obligatory CIC of a cutaneous stoma. Bergman et al. showed an 88% dry rate in a retrospective review of patients with mixed etiology incontinence who failed medical therapy and underwent bladder neck closure as their primary surgery (19). This is similar to findings by Liard et al. who evaluated 21 patients with BNC as primary surgical therapy and showed an 80% dry rate (20). Another retrospective study by Hoebeke et al. evaluated 17 children undergoing BNC and demonstrated a dry rate of 100% but difficulty with catheterization in 47% of patients (21). Kavanagh et al. more recently reviewed 28 consecutive patients undergoing BNC and found an initial success rate in 96.4% (27 of 28) of patients. Importantly, 68% of these patients had undergone previous unsuccessful bladder neck procedures, demonstrating safety and efficacy of BNC as a secondary surgical intervention, though a relatively high total surgical re-intervention rate of 39.3% (11 of 28) should be noted (22).

Robotic BNC has been reported in the literature (23), but all current reports include BNC as a concomitant procedure performed as part of a larger study. Murthy et al. preformed 4 RAL-BNC in conjunction with RAL-augmentation ileocystoplasty and APV with good short-term results, but updated interim results revealed that 3 of 4 RAL-BNC required further surgical intervention due to dehiscence (23). The feasibility of RAL-BNC is expected given the excellent exposure to the pelvis and bladder provided by a robotic-assisted approach, but to date published literature on RALS-BNC in the pediatric population is too limited to confirm safety, provide continence rates or compare to open series.

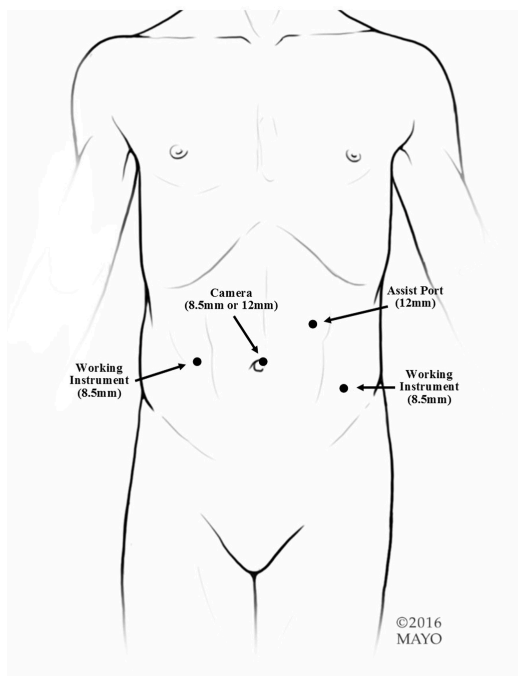

FIGURE 1 | Port placement. We use an 8.5-mm or 12-mm camera and two 8.5-mm working ports. If any bowel work is going to be performed or if a sling is going to be used, we suggest a 12-mm assist in the left upper quadrant. If just an APV is going to be performed, a 5-mm assist port can be used.

BLADDER NECK RECONSTRUCTION

Various reconstructive procedures and operative techniques are available to increase the resistance at the bladder outlet, including the Young-Dees Leadbetter (YDL), the Pippi-Salle, the Kropp repair, and the modified LM repair. To date, no single technique has demonstrated consistently superior outcomes, in large part due to multiple limitations of the published literature including: retrospective studies with significant confounders (various primary diagnoses, previous or concurrent procedures, use of augmentation cystoplasty), non-standardized protocols, and multiple definitions of what constitutes urinary continence. Cole et al. compared these techniques in a retrospective review of 49 continence procedures for patients with varying etiologies of incontinence and found continence rates of 79% for YDL and 75% for Kropp and Pippi-Salle repairs (24). Another retrospective review of 18 children with neurogenic incontinence showed a dry rate (4 h or more between catheterizations) of 61% following Pippi-Salle reconstruction (25). As previously described, Snodgrass and Barber were able to achieve 82% continence rate with LM BNR plus BNS with a mean follow-up of 13 months, with 60% still dry at maximum follow-up of 55 months (17). Despite the limitations in evaluation, these open BNR series demonstrate continence rates ranging from 50 to 85% (2).

Grimsby and colleagues reviewed the perioperative and short-term outcomes between 26 open and 19 RAL-BNRs. They found that while operative time was significantly longer in the robotic group (8.2 vs. 4.5 h, $p < 0.001$), there was no difference in length of stay (median 4 days), acute complications or continence outcomes (26). Re-operation rates were slightly less in the robotic group with 56% (14 patients) in the open group undergoing a total of 23 subsequent surgeries, compared to 42% (8 patients) in the robotic group undergoing 12 additional procedures ($p = 0.5$), although follow-up was longer in the open group (26). Operative time at re-operation was not reported in this study, but a previous report by the same authors comparing 28 open APVs and 39 RAL-APVs, found that while there was no difference in number of complications ($p = 0.788$) or number of re-operations ($p = 0.791$), the first re-operation had a significantly shorter operative time in the robotic group (6).

At our institution, the procedure of choice for management of neurogenic bladder with persistent urinary incontinence (despite CIC and anticholinergic therapy) includes creation of a RAL-APV (or Monti channel when the appendix is inadequate) and LM BNR along with BNS placement. This combination of procedures and the specific technique to complete them robotically was first described by this author in “Robotic-assisted bladder neck repair: feasibility and outcomes” in 2015, with relatively few adjustments made to the procedure since this date (2). Our RAL approach to BNR allows for minimal incisions, limited to an inverted “V”-shaped incision in the umbilicus, an assist port in the left upper quadrant and two 8.5-mm working ports, as represented in **Figure 1**. In addition, this technique

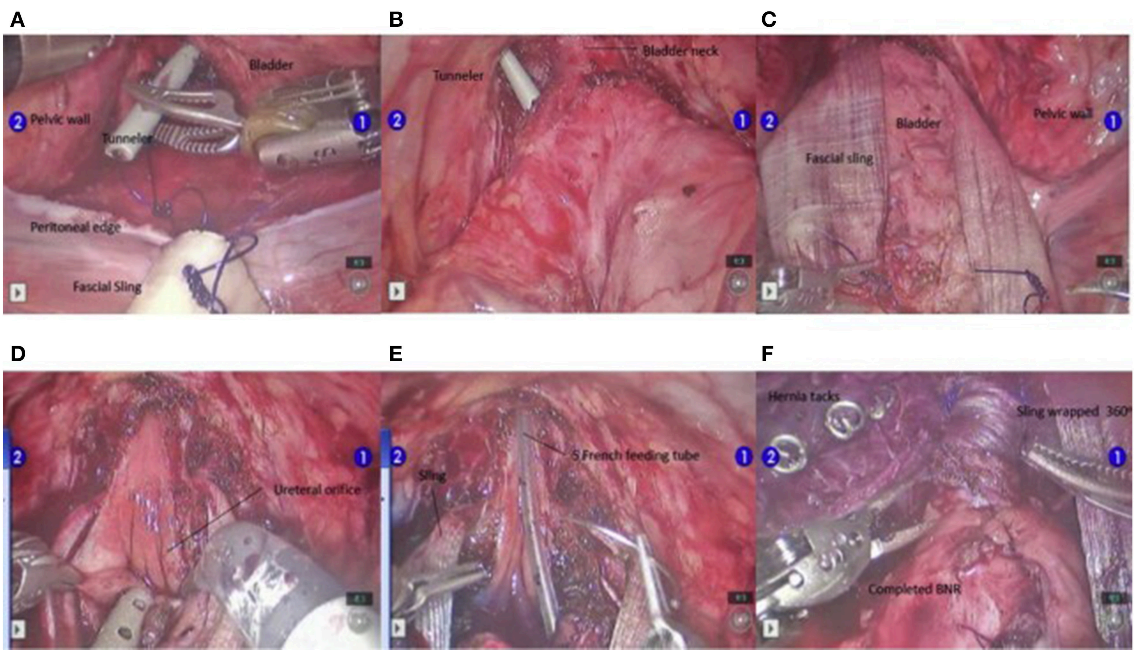

FIGURE 2 | Steps in the BNR. The tunnelers are passed ventrally from the posterior bladder dissection into the developed space of Retzius **(A,B)**. Once the sling is passed from posterior to anterior **(C)**, the urethra is unroofed up through the bladder neck to the level of the interureteric ridge **(D)**. At this point, the Foley catheter is exchanged for a 5-F feeding tube, and the urethra is retubularized in 2 layers with a running simple suture of 4-0 Vicryl followed by 3-0 Vicryl **(E)**. After the LM repair is completed, the sling is tightly wrapped 360° and attached to the pubic bone using 6 screws from a hernia tacker **(F)**. Permission for use of this figure has been obtained from Elsevier Publishing Company. The originally published form can be found at Gargollo (2).

facilitates dissection, creating excellent exposure to the pelvis and the bladder, and providing the ability to accommodate any type of bladder neck repair (e.g., LM, Pippi-Salle, Kropp and YDL). As previously described, our institution utilizes retrovesicular placement of the sling, LM BNR, retubularization of the urethra around a 5-Fr feeding tube and 360 degree sling wrapping, as shown in **Figure 2**. We then hitch the bladder to the anterior abdominal wall prior to creation of the APV.

Using this technique in 38 patients, 82% ($n = 31$) became completely dry during the day on CIC every 3 h and of the 7 patients who were wet, 4 were non-compliant with CIC (2). This is consistent with the 85.2% initial continence rate reported by Gundeti et al. in a multi-institutional review of 88 patients undergoing RAL-APV and various concomitant bladder neck procedures (including BNR in 21, BNS in 17, and BNC in 4) (27).

Our mean operative time for this reconstruction is 5.8 h (3.6–12.25 h), with longer operative times being significantly higher in the first 10 vs. the last 28 cases ($P = 0.0001$), demonstrating the ability to mitigate some of the increase in operative time with increased surgeon experience (2). In follow-up, 5.3% ($n = 2$) required augmentation cystoplasty due to the post-operative development of decreased bladder compliance, 10.5% ($n = 4$) developed *de novo* reflux (grades 2 and 3), and 5.3% ($n = 2$) developed bladder stones (2). These complications are consistent with those seen in the bladder outlet procedures described previously, but to date, have occurred at a relatively lower rate, though direct comparison is challenged by multiple confounders.

Finally, the majority of the BNR procedures described above have occurred as primary surgical intervention in patients with neurogenic bladder, but the techniques utilized in this repair have already been expanded to include a broader patient population. Last year, our institution presented the first RAL-BNR in a patient with classic bladder exstrophy at the American Urologic Association Annual Meeting (Gargollo et al., under review). This year, our institution published the first study demonstrating the feasibility and safety of RAL-BNR in patients with PAS. In 36 patients with PAS, the mean operative time was 8.2 h, with the first 18 cases taking significantly longer than the last 18 cases (mean 9.1 h vs. mean 7.5 h, $p = 0.002$), again demonstrating a learning curve for this procedure. Throughout this study, there were 5 cases that were converted to open due to failure to progress. All conversions were secondary to intra-abdominal adhesions and all occurred in patients with multiple previous ventriculoperitoneal (VP) shunt revisions. At a mean follow-up of 2 years (range 2–36 months), 5.5% ($n = 2$) of patients who had previously undergone a BNR required a BNC for persistent incontinence and 8% ($n = 3$) underwent surgery for bladder calculi. While further studies comparing open and robotic approaches to BNR are needed in patients with PAS to determine equivalency or superiority of one approach over the other, our initial reports to date of RAL-BNR appear promising.

CONCLUSION

RAL surgical techniques have immense potential in the surgical treatment of pediatric incontinence. Our review demonstrates that RAL techniques can be adapted to a variety of procedure types with equivalent continence rates. In addition, the added benefits of improved cosmesis, less intraoperative blood loss, less post-operative pain and decreased adhesion formation make a robotic approach the preference at our institution. Longer operative times can be expected, especially early in the surgical experience, but over time, operative times become significantly shorter and more similar to the duration expected for traditional open surgery for these procedures. Our data also support the feasibility and safety of expanding the range of RAL surgical candidates to include selected patients with PAS. Overall, while there is still a lack of expert consensus on the preferred reconstructive procedure (or combination of procedures) for the treatment of pediatric incontinence, it appears that RAL surgical techniques will continue to push the frontier.

AUTHOR CONTRIBUTIONS

PG conceived of the presented idea, developed the surgical technique described, participated in drafting of the manuscript and critically revised the manuscript for important intellectual content. LW completed the comprehensive literature review, participated in drafting of the manuscript and formatted the manuscript for submission, under supervision of PG. All authors reviewed and approved the final manuscript.

REFERENCES

1. Gargollo PC, Granberg C, Gong E, Tu D, Whittam B, Dajusta D. Complex robotic lower urinary tract surgeries in patients with previous open surgery. *J Urol.* (2018) 1:162–168. doi: 10.1016/j.juro.2018.06.017
2. Gargollo PC. Robotic-assisted bladder neck repair: feasibility and outcomes. *Urol Clin.* (2015) 42:111–20. doi: 10.1016/j.ucl.2014.09.013
3. Bagrodia A, Gargollo P. Robot-assisted bladder neck reconstruction, bladder neck sling, and appendicovesicostomy in children: description of technique and initial results. *J Endourol.* (2011) 25:1299–305. doi: 10.1089/end.2011.0031
4. Freilich DA, Penna FJ, Nelson CP, Retik AB, Nguyen HT. Parental satisfaction after open versus robot assisted laparoscopic pyeloplasty: results from modified Glasgow Children's benefit inventory survey. *J Urol.* (2010) 183:704–8. doi: 10.1016/j.juro.2009.10.040
5. Pattaras JG, Moore RG, Landman J, Clayman RV, Janetschek G, McDougall EM, et al. Incidence of postoperative adhesion formation after transperitoneal genitourinary laparoscopic surgery. *Urology.* (2002). 59:37–41. doi: 10.1016/S0090-4295(01)01474-1
6. Grimsby GM, Jacobs MA, Gargollo PC. Comparison of complications of robot-assisted laparoscopic and open appendicovesicostomy in children. *J Urol.* (2015) 194:772–6. doi: 10.1016/j.juro.2015.02.2942
7. Abrams P. The standardization of terminology of lower urinary tract function: report from the standardization sub-committee of the international continence society. *Neurourol Urodyn.* (2002) 21:167–78.
8. Simeoni J, Guys JM, Mollard P, Buzelin JM, Moscovici J, Bondonny JM, et al. Artificial urinary sphincter implantation for neurogenic bladder: a multi-institutional study in 107 children. *Br J Urol.* (1996) 78:287–93.

9. Catti M, Lortat-Jacob S, Morineau M, Lottmann H. Artificial urinary sphincter in children—voiding or emptying? An evaluation of functional results in 44 patients. *J Urol.* (2008) 180:690–3. doi: 10.1016/j.juro.2008.04.039
10. Bauer SB. Long-term efficacy of artificial urinary sphincters in children. *J Urol.* (2008) 180:441. doi: 10.1016/j.juro.2008.05.082
11. Castera R, Podestá ML, Ruarte A, Herrera M, Medel R. 10-year experience with artificial urinary sphincter in children and adolescents. *J Urol.* (2001) 165:2373–6. doi: 10.1016/S0022-5347(05)66207-6
12. Ruiz E, Puigdevall J, Moldes J, Lobos P, Boer M, Ithurralde J, et al. 14 years of experience with the artificial urinary sphincter in children and adolescents without spina bifida. *J Urol.* (2006) 176:1821–5. doi: 10.1016/j.juro.2006.05.024
13. Levesque PE, Bauer SB, Atala A, Zurakowski D, Colodny A, Peters C. Ten-year experience with the artificial urinary sphincter in children. *J Urol.* (1996) 156:625–8.
14. Moscardi PRM, Ballesteros N, Abd-El-Barr AE, Salvitti M, Castellan M. Robotic-assisted laparoscopic artificial urinary sphincter and MACE procedure on a pediatric patient. *J Pediatr Urol.* (2017) 13:527–8. doi: 10.1016/j.jpurol.2017.06.011
15. Kryger JV, Gonzalez R, Barthold JS. Surgical management of urinary incontinence in children with neurogenic sphincteric incompetence. *J Urol.* (2000) 163:256–63. doi: 10.1016/S0022-5347(05)68031-7
16. Snodgrass WT, Elmore J, Adams R. Bladder neck sling and appendicovesicostomy without augmentation for neurogenic incontinence in children. *J Urol.* (2007) 177:1510–5. doi: 10.1016/j.juro.2006.11.080
17. Snodgrass W, Barber T. Comparison of bladder outlet procedures without augmentation in children with neurogenic incontinence. *J Urol.* (2010) 184:1775–80. doi: 10.1016/j.juro.2010.04.017
18. Grimsby GM, Menon V, Schlomer BJ, Baker LA, Adams R, Gargollo PC, et al. Long-term outcomes of bladder neck reconstruction without augmentation cystoplasty in children. *J Urol.* (2016) 195:155–61. doi: 10.1016/j.juro.2015.06.103
19. Bergman J, Lerman SE, Kristo B, Chen A, Boechat MI, Churchill BM. Outcomes of bladder neck closure for intractable urinary incontinence in patients with neurogenic bladders. *J Pediatr Urol.* (2006) 2:528–33. doi: 10.1016/j.jpurol.2005.12.001
20. Liard A. The Mitrofanoff procedure: 20 years later. *J Urol.* (2001) 165(6 Pt 2):2394–8. doi: 10.1016/S0022-5347(05)66213-1
21. Hoebeke P, De Kuyper P, Goeminne H, Van Laecke E, Everaert K. Bladder neck closure for treating pediatric incontinence. *Eur Urol.* (2000) 38:453–6. doi: 10.1159/000020323
22. Kavanagh A, Afshar K, Scott H, MacNeily AE. Bladder neck closure in conjunction with enterocystoplasty and Mitrofanoff diversion for complex incontinence: closing the door for good. *J Urol.* (2012) 188:1561–6. doi: 10.1016/j.juro.2012.02.027
23. Murthy P, Cohn JA, Selig RB, Gundeti MS. Robot-assisted laparoscopic augmentation ileocystoplasty and Mitrofanoff appendicovesicostomy in children: updated interim results. *Eur Urol.* (2015) 68:1069–75. doi: 10.1016/j.eururo.2015.05.047
24. Cole EE, Adams MC, Brock JW 3rd, Pope JC 4th. Outcome of continence procedures in the pediatric patient: a single institutional experience. *J Urol.* (2003) 170(2 Pt 1):560–3 (discussion: 563). doi: 10.1097/01.ju.0000078015.55801.52
25. Jawaheer G, Rangecroft L. The Pippi Salle procedure for neurogenic urinary incontinence in childhood: a three-year experience. *Eur J Pediatr Surg.* (1999) 9(Suppl. 1):9–11.
26. Grimsby GM, Jacobs MA, Menon V, Schlomer BJ, Gargollo PC. Perioperative and short-term outcomes of robotic vs open bladder neck procedures for neurogenic incontinence. *J Urol.* (2016) 195:1088–92. doi: 10.1016/j.juro.2015.11.043
27. Gundeti MS, Petravick ME, Pariser JJ, Pearce SM, Anderson BB, Grimsby GM, et al. A multi-institutional study of perioperative and functional outcomes for pediatric robotic-assisted laparoscopic Mitrofanoff appendicovesicostomy. *J Pediatr Urol.* (2016) 12:386.e1–5. doi: 10.1016/j.jpurol.2016.05.031

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

REVIEW
published: 14 May 2019
doi: 10.3389/fped.2019.00187

Robotic Urologic Surgery in Infants: Results and Complications

*Christina Kim**

Department of Urology, University of Wisconsin-Madison, Madison, AL, United States

Over the last 30 years, robotic surgery has evolved into the preferred surgical approach for many operative cases. Robotics has been associated with lower pain scales, shorter hospitalizations, and improved cosmesis (1, 2). However, its acceptance in pediatrics have been hampered by longer operative times, smaller working space, and limited fine surgical instruments. Many find these challenges even more pronounced when performing robotic surgery in infants (i.e., children <1 year old). Although the data in infants is less robust, many studies have shown benefits similar to the adult population. Specifically, multiple reports of robotic surgery in infants have shown lower postoperative analgesic use. Additionally, hospital stays are shorter, which may lead to quicker return to work for parents and guardians. Multiple reports have shown low complication rates of robotic surgery in infants. When complications have occurred, they are usually Clavien Grade 1 and 2, with occasional grade 3. Often the complications are not from the robotic technique, but are linked to other factors such as the ureteral stents (3, 4). Most importantly, the success rates of surgery are comparable to open surgery. This chapter will review indications for the most common urologic robotic surgeries performed in infants. Also, we will review reported results and complications of robotic surgery in children, with specific attention to the infant population. However, data focused only on infants is limited. Many studies have some infant patients, but their results are often mixed with all pediatric patients.

Keywords: infants, robotic, pediatric, laparoscopy, outcomes, complications, indications

OPEN ACCESS

Edited by:
Miguel Alfedo Castellan, University of Miami, United States

Reviewed by:
Marie-Klaire Farrugia, Chelsea and Westminster Hospital NHS Foundation Trust, United Kingdom
Baran Tokar, Eskişehir Osmangazi University, Turkey

***Correspondence:**
Christina Kim
ckim@urology.wise.edu

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *07 February 2019*
Accepted: *23 April 2019*
Published: *14 May 2019*

Citation:
Kim C (2019) Robotic Urologic Surgery in Infants: Results and Complications. Front. Pediatr. 7:187. doi: 10.3389/fped.2019.00187

BACKGROUND

Initially, urologic interest in minimally invasive surgery was demonstrated in the adult population. In 1993, Kavoussi and Peters described laparoscopic pyeloplasty as an alternative to the open technique. This was in a 24 year old female (5). Moore et al. reported the first 30 adult laparoscopic pyeloplasties at John Hopkins. Mean operative time was 4.5 h. At the time, their postoperative morbidity was low with convalescence of 3 weeks and a mean hospital stay of 3.5 days. Mean follow up of 16.3 months demonstrated radiographic improvement in 97% of the patients (6).

Similar results have been seen when looking at minimally invasive surgery in children. Bauer et al compared outcomes of laparoscopic and open surgery. In 1999, they compared 42 laparoscopic and 35 open pyeloplasties. Pain relief, improved activity levels, and radiographic improvement were similar in these two groups (7). Other series continued to show advantages relative to length of stay (LOS), pain, and cosmesis when comparing laparoscopic and open pyeloplasties (7, 8).

When robotic surgery was introduced, there was excitement due to three-dimensional imaging, 10-fold camera magnification, tremor filtering, and new camera control by the surgeon. Also, there is instrument articulation with full range of motion. Surgeons hoped these enhancements would allow precise suturing, improve tissue handling, and increase ease of doing complex surgical cases. Robotics quickly gained popularity in adult urology for prostate surgery (9, 10). In 1995, Partin et al. described a variety of robotic procedures in 17 adult patients. They saw 3 minor complications and no significant difference in operative time. They were encouraged by the feasibility of robotic surgery, but encouraged more data collection to assess safety and efficacy of robotic surgery (11).

Similar to the adult literature, pediatric robotic surgery has been associated with lower pain scales, less narcotic use, and shorter hospital stays (12).

COSMESIS OF ROBOTIC SURGERY

From a cosmetic standpoint, satisfaction cannot be self-assessed by an infant. But Barbosa et al. looked at parental and non-infant patient preference regarding scar appearance. Three groups were presented comparing scars with open and robotic pyeloplasties, ureteral reimplantation, and bladder augmentation. For patients under the age of 7 years, their parents were also asked to fill out the survey. One hundred and sixteen parents and 19 patients filled out the surveys. For pyeloplasty, the most important factors were scar visibility, scar size, scar location, and ability to cover the scar. These results support the concept that smaller scars associated with robotic surgery is preferred by patients and parents. However, the preference was less marked in the pyeloplasty group. And the most common urologic infant robotic surgery is pyeloplasty (13).

Casale supports robotic surgery in infants due to equivalent surgical outcomes with robotics with negligible external scars and less manipulation of tissue. There is less collagen deposition with robotic incisions when compared to open surgery. So scarring from smaller robotic ports may be advantageous not only from aesthetics, but also from tissue healing (14).

When comparing one longer open incision to multiple small robotic ports, studies have shown less total tension across non-linear wounds, compared to a longer single incision. Pathologic scarring is consistently greater with high tension wounds (e.g., keloids) (15). Therefore, smaller trocar incisions should minimize pain and associated scarring (16).

PAIN WITH ROBOTIC SURGERY

Looking at pain management with robotic surgery in children, there is a paucity of data. Many of the physiologic effects of robotic surgery are well-understood. Due to increased intra-abdominal pressure, there is decreased lung compliance, decreased functional residual capacity, and increased airway resistance. When pressures are high enough, there can be increased cardiac output with peripheral vasoconstriction. Also, there can be increased renovascular resistance and decreased flow through the renal vein (17). However, there is little data reviewing the anesthetic considerations and postoperative management for robotic surgery in children.

Most reports on pain simply summarize narcotic use. Tanaka et al. compared open and laparoscopic pyeloplasties and saw a lower narcotic charge in pre-adolescent and adolescent populations. However, they did not see a difference in patients under the age of 10 years (18). Smith et al. compared open and robotic reimplantation in 50 patients ranging 3–144 months old. When compared to open repairs, they saw lower narcotic use in the bilateral robotic reimplantation. However, they did not see a statistically significant difference when comparing the unilateral reimplantations. Also, they did not outline the use of non-narcotic analgesics (19).

Some reports assessed both narcotic use and pain scales. Marchini et al. did a retrospective review of open and robotic reimplantation where pain scales and narcotic use were summarized. Although there was no significant difference in pain for the two cohorts, their analysis only included patients with pain scales >2 (20). Lee et al. compared results between an open and laparoscopic cohort. They did not see a statistically significant difference in pain scales for patients <2 years old (21). Harel et al. did a prospective review comparing pain assessment after robotic and open ureteral reimplantation. Amongst 34 patients, 11 patients had open surgery and 23 patients had robotic surgery. Robotic patients had lower narcotic requirement and lower intensity of postoperative pain. Although there was no significant difference between the two groups' subjective pain scores, the open cohort had more severe pain (45 vs. 9%). However, this was a small sample size that lacked randomization. And similar to the other studies described, this experience was not limited to an infant population (12).

COSTS OF ROBOTIC SURGERY

It is challenging to compare costs of surgery. The "comparative cost" of surgery is the quality divided by cost. Quality includes many factors (e.g., effectiveness, safety, patient satisfaction). And data summarizing these factors is still limited in both adult and pediatric patients. In 2009, a KID database comparison showed a $2,500 advantage with open pyeloplasties (22). In 2010, Varda et al showed a $3,500 discrepancy favoring open pyeloplasty (23).

As stated earlier, the use of robotics continues to increase each year. The increased experience should drive down operative times. As operative times decrease, operative costs decrease as well. Also, the more experienced robotic surgeons may lower costs with their judicious use of disposable instruments (24).

Some studies omit the amortization cost of the device, as well as the cost of maintenance for the machine. Many reports simply summarize the cost of the instruments used for that specific case. However, the estimated additional cost per case from amortization is $1,600 (25). Dangle et al. did not see a significant difference in direct cost of robotic and open pyeloplasties (4). Casella et al. compared robotic and laparoscopic pyeloplasties. There were 23 patients in each group. There was no significant difference in cost between the two groups. When looking at a subgroup of robotic cases where the stent was placed antegrade, they did see decreased operative time and lower total costs ($p < 0.001$) (24).

Varda et al. recently reviewed national trends in pediatric pyeloplasties. This analysis reviewed 2003–2015. Although the overall total volume of pyeloplasties has decreased by 7%, the number of robotically-assisted pyeloplasties has risen by 29% annually. There were few open cases in adolescents and few robotic cases in infants. They tried to analyze the adjusted outcomes and median costs for open and robotic pyeloplasties. Also, they tried to determine the primary drivers of cost for both open and robotic pyeloplasties. The three primary cost contributors were: operating room (OR) cost, equipment costs, and room/board. Room/board costs were higher for the open cases, whereas OR and equipment costs were higher for robotic cases. They found a higher median cost with robotic cases, and an absolute difference in cost per case of $1,060 (26).

There are many quality factors that may still favor robotic surgery (e.g., cosmesis, patient satisfaction, parental return to work). Improvement in these factors can improve the hospital's reputation. This may expand referral patterns not only for pediatric urology, but also for other departments in the hospital. Therefore, the cost and value of robotic surgery for a pediatric hospital is complex and nuanced.

TECHNICAL CHALLENGES OF INFANT ROBOTIC SURGERY

One potential barrier to robotic surgery in infants is robotic arm collisions due to the small working space. Finkelstein et al looked at 45 robotic cases performed in infants 3–12 months old. They looked at console time and number of robotic collisions. They found less collisions when the anterior superior iliac spine measurement (ASIS) of >13 cm or puboxyphoid distance (PXD) of >15 mm. These results were from a single surgeon, so it may not be translatable to the masses (27).

In regards to proficiency in technique, laparoscopic intracorporeal suturing is cumbersome and technically challenging for many surgeons. These technical challenges hampered enthusiasm for standard laparoscopic pyeloplasties and ureteral reimplantations. However, robotics offered more precise and efficient suturing (21). This widened the utilization of minimally invasive surgery for not only ureteropelvic junction obstruction (UPJO) and vesicoureteral reflux (VUR), but also for partial nephrectomy, bladder augmentation, and creation of catheterizable stomas.

In contrast to standard laparoscopy, robotic surgery has a quicker learning curve (28). Sorenson et al. compared the first 33 robotic and open pyeloplasties performed by senior faculty. When comparing the groups, there was no significant difference in length of stay, pain score, or surgical success. The number of complications were identical in the two groups. However, after the first 15–20 robotic cases, overall robotic operative times were within one standard deviation of the open pyeloplasty (29). Dangle et al. found their operative time decreased by 20 min after their first 5 robotic cases (4). Lee et al. compared outcomes with open (OPN) and robotic (RALP) pyeloplasties. Linear regression and ANOVA showed no significant change in time for the OPN group, but there was significant improvement in the RALP group (21). Kassite et al. analyzed the learning curve for two surgeons who were new to performing robotic surgery. A total of 42 RALP were performed in 41 patients. They accounted for patient complexity factors. Not surprisingly, they found that complexity factors influenced surgical outcomes. After looking at patient complexity factors and the perioperative data, they felt that more than 41 cases are needed to achieve mastery (30).

ROBOTIC CASE SELECTION

Over time, data has grown in pediatric robotic surgery. In other disciplines, pediatric robotic surgery has been used for a wide variety of surgical cases. The majority of these cases have been abdominal, but some have been thoracic cases. In 2008, Meehan reported 24 different robotic procedures in children. The majority of these cases had never been done with a minimally invasive approach by these specific authors. In this series, the only conversions were due to equipment failures or issues with standard laparoscopic equipment through the robotic ports. But no conversions were due to injuries from robotic instruments. They felt nursing team was critical to positive outcomes. In an effort to strengthen central organization, their hospital appointed a scrub nurse as their robotic coordinator. They streamlined training for the circulating nurse. They felt the designated personnel improved their set up and turnover time. Once in place, all technical aspects of robotic cases improved (31).

Although the data of robotic surgery in infants is less robust, results have shown benefits similar to the adult population. Reports in infants have shown lower postoperative analgesic use. Also, hospital stays are shorter, which may lead to quicker return to work for parents and guardians (4, 32, 33).

Multiple reports have shown low complication rates of robotic surgery in children. When complications have occurred, they are usually Clavien Grade 1 and 2. Often the complications are not from the robotic technique, but are linked to the ureteral stents (3, 4, 34). Most importantly, the success rates of surgery are comparable to open surgery.

A wide variety of robotic procedures have been described in children. However, reported outcomes in children (particularly in infants) are limited. To date, pyeloplasty is the primary pediatric robotic surgery with comparable safety and efficacy when compared to open or standard laparoscopic approach. This has been supported by large multi-centric studies (35). Also, this has been supported by the European Association of Urology Pediatric guidelines. The guidelines recognize the benefits of minimally invasive surgery by stating that "in experienced hands, laparoscopic or retroperitoneoscopic techniques and robot-assisted techniques have the same success rates as standard open procedures." Also, they state that "Robotic-assisted laparoscopic pyeloplasty has all the same advantages as laparoscopic pyeloplasty plus better maneuverability, improved vision, ease in suturing and increased ergonomics but higher costs." However, the role for robotic pyeloplasty in infants is less supported when the EUA states "There does not seem to be any clear benefit of minimal invasive procedures in a very young child, but current data is insufficient to defer a cut-off age (36)."

Laparoscopic and robotic ureteral reimplantation have not been widely accepted due to longer operative times and varied success rates. Many reports show success rates with robotic reimplantation lower than open repairs (37–39). And anti-reflux surgery is rarely indicated in infancy.

Robotic partial nephrectomy has been described in children and in some infants. Some find the dexterity and visualization of vascularity superior with robotics. Many find suturing more efficient with robotics. This is pertinent when buttressing sutures are placed in the remaining healthy renal tissue. Also, suturing may be required in the collecting system.

Given the increased dexterity, robotics can be helpful when performing complex reconstruction (e.g., bladder augmentation, Mitrofanoff creation, bladder neck reconstruction). This was first described in 2002 (40). Robotic bladder augmentation have longer operative times than open surgery, but also have lower blood loss and shorter hospital stays (41, 42). However, these complex reconstructive cases represent a small part of the existing literature in pediatric robotic surgery (43–45). And these complicated reconstructive cases are not done in infancy.

Although a wide variety of pediatric urologic cases have been performed with robotic assistance, its primary indication in pediatrics is for robotic pyeloplasty.

CASE SPECIFIC SURGICAL OUTCOMES

Pyeloplasty Surgical Outcomes

As stated earlier, the most commonly performed urologic robotic surgery is a pyeloplasty for a ureteropelvic junction obstruction (UPJO). For many years, open pyeloplasty has been considered the gold standard for therapy (36). Many early reports on pediatric robotic-assisted laparoscopic pyeloplasties (RALP) compared results with laparoscopic and open techniques. However, these were small, single center case series on 10 or fewer patients (32, 46, 47).

In 2006, Lee et al. compared robot assisted laparoscopic dismembered pyeloplasty (RALP) to an age matched cohort of patients undergoing open pyeloplasties (OPN). There were 33 patients in each cohort. In this series RALP was safe and effective. Thirty-one of the 35 RALP had improvement in radiographic follow up and/or symptoms. Their LOS was shorter (2.3 vs. 3.5 days). RALP patients had higher intraoperative narcotic use. But use of epidurals was vastly different. Eighteen OPN patients had an epidural and no RALP patients had an epidural. Overall, the RALP patients had lower postoperative and total narcotic use ($p = 0.001$). Also, linear regression analysis showed a longer LOS in the OPN group as age of patient increased. However, there was no difference in LOS for the RALP group. There was similar estimated blood loss (EBL) in both cohorts. And no blood transfusions were required for either group. Mean operative time was higher in the RALP group (219 vs. 181 min). But this was not statistically significant ($p = 0.031$). There were no complications in the OPN group. One patient from the RALP group required repeat surgery. This patient initially had a retroperitoneal surgery and crossing vessels were not recognized. Due to persistent obstruction, this patient had a temporary percutaneous nephrostomy tube and later had a transperitoneal repair. Follow up in this series was short, with a mean follow up of 10 months for the RALP cohort. Similar to other studies, increased experience correlated with quicker operative times (21).

When looking specifically at results in infants, the data is less robust. Ballouhey et al. evaluated robotic surgical results in patients under and over 15 kg. They found success rates were comparable. They had 62 patients with a mean weight of 11.1 kg and 116 patients with a mean weight of 30.2 kg. The mean follow up was 37 months. The most common surgeries were pyeloplasty, nephrectomy, and fundoplication. Although set up time was longer in the smaller patients, the overall surgical time and hospital stays were not statistically different (48).

Kutikov et al. had one of the earliest reports of robotic surgery in infants. They did a retrospective review of robotic pyeloplasties in 9 infants aged 3–8 months. Mean operative time was 122. Eight minutes with a mean console time of 72.1 min. The mean hospital stay was 1.4 days. Seventy-eight percent had resolution or improvement in their hydronephrosis. No patient required conversion to open or standard laparoscopic techniques (32).

Kawal et al. looked at their 4 year experience of robotic pyeloplasties in 138 patients, 34 of whom were infants. In their series, multivariate and comparative analysis showed lower morphine equivalents in infants. Of note, infants had a higher chance of placing a percutaneous stent. The infant cohort had success rates of 96%. Six patients (4%) required repeat surgery. Although infants had a 29.4% complication rate, this was similar to the older population (30.8%). Reported complications were low grade: 60% were Clavien grade 1 and 2 (pain, urinary tract infection). Forty percent were Clavien grade 3 (stent dislodgement and replacement). The most common complications with both infants and older children were stent related, with evaluation in the emergency room for pain and hematuria (49).

Dangle et al. reviewed their experience with infant pyeloplasties comparing open and robotic approaches. They had 10 patients in each arm. Mean patient age was 3.31 months. Postoperative outcomes were similar in for the open vs. robotic arms: length of stay (2.2 vs. 2.1 days), estimated blood loss (6.5 vs. 7.6 ml), days to regular diet (1 vs. 1.1 days), and time to foley removal (1.3 vs. 1.3 days). However, total operating time was longer in the robotic group (199 vs. 242 min). When excluding amortization, robotic cost, maintenance and depreciation, direct costs were similar ($4,410 vs. $4,979 per case). In regards to surgical success, improvement in hydronephrosis was identical in both groups. These authors recognize the importance of surgeon experience before performing robotic surgery infants. Their senior author had performed 28 pyeloplasties and 60 other complex robotic procedures in older children before forging into robotic surgery in infants (4).

In 2015, Avery et al. reported a multi-institutional experience of infant robotic pyeloplasty. They reported the results by 6 surgeons at 5 different institutions. Sixty patients under the age of 12 months underwent 62 robotic pyeloplasties. All patients had this done with a transperitoneal approach. Mean age was 7.3 months and mean weight was 8.1 kg. There was a 91% success rate with an 11% complication rate. The complications were Grade 1 (1 patient), Grade 2 (2 patients), and Grade 3 (4 patients). No visceral or vascular injuries occurred. But the complications included: two port hernias, one urine leak, one retained stent, one ileus, one renal calculus, and one urinary tract infection. Seventy-two percent were discharged on postoperative day 1. All six surgeons did have more than 5 years of experience post fellowship training (3).

Since 5 mm robotic instruments have a longer articulating arm, some surgeons steer away from using the 5 mm instruments, in favor of 8 mm instruments. Baek et al. compared the perioperative parameters for infant and non-infant RALP over a 2 year period of time. There were 16 infants and 49 non-infants. There was no difference in operative time, hospital pain medication use, or hospital stay. Success rates were similar: 93% for infants and 100% or non-infants ($p = 0.08$) (50).

Ureteral Reimplantation Surgical Outcomes

Outcomes with robotic ureteral reimplantation are still evolving. And the data is very limited for infants. Initial robotic experience entailed an intravesical approach. This approach had varied success rates between 83 and 100%. And complication rates were 0–52% (20, 51, 52).

There is more data with robotic ureteral reimplantation surgery performed with an extravesical approach. In these series, complication rates have ranged from 0 to 40%. However, success rates have varied between 77 and 100%. Robotic ureteral reimplantation has not become a standard of care for anti-reflux surgery (4, 21, 37, 38, 53–55).

However, in many robotic ureteral reimplantation series, the youngest patients are still over a year old. Herz et al. reported their experience with extravesical ureteral reimplantation in 72 ureters (54 patients). They had success in 84.7%, but the youngest patient was 2.5 years old (37). Chalmers et al reported their results in 17 patients with a 90.9% success. However, all patients were over 2 years old (55). Dangle et al. reported on 29 patients with a success rate of 87.5% but the youngest patient was 3 years old (56). Grimsby et al. reported the combined experience from two institutions with 93 ureters treated in 61 patients. Although some patients were under 1 year, the mean age was 6.7 years. Their success rate was 72%. Boysen et al. showed improved results in a prospective multi-institutional study of extravesical reimplantation. They reported from 7 institutions treating 143 patients (199 ureters). Success rate was 93.8%. Mean age was 6.6 years (57). Akhavan et al. reported on 78 ureteral reimplantations performed at their institution. Success rates were good with only 7.7% of patients with persistent reflux. Also, there was 10% complication rate. However, the mean age was 6.2 years old with the youngest patient 1.9 years old. Although the authors felt RALUR was effective and safe treatment for primary vesicoureteral reflux, it was not an experience for infant patients (53).

In 2011, Smith et al. described an infant extravesical robotic reimplantation on a 3 month old infant (19).

Complication rates with robotic ureteral reimplantations have been low. Boysen et al. did a multi-institutional review from nine institutions. This included a total of 260 patients (363 ureters). The overall complication rate was 9.6%. There were no Clavien Grade 4 or 5 complications. This was a large cohort, but not specific to infants (58).

When indicated, performing a ureteral reimplantation has restricted use in infants due to their small bladder capacity. With an intravesical approach a bladder capacity of 130 mL is preferred (59). Given the limited data and rare need for intervention in infancy, there is no defined role for robotic ureteral reimplantation surgery in infants.

Miscellaneous Cases

Ballouhey et al. looked at robotic partial nephrectomy in small children. This was not specific to infants, but it was a cohort of 28 patients all <15 kg: 15 patients done with a robotic approach and 13 patients done with an open approach. Mean at the time of surgery was 20.2 months for the robotic arm and 18.4 months for the open arm. The mean hospital stay was significantly longer for the open arm (6.3 vs. 3.4 days) $P < 0.001$. Also, the postoperative pain control in total morphine equivalent intake was significantly greater in the open arm (1.08 vs. 0.52 mg/kg/day) $P < 0.001$. There was no significant difference in terms of operating time, complication rate, or renal outcomes (60).

Robotic partial nephrectomy has been demonstrated in infants. Wietsma et al. described their experience doing a robotic lower pole partial nephrectomy in an 11 month old male who was 10.7 kg. This patient had no intraoperative or postoperative complications. He was discharged home on postoperative day 1 (61). However, the experience in infants is still limited, so it is not a standard of care.

Bansal et al. described a bilateral upper tract robotic surgery in a 4 month old infant (left ureteroureterostomy and Right upper pole partial nephrectomy). There were no intraoperative complications and the patient went home on postoperative day 1 (62). They expanded their review of 10 infants who underwent robotic upper tract reconstructive surgery at their institution between March 2009 and February 2013. Eight patients underwent pyeloplasty and 2 underwent ureteroureterostomy. The mean age was 10 months and mean weight was 7.7 kg. Mean follow up was 10 months. Postoperative ultrasound showed improved in all patients. There were three complications (one Grade 1 and two Grade IIIb). Complications included ileus, urinary tract infection, and one urine leak (63).

Looking a broader view of robotic cases, Fuchs et al. did a retrospective review of multiple upper tract surgeries done in infants. A total of 67 patients had surgery: 26 pyeloplasties, 18 heminephrectomies, and 23 nephrectomies. Mean weight was 6.4 kg and mean operative time was 113 min. One pyeloplasty required conversion to open technique. One patient had a missed intraoperative bowel injury. No blood transfusions were required. The pyeloplasties had improvement in their drainage time. And the heminephrectomy patients had stable postoperative renal function. This group preferred a transperitoneal approach due to the size limitations in infants (64).

Srougi et al. looked at their institution's experience doing robotic surgery in infants and toddlers. However, of the 65 patients in their series, only 14 patients were infants under the age of 1 year. There was a wide range of cases performed (pyeloplasty, nephrectomy, reimplantation, ureteroureterostomy, orchidopexy, excision of Mullerian remnant, and pyelolithotomy). Mean hospital stay was 1.3 days. Mean weight was 11.6 kg, but they did evaluate the complication rate in children <10 kg. They had 23 patients under 10 kg (34%). There were 12 post-operative complications. Most were Clavien grade I and II. But there was one grade IIIB complication. There was not a higher complication rates in the smaller children. In fact, the patients >10 kg had higher complication rates, but it was not statistically significant (65).

Feasibility of performing robotic surgery in infants has been shown in other fields. Meehan et al. reported on 45 infants who underwent robotic surgery. Eighty-nine percent of the patients had surgery completed with a robotic technique. The average age was 8 months and average weight was 6.8 kg (66). Dawrant et al. described their experience doing robotic-assisted resection of choledochal cysts and hepaticojejunostomy in infants <10 kg. In 2009, they performed this surgery in 5 children. Mean age was 1 year and mean weight was 8.5 kg. Mean discharge was on postoperative day 6. There were no postoperative complications (67).

Overall complication rates of robotic surgery in children has been reportedly low. Bansal et al. looked the complication rate by 3 surgeons during the first 4 years of their robotic program. This review included 10 infants, but was primarily non-infant pediatric cases. Ten different surgeries were performed in 136 patients. Only one of the surgeons performed surgery on infants. They were all performed transperitoneally. There were no intraoperative complications, robotic malfunctions or conversions to open surgery. Eleven patients experienced a postoperative complication. Three of these 11 complications occurred in infants. Therefore, the complication rate for infants was 30% (3 out of 10) and 8.6% for the other pediatric patients (8 out of 126 non-infants) $p = 0.035$. There were 2 Clavien grade 1, 7 Clavien grade II, and 2 Clavien grade IIIb. The degree of complications was not higher in the infant patients. And none of the complications were due to intraoperative or due to robotic malfunction (34).

CONCLUSION

Robotic surgery continues to evolve in pediatric urology. There are multiple series demonstrating excellent surgical results. The benefits of shorter hospital stays, less narcotic use, improved cosmesis has been demonstrated in both adult and pediatric populations. However, there remains limited data on robotic surgery in infants.

Robotic surgery in pediatrics had steadily gained acceptance, but there are many surgeons still hesitant to utilize this technique in infants. Concerns include the limited operative space, relatively large port sizes, increased operative time, and potential decreased anesthesia access to the patient (68, 69). National trends in pediatric pyeloplasties have remained fairly stable. The volume of robotic repairs has increased and the number of open repairs has decreased. However, a review of national trends showed that infants were 40 times less likely to have a robotic repair when compared to older children (23).

However, hesitancy to use robotics in infants and children may be misguided. There are many reports of robotic surgery that confirm it is a safe and feasible technique. Although it has been used for a wide variety of urologic cases, its primary indication is limited to pyeloplasty. Many reports demonstrate comparable results of robotic pyeloplasty relative to open surgery. Robotic partial nephrectomy has also been shown safe and effective, albeit in modest data.

More data is needed, but robotics is a safe and effective approach for a wide array of urologic cases, even in infants.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

REFERENCES

1. Reddy MN, Nerli RB. The laparoscopic pyeloplasty: is there a role in the age of robotics? *Urol Clin North Am*. (2015) 42:43–52. doi: 10.1016/j.ucl.2014.09.004
2. Tasian GE, Wiebe DJ, Casale P. Learning curve of robotic assisted pyeloplasty for pediatric urology fellows. *J Urol*. (2013) 190(4 Suppl):1622–6. doi: 10.1016/j.juro.2013.02.009
3. Avery DI, Herbst KW, Lendvay TS, Noh PH, Dangle P, Gundeti MS, et al. Robot-assisted laparoscopic pyeloplasty: multi-institutional experience in infants. *J Pediatric Urol*. (2015) 11:139.e1–5. doi: 10.1016/j.jpurol.2014.11.025
4. Dangle PP, Kearns J, Anderson B, Gundeti MS. Outcomes of infants undergoing robot-assisted laparoscopic pyeloplasty compared to open repair. *J Urol*. (2013) 190:2221–6. doi: 10.1016/j.juro.2013.07.063
5. Kavoussi LR, Peters CA. Laparoscopic pyeloplasty. *J Urol*. (1993) 150:1891–4. doi: 10.1016/S0022-5347(17)35926-8
6. Moore RG, Averch TD, Schulam PG, Adams JB, 2nd, Chen RN, Kavoussi LR. Laparoscopic pyeloplasty: experience with the initial 30 cases. *J Urol*. (1997) 157:459–62. doi: 10.1016/S0022-5347(01)65170-X
7. Bauer JJ, Bishoff JT, Moore RG, Chen RN, Iverson AJ, Kavoussi LR. Laparoscopic versus open pyeloplasty: assessment of objective and subjective outcome. *J Urol*. (1999) 162(3 Pt 1):692–5. doi: 10.1097/00005392-199909010-00016
8. Klingler HC, Remzi M, Janetschek G, Kratzik C, Marberger MJ. Comparison of open versus laparoscopic pyeloplasty techniques in treatment of uretero-pelvic junction obstruction. *Euro Urol*. (2003) 44:340–5. doi: 10.1016/S0302-2838(03)00297-5
9. Abdelshehid CS, Eichel L, Lee D, Uribe C, Boker J, Basillote J, et al. Current trends in urologic laparoscopic surgery. *J Endourol*. (2005) 19:15–20. doi: 10.1089/end.2005.19.15
10. Eichel L, Ahlering TE, Clayman RV. Role of robotics in laparoscopic urologic surgery. *Urol Clin North Am*. (2004) 31:781–92. doi: 10.1016/j.ucl.2004.06.014
11. Partin AW, Adams JB, Moore RG, Kavoussi LR. Complete robot-assisted laparoscopic urologic surgery: a preliminary report. *J Am College Surg*. (1995) 181:552–7.
12. Harel M, Herbst KW, Silvis R, Makari JH, Ferrer FA, Kim C. Objective pain assessment after ureteral reimplantation: comparison

of open versus robotic approach. *J Pediatric Urol.* (2015) 11:82.e1–8. doi: 10.1016/j.jpurol.2014.12.007
13. Barbosa JA, Barayan G, Gridley CM, Sanchez DC, Passerotti CC, Houck CS, et al. Parent and patient perceptions of robotic vs open urological surgery scars in children. *J Urol.* (2013) 190:244–50. doi: 10.1016/j.juro.2012.12.060
14. Casale P. Minimally invasive survey in infants. *Pro J Urol.* (2012) 188:1665–6. doi: 10.1016/j.juro.2012.08.049
15. Akaishi S, Akimoto M, Ogawa R, Hyakusoku H. The relationship between keloid growth pattern and stretching tension: visual analysis using the finite element method. *Anna Plast Surg.* (2008) 60:445–51. doi: 10.1097/SAP.0b013e3181238dd7
16. Thane B. Incisons do not simply sum. *Surg Endoscopy.* (2010) 24:1746–51. doi: 10.1007/s00464-009-0854-z
17. Munoz CJ, Nguyen HT, Houck CS. Robotic surgery and anesthesia for pediatric urologic procedures. *Curr Opin Anaesthesiol.* (2016) 29:337–44. doi: 10.1097/ACO.0000000000000333
18. Tanaka ST, Grantham JA, Thomas JC, Adams MC, Brock JW, Pope JC. A comparison of open vs laparoscopic pediatric pyeloplasty using the pediatric health information system database–do benefits of laparoscopic approach recede at younger ages? *J Urol.* (2008) 180:1479–85. doi: 10.1016/j.juro.2008.06.044
19. Smith RP, Oliver JL, Peters CA. Pediatric robotic extravesical ureteral reimplantation: comparison with open surgery. *J Urol.* (2011) 185:1876–81. doi: 10.1016/j.juro.2010.12.072
20. Marchini GS, Hong YK, Minnillo BJ, Diamond DA, Houck CS, Meier PM, et al. Robotic assisted laparoscopic ureteral reimplantation in children: case matched comparative study with open surgical approach. *J Urol.* (2011) 185:1870–5. doi: 10.1016/j.juro.2010.12.069
21. Lee RS, Retik AB, Borer JG, Peters CA. Pediatric robot assisted laparoscopic dismembered pyeloplasty: comparison with a cohort of open surgery. *J Urol.* (2006) 175:683–7; discussion 7. doi: 10.1016/S0022-5347(05)00183-7
22. Liu DB, Ellimoottil C, Flum AS, Casey JT, Gong EM. Contemporary national comparison of open, laparoscopic, and robotic-assisted laparoscopic pediatric pyeloplasty. *J Pediatric Urol.* (2014) 10:610–5. doi: 10.1016/j.jpurol.2014.06.010
23. Varda BK, Johnson EK, Clark C, Chung BI, Nelson CP, Chang SL. National trends of perioperative outcomes and costs for open, laparoscopic and robotic pediatric pyeloplasty. *J Urol.* (2014) 191:1090–5. doi: 10.1016/j.juro.2013.10.077
24. Casella DP, Fox JA, Schneck FX, Cannon GM, Ost MC. Cost analysis of pediatric robot-assisted and laparoscopic pyeloplasty. *J Urol.* (2013) 189:1083–6. doi: 10.1016/j.juro.2012.08.259
25. Barbash GI, Glied SA. New technology and health care costs–the case of robot-assisted surgery. *N Engl J Med.* (2010) 363:701–4. doi: 10.1056/NEJMp1006602
26. Varda BK, Wang Y, Chung BI, 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 pediatric pyeloplasty in the United States from 2003 to 2015. *J Pediatric Urol.* (2018) 14:336.e1–e8. doi: 10.1016/j.jpurol.2017.12.010
27. Finkelstein JB, Levy AC, Silva MV, Murray L, Delaney C, Casale P. How to decide which infant can have robotic surgery? just do the math. *J Pediatric Urol.* (2015) 11:170.e1–4. doi: 10.1016/j.jpurol.2014.11.020
28. Samadi D, Levinson A, Hakimi A, Shabsigh R, Benson MC. From proficiency to expert, when does the learning curve for robotic-assisted prostatectomies plateau? the Columbia university experience. *World J Urol.* (2007) 25:105–10. doi: 10.1007/s00345-006-0137-4
29. Sorensen MD, Delostrinos C, Johnson MH, Grady RW, Lendvay TS. Comparison of the learning curve and outcomes of robotic assisted pediatric pyeloplasty. *J Urol.* (2011) 185(6 Suppl):2517–22. doi: 10.1016/j.juro.2011.01.021
30. Kassite I, Braik K, Villemagne T, Lardy H, Binet A. The learning curve of robot-assisted laparoscopic pyeloplasty in children: a multi-outcome approach. *J Pediatric Urol.* (2018) 14:570.e1–e10. doi: 10.1016/j.jpurol.2018.07.019
31. Meehan JJ, Sandler A. Pediatric robotic surgery: a single-institutional review of the first 100 consecutive cases. *Surg Endoscopy.* (2008) 22:177–82. doi: 10.1007/s00464-007-9418-2
32. Kutikov A, Nguyen M, Guzzo T, Canter D, Casale P. Robot assisted pyeloplasty in the infant-lessons learned. *J Urol.* (2006) 176:2237–9; discussion 9–40. doi: 10.1016/j.juro.2006.07.059
33. Pelizzo G, Nakib G, Goruppi I, Avolio L, Romano P, Raffaele A, et al. Pediatric robotic pyeloplasty in patients weighing less than 10 kg initial experience. *Surg Laparos Endos Percutan Tech.* (2014) 24:e29–31. doi: 10.1097/SLE.0b013e31828e3f18
34. Bansal D, Defoor WR, Jr., Reddy PP, Minevich EA, Noh PH. Complications of robotic surgery in pediatric urology: a single institution experience. *Urology.* (2013) 82:917–20. doi: 10.1016/j.urology.2013.05.046
35. Spinoit AF, Nguyen H, Subramaniam R. Role of robotics in children: a brave new world! *Euro Urol Focus.* (2017) 3:172–80. doi: 10.1016/j.euf.2017.08.011
36. Tekgul S, Dogan HS, Hoebeke P, Kocvara R, Nijman JM, Radmayr C, Stein R. EUA guidelines on paediatric urology. *Eur Assoc Urolog.* (2016).
37. Herz D, Fuchs M, Todd A, McLeod D, Smith J. Robot-assisted laparoscopic extravesical ureteral reimplant: a critical look at surgical outcomes. *J Pediatric Urol.* (2016) 12:402.e1–e9. doi: 10.1016/j.jpurol.2016.05.042
38. Schomburg JL, Haberman K, Willihnganz-Lawson KH, Shukla AR. Robot-assisted laparoscopic ureteral reimplantation: a single surgeon comparison to open surgery. *J Pediatric Urol.* (2014) 10:875–9. doi: 10.1016/j.jpurol.2014.02.013
39. Timberlake MD, Peters CA. Current status of robotic-assisted surgery for the treatment of vesicoureteral reflux in children. *Curr Opin Urol.* (2017) 27:20–6. doi: 10.1097/MOU.0000000000000357
40. Pedraza R, Weiser A, Franco I. Laparoscopic appendicovesicostomy (Mitrofanoff procedure) in a child using the da Vinci robotic system. *J Urol.* (2004) 171:1652–3. doi: 10.1097/01.ju.0000116066.72132.9a
41. Grimsby GM, Jacobs MA, Gargollo PC. Comparison of complications of robot-assisted laparoscopic and open appendicovesicostomy in children. *J Urol.* (2015) 194:772–6. doi: 10.1016/j.juro.2015.02.2942
42. Grimsby V. Menon BJ. Schlomer LA. Baker R, Adams PC, Gargollo MA. Long-term outcomes of bladder neck reconstruction without augmentation cystoplasty in children. *Jacobs J Urol.* (2016) 195:155–61. doi: 10.1016/j.juro.2016.01.116
43. Bagrodia A, Gargollo P. Robot-assisted bladder neck reconstruction, bladder neck sling, and appendicovesicostomy in children: description of technique and initial results. *J Endourol.* (2011) 25:1299–305. doi: 10.1089/end.2011.0031
44. Murthy P, Cohn JA, Selig RB, Gundeti MS. Robot-assisted laparoscopic augmentation ileocystoplasty and mitrofanoff appendicovesicostomy in children: updated interim results. *European urology.* (2015) 68:1069–75. doi: 10.1016/j.eururo.2015.05.047
45. Thakre AA, Yeung CK, Peters C. Robot-assisted mitrofanoff and Malone antegrade continence enema reconstruction using divided appendix. *J Endourol.* (2008) 22:2393–6; discussion 6. doi: 10.1089/end.2008.0256
46. Kozlov Y, Kovalkov K, Nowogilov V. 3D Laparoscopy in neonates and infants. *J Laparoendosc Adv Surg Tech A.* (2016) 26:1021–7. doi: 10.1089/lap.2016.0155
47. Yee DS, Shanberg AM, Duel BP, Rodriguez E, Eichel L, Rajpoot D. Initial comparison of robotic-assisted laparoscopic versus open pyeloplasty in children. *Urology.* (2006) 67:599–602. doi: 10.1016/j.urology.2005.09.021
48. Ballouhey Q, Villemagne T, Cros J, Szwarc C, Braik K, Longis B, et al. A comparison of robotic surgery in children weighing above and below 15.0 kg: size does not affect surgery success. *Surg Endosc.* (2015) 29:2643–50. doi: 10.1007/s00464-014-3982-z
49. Kawal T, Srinivasan AK, Shrivastava D, Chu DI, Van Batavia J, Weiss D, et al. Pediatric robotic-assisted laparoscopic pyeloplasty: Does age matter? *J Pediatric Urol.* (2018) 14:540.e1–e6. doi: 10.1016/j.jpurol.2018.04.023
50. Baek M, Silay MS, Au JK, Huang GO, Elizondo RA, Puttmann KT, et al. Does the use of 5 mm instruments affect the outcomes of robot-assisted laparoscopic pyeloplasty in smaller working spaces? a comparative analysis of infants and older children. *J Pediatric Urol.* (2018) 14:537.e1–537.e6. doi: 10.1016/j.juro.2017.02.1637
51. Peters C, Woo, R. Intravesical robotically assistend bilateral ureteral reimplantation. *J Endourol.* (2005) 19:618–21. doi: 10.1089/end.2005.19.618
52. Chan KW, Lee KH, Tam YH, Sihoe JD. Early experience in robotic-assisted laparoscopic bilateral intravesical ureteral reimplantation

for vesicoureteral reflux in children. *J Robo Surg.* (2012) 6:259–62. doi: 10.1007/s11701-011-0288-1
53. Akhavan A, Avery D, Lendvay TS. Robot-assisted extravesical ureteral reimplantation: outcomes and conclusions from 78 ureters. *J Pediatric Urol.* (2014) 10:864–8. doi: 10.1016/j.jpurol.2014.01.028
54. Grimsby GM, Dwyer ME, Jacobs MA, Ost MC, Schneck FX, Cannon GM, et al. Multi-institutional review of outcomes of robot-assisted laparoscopic extravesical ureteral reimplantation. *J Urol.* (2015) 193(5 Suppl):1791–5. doi: 10.1016/j.juro.2014.07.128
55. Chalmers D, Herbst K, Kim C. Robotic-assisted laparoscopic extravesical ureteral reimplantation: an initial experience. *J Pediatric Urol.* (2012) 8:268–71. doi: 10.1016/j.jpurol.2011.04.006
56. Dangle PP, Shah A, Gundeti MS. Robot-assisted laparoscopic ureteric reimplantation: extravesical technique. *BJU Int.* (2014) 114:630–2. doi: 10.1111/bju.12813
57. Boysen WR, Akhavan A, Ko J, Ellison JS, Lendvay TS, Huang J, et al. Prospective multicenter study on robot-assisted laparoscopic extravesical ureteral reimplantation (RALUR-EV): outcomes and complications. *J Pediatric Urol.* (2018) 14:262.e1–.e6. doi: 10.1016/j.jpurol.2018.01.020
58. Boysen WR, Ellison JS, Kim C, Koh CJ, Noh P, Whittam B, et al. Multi-institutional review of outcomes and complications of robot-assisted laparoscopic extravesical ureteral reimplantation for treatment of primary vesicoureteral reflux in children. *J Urol.* (2017) 197:1555–61. doi: 10.1016/j.juro.2017.01.062
59. Kutikov A, Guzzo TJ, Canter DJ, Casale P. Initial experience with laparoscopic transvesical ureteral reimplantation at the children's hospital of Philadelphia. *J Urol.* (2006) 176:2222–5; discussion 5–6. doi: 10.1016/j.juro.2006.07.082
60. Ballouhey Q, Binet A, Clermidi P, Braik K, Villemagne T, Cros J, et al. Partial nephrectomy for small children: Robot-assisted versus open surgery. *Int J Urol.* (2017) 24:855–60. doi: 10.1111/iju.13466
61. Wiestma AC, Cho PS, Hollis MV, Badway J, Yu RN. Robot-assisted laparoscopic lower pole partial nephrectomy in the pediatric patient. *J Pediatric Urol.* (2016) 12:428–9. doi: 10.1016/j.jpurol.2016.09.007
62. Bansal D, Bean CM, Vanderbrink BA, Noh PH. Infant robotic bilateral upper urinary tract surgery. *Korean J Urol.* (2014) 55:288–91. doi: 10.4111/kju.2014.55.4.288
63. Bansal D, Cost NG, Bean CM, Vanderbrink BA, Schulte M, Noh PH. Infant robot-assisted laparoscopic upper urinary tract reconstructive surgery. *J. Pediatric Urol.* (2014) 10:869–74. doi: 10.1016/j.jpurol.2014.01.029
64. Fuchs J, Luithle T, Warmann SW, Haber P, Blumenstock G, Szavay P. Laparoscopic surgery on upper urinary tract in children younger than 1 year: technical aspects and functional outcome. *J Urol.* (2009) 182:1561–8. doi: 10.1016/j.juro.2009.06.063
65. Srougi V, Yorioka M, Sanchez DC, Onal B, Houck CS, Nguyen HT. The feasibility of robotic urologic surgery in infants and toddlers. *J Pediatric Urol.* (2013) 9(6 Pt B):1198–203. doi: 10.1016/j.jpurol.2013.05.011
66. Meehan JJ. Robotic surgery in small children: is there room for this? *J Laparoendosc Adv Surg Tech A*. (2009) 19:707–12. doi: 10.1089/lap.2008.0178
67. Dawrant MJ, Najmaldin AS, Alizai NK. Robot-assisted resection of choledochal cysts and hepaticojejunostomy in children less than 10 kg. *J Pediatric Surg.* (2010) 45:2364–8. doi: 10.1016/j.jpedsurg.2010.08.031
68. Mariano ER, Furukawa L, Woo RK, Albanese CT, Brock-Utne JG. Anesthetic concerns for robot-assisted laparoscopy in an infant. *Anesthesia Analgesia.* (2004) 99:1665–7. doi: 10.1213/01.ANE.0000137394.99683.66
69. Peters CA. Robotically assisted surgery in pediatric urology. *Urol Clin North Am.* (2004) 31:743–52. doi: 10.1016/j.ucl.2004.06.007

Conflict of Interest Statement: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

ORIGINAL RESEARCH
published: 21 May 2019
doi: 10.3389/fped.2019.00200

Check for updates

Robot-Assisted Laparoscopic and Thoracoscopic Surgery: Prospective Series of 186 Pediatric Surgeries

Mario Navarrete Arellano[1]* *and Francisco Garibay González*[2]

[1] Hospital Central Militar, SEDENA, Mexico City, Mexico, [2] Department of Pediatrics, Hospital Militar de Especialidades de la Mujer y Neonatología, SEDENA, Mexico City, Mexico

Objective: We present the applications and experiences of robot-assisted laparoscopic and thoracoscopic surgery (RALTS) in pediatric surgery.

Materials and Methods: A prospective, observational, and longitudinal study was conducted from March 2015 to March 2018 that involved a non-random sample of a pediatric population that was treated with RALTS. The parameters examined were: gender, age, weight, height, diagnoses, surgical technique, elapsed time of console surgery, estimated bleeding, need for hemotransfusion, complications, surgical conversions, postoperative hospital stay, and follow-up. The Clavien-Dindo classification of complications was used. The surgical system used was the da Vinci model, Si version (Intuitive Surgical, Inc., Sunnyvale, CA. U.S.A), with measures of central tendency.

Results: In a 36-months period, 186 RALTS cases were performed, in 147 pediatric patients and an adult; 53.23% were male, and the remaining were female. The average age was 83 months, ranging from 3.5 to 204 months, plus one adult patient of 63 years. The stature was an average of 116.6 cm, with a range of 55–185 cm; the average weight was 26.9 kg, with a range of 5–102 kg; the smallest patient at 3.5 months was 55 cm in stature and weighed 5.5 kg. We performed 41 different surgical techniques, grouped in 4 areas: urological 91, gastrointestinal and hepatobiliary (GI-HB) 84, thoracic 6, and oncological 5. The console surgery time was 137.2 min on average, ranging from 10 to 780 min. Surgeon 1 performed 154 operations (82.8%), and the remainder were performed by Surgeon 2, with a conversion rate of 3.76%. The most commonly performed surgeries were: pyeloplasty, fundoplication, diaphragmatic plication, and removal of benign tumors, by area. Hemotransfusion was performed for 4.83%, and complications occurred in 2.68%. The average postoperative stay was 2.58 days, and the average follow-up was 23.5 months. The results of the 4 areas were analyzed in detail.

Conclusion: RALTS is safe and effective in children. An enormous variety of surgeries can be safely performed, including complex hepatobiliary, and thoracic surgery in small children. There are few published prospective series describing RALTS in the pediatric population, and most only describe urological surgery. It is important to offer children

OPEN ACCESS

Edited by:
Miguel Alfedo Castellan,
University of Miami, United States

Reviewed by:
Marcos Raymond Perez-Brayfield,
University of Puerto Rico, Puerto Rico
Mohan S. Gundeti,
University of Chicago, United States
Juan Ignacio Bortagaray,
Monash Children's Hospital, Australia

Correspondence:
Mario Navarrete Arellano
drcirugiaroboticamx@gmail.com

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *10 December 2018*
Accepted: *30 April 2019*
Published: *21 May 2019*

Citation:
Navarrete Arellano M and Garibay González F (2019) Robot-Assisted Laparoscopic and Thoracoscopic Surgery: Prospective Series of 186 Pediatric Surgeries. Front. Pediatr. 7:200. doi: 10.3389/fped.2019.00200

the advantages and safety of minimal invasion with robotic assistance; however, this procedure has only been slowly accepted and utilized for children. It is possible to implement a robust program of pediatric robotic surgery where multiple procedures are performed.

Keywords: robotic surgery, pediatric surgery, robotic urological surgery, robotic gastrointestinal surgery, robotic thoracic surgery, robotic oncological surgery, minimally invasive surgery, children

INTRODUCTION

Robotic surgery is one technology that has gained an enormous surge in use on adults. The general surgical applications have been quite varied in adults, but the technique has been particularly useful in urology for prostate surgery (1–4). There have been few reports that have been published for robotic general pediatric surgery (5–14). Thus, far, the largest number of procedures and publications have been produced for robotic urological pediatric surgery (15–34).

Trends in the literature indicate that pediatric robot-assisted minimally invasive surgery is continuing to be globally utilized (15–23, 31–34). Numerous case reports, case series, and comparative studies have unequivocally demonstrated that robotic surgery in children is safe (35). Robotic enhancements offer improvements to conventional minimal access surgery, permitting technical capabilities beyond existing threshold limits of human performance for surgery within the spatially constrained operative workspaces in children (15).

The first robotic procedure in children was fundoplication, were carried out by Meininger et al. in July 2000 and reported in April 2001 (36, 37).

If traditional laparoscopy is used, the reconstructive procedures are very challenging, and long periods of time are necessary to acquire the appropriate skills and confidence, vs. with RALS (robot-assisted laparoscopic surgery), the learning curve is shorter (31, 38–40).

In systematic investigations of databases of pediatric robot-assisted surgery, the global surgical conversion rate was 4.7% (7), other a net overall reported surgical conversion rate of 2.5% (15). Najmaldin and Antao (41) reported their initial 16-months experience with 50 abdominal procedures involving the gastrointestinal and hepatobiliary (GI-HB) and urological areas. Twelve different robotic surgical techniques were used, and the most frequent surgeries were fundoplication and pyeloplasty, with 6% conversions (41).

In published studies of pediatric robotic surgery, transoperative complications are infrequent, and in the postoperative period, the frequency varies from 0 to 15% (7, 41–43).

Minimally invasive surgery is commonly used for many applications in adult surgical oncology, including biopsy and resection of malignant disease in the chest and abdomen, and management of therapeutic complications. Because there has been an increasing availability of smaller instruments and equipment more suitable to the pediatric patient, for conventional laparo-thoracoscopy, there has been an increase in the use of these techniques with children. With robotic assistance there are also risks, among others, are port-site metastases and peritoneal spread, after resection due to minimal invasion of neoplasms (44, 45). The current status of robotic surgery for tumors in children is low volume usage, and globally a relatively static adoption (46–48).

There is a scarcity of publications from Latin American countries to date describing pediatric patients that have undergone robotic surgery. Secin et al. (49) conducted a survey among the main urologists working in public hospitals in Latin America, in 10 robotic programs based in 4 countries: 4 in Brazil, 3 in Mexico, 2 in Argentina, and 1 in Venezuela. In Venezuela, at the University Hospital of Caracas, 4 robotic surgeries had been performed in pediatric patients, with 2 pyeloplasties, one megacolon surgery, and one resection of an ovarian tumor that had been treated in the period from 2010 to 2012 (unpublished data). For adult patients, there are publications for various specialties (50–54).

The objective of this publication is to present the applications and our experience of RALTS in pediatric surgery.

MATERIALS AND METHODS

This prospective, observational and longitudinal study of the robotic surgeries performed on a pediatric population was conducted from March 2015 to March 2018. Our hospital is a public tertiary care facility, and the robotic surgery program includes several surgical specialties in adult and pediatric surgery. The diagnoses of the pathologies were made with laboratory, radiological, cabinet, and special studies according to the case.

Non-random samples were all treated with RALTS. The parameters recorded were gender, age, weight, height, diagnoses, surgical technique, elapsed time of console surgery, estimated bleeding, hemotransfusion, complications, conversions, postoperative hospital stay, and follow-up. Both authors (surgeons) initially performed some simple surgical techniques, and then advanced to more complex surgeries, with subsequent advancement to different points of the learning curve for robotic surgery.

The Clavien-Dindo classification of surgical complications was used (55, 56). The surgical system used was the da Vinci model, Si version (Intuitive Surgical, Inc., Sunnyvale, CA. U.S.A). We used 8-mm robotic instruments consisting of 2 or 3 robotic trocars according to the surgical technique, 8.5-mm or 12-mm robotic 30° lens for a three-dimensional camera, and a 5-mm trocar laparoscopic for one assistant.

In the following procedures, we used 3 robotic work arms: for urological surgery, in the Mitrofanoff procedure with or without augmentation cystoplasty; for GI-HB surgery, in fundoplications and in the biliodigestives; and in thoracic surgery, in lobectomies, and in oncological surgery, in 4 of the 5 procedures, the exception was the resection of the mediastinal teratoma. In the first 10 fundoplications, we used a 1-0 silk suture to elevate the liver, but after lesion of the left hepatic duct occurred, and we subsequently opted to use the third robotic instrument for that purpose. The docking charts for robotic surgery that are suggested for surgical techniques in adults were not applicable for children. Thus, at times, 3 cm of separation was required between each trocar when performing surgery on infants, due to the limited space in such a small patient.

The postoperative follow-up was at 8, 30, and 90 to 120 days, and then every 6 months. Between 90 and 120 days, radiographic and cabinet studies were carried out according to the treated pathology to evaluate the results. We used measures of central tendency. The analysis of the results was made based on the number of procedures. The data was entered into a spreadsheet in Microsoft Office Excel 2013 version.

In relation to ethical considerations of the study, being of an observational nature, it was not necessary to consent to enter the study to the patients. The Research Ethics Committee of the Hospital evaluated and approved the study. In Mexico, robot-assisted surgery complies with the records and regulations of the Mexican health authorities. In our institution, robotic surgery is routinely authorized for execution. In order to perform the medical-surgical procedures, we obtained the informed consent in writing from the parents or guardians and the adult patient.

RESULTS

In a 36-months period, we performed 186 RALTS in 147 pediatric patients and one adult patient. Of the procedures, 53.23% (99) were in male, and the rest were female; the average age was 83 months, ranging from 3.5 to 204 months, plus one patient of 63 years. The average height was 116.6 cm, and ranged from 55 to 185 cm, with an average weight of 26.9 kg, ranging from 5 to 102 kg; the smallest patient was 3.5 months old with a height of 55 cm and weight 5.5 kg (**Supplementary Table 1**).

We performed 41 different surgical techniques, grouped in 4 areas: urological 91 (48.92%), GI-HB 84 (45.16%), thoracic 6 (3.23%), and oncological 5 (2.69%), as shown in **Table 1**. Our 3 most frequent urological procedures were pyeloplasty, nephrectomy, and ureteral reimplantation, totaling 54 and representing 59.34% of this area. GI-HB, primary fundoplication, redo-fundoplication, and cholecystectomy totaled 62 and represented 73.8% in this area. Diaphragmatic plication and lobectomy were the most frequent for thoracic surgery, and there were only isolated cases of oncological surgery.

Of the total procedures, the elapsed console surgery time was an average of 137.2 min, ranging from 10 to 780 min. Surgeon 1 performed 154 procedures (82.8%), and Surgeon 2 performed 32 procedures (17.2%). Global hemotransfusion occurred in 4.83%, and complications occurred in 2.68%, with a surgical conversion rate of 3.76%. The average postoperative stay was 2.58 days, and the average follow-up was 23.5 months.

There was a predominance of patients males in urological (62.6%), and oncological (80%), and a predominance of patients females in thoracic (66.6%) and GI-HB (53.5%). In relation to age, weight, and height, the smallest group of patients underwent thoracic procedures (14.5 months, 9.1 kg, 78.8 cm,

TABLE 1 | Prospective series of 186 pediatric surgeries using RALTS.

Area	Procedures	*n* (%)
UROLOGICAL		
	Pyeloplasty	19
	Nephrectomy	18
	Ureteral reimplantation	17
	Mitrofanoff	6
	Nephroureterectomy	6
	Varicocelectomy	5
	Release of extrinsic obstruction	
	UP union	3
	Inguinal hernia repair	3
	Desderivation of ureterostomy and ureteral reimplantation	2
	Cystolithotomy	2
	Various*	10
	Subtotal	**91 (48.92)**
GI-HB		
	Primary fundoplication	38
	Redo fundoplication	13
	Cholecystectomy	11
	Gastrostomy	9
	Biliodigestive**	6
	Operation of malone	2
	Various***	5
	Subtotal	**84 (45.16)**
THORACIC		
	Diaphragmatic plication	3
	Lobectomy	2
	Bronchogenic cyst excision	1
	Subtotal	**6 (3.23)**
Oncological		
	Mediastinal teratoma	1
	Resection of carcinoid in stomach	1 (adult)
	Left radical nephrectomy	1
	Retroperitoneal lipoma	1
	Left adrenalectomy (pheochromocytoma)	1
	Subtotal	**5 (2.69)**

Ureteroureterostomy, augmentation cystoplasty, bladder neck closure, heminephrectomy with ureterectomy, perirenal abscess drainage, colostomy closure, enterovesical fistula closure, review of Mitrofanoff, ureterostomy, and ureteropyelography.
**Roux-en-Y hepaticojejuno (5) or portojejuno (1) anastomosis reconstruction.*
***Duodenoplasty with adherensiolysis, extraction of gastric trichobezoar, drainage, and debridement of recurrent retrohepatic abscess post-appendectomy, gastrojejunoanastomosis with Roux-en-Y and splenectomy.*

average values), and the largest underwent GI-HB surgery (97.7 months, 29.7 kg, 125 cm, average values), intermediate average values those subjected to urological surgery (72.9 months, 20.3 kg, 110 cm), and oncological patients (57.3 months, 18 kg, 113 cm, average values). Patients of 10 kg or less were 12 of urological, 10 of GI-HB, 4 of thoracic and 1 of oncological procedures, totaling 27 cases, representing 14.5% of our casuistry.

The evolution of the console surgery times is exemplified by the most frequently performed procedures, which were urological, pyeloplasty, and GI-HB, primary fundoplication. Surgeon 1 consistently reduced the time required for surgery as the procedures continued to evolve and advance, of 227 min in the first pyeloplasty at 115 min in the procedure 19, and for primary fundoplication, it was reduced of 115 min in the first fundoplication at 56 min in the procedure 26 (**Supplementary Figures 1**, **2**).

Of the three most frequently performed procedures by area, the following results were obtained. For urological procedures, 19 pyeloplasty surgeries were performed, with console surgery time of 183 min on average, 0% conversions, 5.2% complications (1 case), stay PO of 3.4 days, with a success rate of 100%. There were 18 nephrectomy surgeries, with console surgery time of 102 min on average, 0% conversions, 5.2% complications (1 case), and stay PO of 1.9 days. There were 17 units of ureteral reimplantation, with console surgery time of 139 min on average, 0% conversions, 0% complications, stay PO of 2.1 days, with 88.24% resolution of reflux; one patient with recurrent bilateral reflux was reoperated and reflux was resolved, with 100% secondary success.

Appendicovesicostomy or Mitrofanoff operation, we performed 6 of these procedures, without predominance of gender, with average age of 9.25 years, weight of 30.7 kg, height of 1.24 m, console surgery time of 262 min, estimated bleeding of 26 ml, with one conversion, and stay PO of 4.34 days. For one patient at 30 days PO, it was improperly manipulated and the Mitrofanoff was dismantled. This complication was not related to surgery, and thus, we can consider a success of 83.34%; open surgery was used for the reoperation, and at the follow-up, all the ducts were continent.

For GI-HB surgery, there were 38 primary fundoplication procedures, plus gastrostomy for feeding in 9 cases, with a console surgery time of 159 min on average, 5.26% conversions (2 cases), 5.26% complications (2 cases), stay PO of 2.4 days; at follow-up PO, there were 2 cases of partial dismantling of fundoplication and hiatal hernia (5.26%), at 11 and 24 months, with a follow-up PO of 17.7 months on average. There were 13 procedures of redo fundoplication (the two robotic cases with recurrence are included), with a console surgery time of 188 min on average, 7.7% conversions (1 case), 0% complications, and stay PO of 2.3 days, with a follow-up PO of 19.5 months on average. There were 11 cholecystectomy procedures, with a console surgery time of 53 min on average, 0% conversions, and 0% complications, with a stay PO of 1.5 days.

The results of 4 patients treated with choledochal cyst, 3 females and 1 male, with average age of 36 months, average weight of 15 kg, and average height of 94.2 cm. There were three cases of cyst type 1-A and one type 1-C; the size of the cyst was 8–12.5 cm, with an average of 9.6 cm. Minimally invasive surgery was performed, with the extracorporeal Roux-en-Y procedure assisted by laparoscopy, and resection of the cyst, cholecystectomy, and the hepaticojejunal anastomosis to Roux-en-Y was performed with robotic assistance. The average surgical times were 130 min with assistance by laparoscopy and 230 min for console surgery time, with an average of 32.5 ml of bleeding. There were no conversions or complications. The average PO stay was 4.7 days, with a 15-months follow-up, and the patients evolved asymptomatically.

For thoracic procedures, there were 3 procedures with diaphragmatic plication, with a console surgery time of 161.6 min on average, 0% conversions, 33.3% complications (1 case), and stay PO of 5.6 days. There were 2 lobectomy procedures, with a console surgery time of 314 min, 50% conversions (1 case), 0% complications, and stay PO of 3 days. There was 1 procedure of resection of a bronchogenic cyst, with console surgery time of 269 min, with no conversion, no complications, and stay PO of 3 days.

There were 5 isolated cases of oncological procedures (**Table 1**).

The estimated average bleeding in each area of procedures performed, in relation to the average weight of the patients, was as follows: blood loss was 6.1 ml/kg for oncological procedures, 2 ml/kg for thoracic, 1.3 ml/kg for urological, and 1.1 ml/kg for GI-HB. However, the highest number of hemotransfusions occurred during the GI-HB procedures, with 5 cases, against 4 cases of the remaining 3 areas of procedures.

There were 2 complications that occurred intraoperatively (IO) a lesion of the left hepatic duct when applying a suture point for traction and elevating the liver during a fundoplication, and rupture of a renal vein when trying to apply a staple during a nephrectomy. These complications were classified as IIIB and II, respectively, according to the Clavien-Dindo classification. The treatment of these complications was Roux-en-Y hepatico-yeyunostomy, and bleeding control and hemotransfusion, respectively.

There were 3 PO complications: (i) a urinoma in a patient with pyeloplasty, with readmission at 9 PO days, (ii) an enterovesical fistula in 2a., 1 week PO, in a patient with augmentation cystoplasty and colostomy closure, and (iii) prolonged drainage of pleural fluid (11 days) in a patient with diaphragmatic plication. According to the Clavien-Dindo classification, the first two corresponded to IIIb, and the third corresponded to I. The treatment of these complications consisted of percutaneous application of a multiproposite catheter for the first patient, a second surgery was performed for the second patient, and the last patient was hospitalized for 12 days to drain fluids.

The robotic procedures that required conversion, was to an open surgery. In the urological procedure, the conversion was required due to the technical difficulty in the appendicovesicostomy anastomosis. In the GI-HB procedures, the reasons for the 4 conversions were multiple intestinal adhesions, technical difficulty in 2 primary fundoplications with gastrostomy, and in a redo of a fundoplication. The reason for the conversion into a lobectomy was technical difficulty, and in the radical nephrectomy, it was difficult to identify the anatomy when dividing the horseshoe kidney.

The longest average PO stay of 4.33 days occurred in patients that underwent a thoracic procedure. In the other 3 areas, the PO stays were 2.48 days in GI-HB, 2.58 days in urological and 2.6 days in oncological. The average PO follow-up among the patients in the 4 areas of surgical procedures was very similar, between 24.5 and 31.4 months, with a range between 7 and 43 months overall (**Supplementary Table 2**).

DISCUSSION

The robotic surgery program began in our hospital in November 2014, and pediatric surgery was incorporated in March 2015. The first procedures with robotic assistance were performed on the pediatric population on March 23, 2015, after Surgeon 1 received training and certification as a console surgeon of the da Vinci surgical system, with previous experience in open surgery and conventional laparo-thoracoscopy. Recommendations were followed to perform some less complex cases and progress toward highly complex procedures, with subsequent integration into the Hospital Committee of Robotic Surgery.

In our experience, the order of frequency of the procedures, from highest to lowest by area, was urological, GI-HB, and thoracic (**Table 1**), which coincides with what has previously been reported (15). There are numerous reports that the most frequent urological procedure performed is pyeloplasty, and the most frequent GI-HB surgery performed is fundoplication, which varies between lobectomy, ligation of the ductus arteriosus, and mediastinal masses in the reports of thoracic procedures, which are aspects that also coincide with our treated pediatric population (5–7, 15).

During the 18 years that have elapsed since the first 2 fundoplications were carried out (36, 37), more than 70 different surgical techniques have been published. Cundy et al. performed a 2013 systematic literature search for all reported cases of robotic surgery in children during an 11-year period. During this time, 137 articles reported 2,393 procedures in 1,840 patients, and the most prevalent gastrointestinal, genitourinary, and thoracic procedures were fundoplication, pyeloplasty, and lobectomy, respectively (15). These 3 previous robotic surgical techniques represented 46.55% and genitourinary procedures 59.92% of the total surgeries, confirming that the greatest amount of these types of published studies are in the field of urology (16–34).

In 11-years period (April 2001 to March 2012), the published literature reporting robotic surgery in children, categorized by study design, comprises 34% case reports, 52% case series, and 14% non-randomized comparative studies ($n = 220$ publications), and the study design was prospective in only 6% of non-randomized comparative studies. As well, 79% of these 220 publications originated from the United States, and the remainder were from 17 other countries, with 14% from Europe, 4% from the Middle East, and 3% from Asia (15).

Qualitatively, we find that with complex and laborious procedures, the time of console surgery is longer as compared to standard open surgery, but we agree that robotic surgery enables more refined hand-eye coordination, superior suturing skills, better dexterity, and precise dissection. It is achieved by the characteristics of robotic surgical platforms that include motion scaling, greater optical magnification, 3D and stereoscopic vision, increased articulated instrument tip dexterity, tremor filtration, operator-controlled camera movement, and elimination of the fulcrum effect (15), and all of this translates into greater safety for patients and advantages for the surgeon.

Considering the examples of 19 procedures of pyeloplasty (with an average of 183 min) and 38 procedures of primary fundoplication plus gastrostomy for feeding in 9 cases (an average of 159 min) as the most frequently performed procedures, our console surgery times are very satisfactory when comparing them with what was reported by other authors as 221 and 170 min, respectively, without including added procedures (7). In a meta-analysis of fundoplication, 6 series of patients were included for a total of 135 patients that underwent robotic fundoplication surgery (with some cases of gastrostomy), and the average console surgery time was 168.3 min, with 3% conversions, 8.9% complications, and 5.31 days PO stay (57).

Robotic ureteral reimplantation for the treatment of pediatric vesicoureteral reflux should be reclassified as a complex reconstructive procedure in pediatric urology. Over the past decade, higher than expected complication rates and suboptimal reflux resolution rates at some centers have been reported. The robotic ureteral reimplantation results have widely varied, with reflux resolution from 77 to 100% and complications from 0 to 12.5% (58). Using a standard technique to improve reimplantation results that was modified according to Gundeti et al. (59), we obtained results with 0% complications, primary success of 88.24%, and secondary success of 100%.

Although it is recommended that a surgeon perform a minimum of one robotic operation per week, it is important to emphasize that 15 to 30 robotic procedures should be performed to achieve optimal console surgery times, according to the type of procedure. Then, the use of this technology can become profitable. The period during which a surgeon finds that the procedures are more difficult, take longer, and there is potentially a higher rate of complications and less effectiveness due to inexperience, which is called the learning curve (60). The use of robot assistance dramatically decreases the learning curve, because overcome the limitations of conventional laparoscopy (31, 38–40). Our console surgery times have evolved in 19 pyeloplasties and in 26 fundoplications, with a decrease of 50% and of almost 52%, respectively.

Robotic assistance has special applications in complex and reconstructive surgery. By areas, urological: pyeloplasty, ureteral reimplantation, augmentation cystoplasty, and Mitrofanoff procedure; GI-HB: revision fundoplication and hiatal hernia and biliary-digestive correction; thoracic tumors: tumor excision and thymectomy; and oncological: resection of tumors of selected cases. For all these procedures, from the open technique, we jump to robotic surgery.

Because of the limitations, conventional laparoscopic surgery in pediatric surgery has been primarily limited to simple or extirpative surgery, more complex or reconstructive surgery by laparoscopy, can only be performed by a limited number of highly qualified surgeons (61).

Since the publication of the initial experience of robotic-assisted laparoscopic ileocistoplasty and the appendicovesicostomy of Mitrofanoff by Gundeti et al (62), it was shown that is a safe, feasible and effective procedure (62). Of the urological surgery, is one of the most complex procedures, in a publication of the retrospective cohort consisted of 18 patients, with mean age of 11 years, console surgery time of 494 min, stay PO of 5.2 days, continence in 94.4%, Clavien-Dindo grade 1 complications in 5 patients and grade IIIb in 2 patients (63).

The patients with neural tube defects may also require redo surgery at the bladder neck for persistent incontinence or any of these procedures with creation of a Malone antegrade continence enema (64, 65).

In a series of cases, retrospectively evaluated for open appendicovesicostomy and robotic, the comparison did not reveal significant differences in the number of acute complications or reoperations between the groups (66).

Our results are satisfactory with the Mitrofanoff, of 6 procedures, one conversion, and all the ducts were continent to follow up.

A multi-center analysis was performed in the United States regarding the complications and conversions in a large cohort of pediatric patients (880 procedures) that underwent robotic urological surgery to 90-day PO. There were with 41 (4.8%) Grade IIIa and Grade IIIb complications, and one patient (0.1%) had a grade IVa complication. Intraoperative visceral injuries secondary to robotic instrument exchange and traction injury were seen in four patients (0.5%), with subsequent conversion to an open procedure. Grade I and II complications were seen in 59 (6.9%) and 70 (8.2%) patients, respectively. The overall 90-day complication rate was similar to those appearing in reports of laparoscopic and open surgical procedures. A total of 14 (1.6%) surgeries were converted to an open or pure laparoscopic procedure (67).

Complications of robotic surgery in urology in a single institution, with 10 different types of procedures performed in included 136 patients, 11 total complications (8.1%): 2 grade I (1.5%), 7 grade II (5.1%), and 2 grade IIIb (1.5%). Complications included ileus in 2 patients, port site infection in 2, urinary leak in 2, urinary retention in 2, urinary tract infection in 2, and stent migration in 1 (43).

There are few reports of minimally assisted surgery by robot for the treatment of choledochal cyst (68–72). Currently, the standard treatment is open surgery. The first cases of resection of choledochal cyst with robotic assistance were reported by Lee et al. (70) and Woo et al. (71).This treatment method is safe and effective, it is associated with earlier postoperative feeding and discharge from the hospital, technically robotic-assistance facilitates performing the biliodigestive anastomosis and for pediatric choledochal cyst showed results comparable to those for open surgery, and thus, is considered to be a valid and alternative surgery for this pathology (71, 72).

A recent systematic review that included a total of 86 patients, 7 patients experienced conversion to open surgery, and the surgery success rate was 91.9%. The hospitalization time was 8.8 days. Eight patients had biliary fistula, one patient had anastomotic stenosis, and one patient had wound dehiscence (73).

The results in the 4 cases that we treat of choledochal cyst confirm the safety and efficacy of this surgical alternative, with 0% complications and conversions.

There are benefits and limitations of using robotic surgery for children with cancer (74), it is feasible for the surgical treatment of tumors in pediatric patients and only isolated adverse events have been reported for malignant tumors, such as tumor spillage and residual disease (45). The current status of robotic surgery for tumors in children is low volume usage, in a relatively static global state of adoption and when applied the oncological surgical principles must be respected (46, 47).

In pediatrics, urologic oncology cases are often managed with open surgery, but is feasibility of using the robotic approach in carefully selected cases, and safely and effectively adapted adult robotic techniques for genitourinary oncology cases in children and young adults (48).

Our experience with robotic-assisted surgery for oncological procedures is limited, with only isolated cases to date. However, the results have been satisfactory, with only one conversion and 0% complications in 5 cases. It is only a matter of time before appropriate cases arise, and we will be going forward in this area with robotic surgery.

Hemotransfusion occurred in 4.83% of the procedures we performed. The average calculation per/kg of weight of estimated bleeding was minimal, and the highest number of hemotransfusions was in the GI-HB procedures, with 5 cases consisting of 4 fundoplications and the case of duodenoplasty with adherensiolysis that merited conversion to open. Complications occurred in 2.68% (5 cases), two IO and three PO. In published reports, rates are very variable, with complications occurring in 8 cases (3%) of 274 robotic procedures during the first 6 years of experience in a London hospital (42). Other reported with 50 abdominal procedures involving the gastrointestinal and hepatobiliary (GI-HB) and urological areas, twelve different robotic surgical techniques were used, there was 6% conversions (41).

In systematic investigations of databases containing information on robot-assisted surgery in children, the global complications ranged from 0 to 15% (7).

Our global conversion rate of 3.76% did not significantly differ from that reported by Cundy et al. (15), with 2.5% overall; by area of procedures, the conversion rates of gastrointestinal, genitourinary, and thoracic procedures were 3.9, 1.3, and 10%, respectively (15). Our conversion rates of the same areas were 4.76, 1.09, and 16.6%, respectively. In their first 100 robotic surgeries, Meehan and Sandler (5) reported conversions of 13.48% in non-urological abdominal procedures and 18.18% in thoracic surgeries. For 96 robotic procedures, De Lambert (2013) reported a conversion rate of 3.1%, which corresponds to patients in the groups of general surgery, urologic surgery, and thoracic surgery (6). A systematic database search was performed that included data from all published reports until October 2007 (31 studies and 513 patients), and the conversion rate for all pediatric robotic procedures was 4.7% (7).

We have not been presented with malfunctions of the robot during the procedures.

There are very few publications of pancreatic pathology in children, treated with a robotic approach, we find only case reports (75–77).

There are approximately 60 da Vinci systems in hospitals in Latin America to date, and there are few that are used to perform surgery on children. The costs of technology, consumables, and maintenance are the main obstacles in Latin American countries that prevent robotic surgery from being practiced more widely. The situation is more adverse in private hospital institutions, because insurance companies only approve a few cases of robotic surgery for adult patients, and children are regularly not approved.

We consider viable, if there is enough experience in Pediatric Surgeons, to implement a robust program of robotic surgery where multiple procedures are performed and after overcoming the learning curve, with efficiency, effectiveness and safety to be used in the complex cases of the different areas of Pediatric surgery is a way to maintain the volume of cases and reduce costs by using robotic assistance routinely in conjunction with other surgical specialties.

The biggest obstacles preventing the use of robotic surgery on a pediatric population are the learning curve, technical limitations, the size of the robotic instruments, and the inconvenience, the costs (78, 79). The manufacturer of the da Vinci surgical robot recommends an 8-cm distance between each port. This is impossible to achieve in neonatal cases (79). This technical limitation, we overcome it have used a 3-cm separation between each trocar, and we have performed various procedures in younger infants with no problems.

There are very few studies that evaluate its cost (30) in an integral way and consider a multitude of factors in addition to the surgical event. The most important factor in Latin American countries is cost, which limits the adoption of robotic surgery.

The outcomes of RALTS are comparable to open surgery and conventional laparoscopic surgery and demonstrate continued improvement with experience. Outcomes can become more cost-efficient if shorter operative times are achieved, and with marketing competition, by providing less expensive robotic systems and instruments. Robotic surgery is suitable in the pediatric practice, which necessitates fine dissections and sutures in narrow anatomical spaces. The results of robotic surgery in the field of pediatrics are encouraging (80).

Our data and other series demonstrate that the short- and long-term morbidity associated with robotic surgery is low in a pediatric population, even during the learning period (44). This information allows affirmation that robot-assisted laparoscopic surgery is safe and efficient in the pediatric population. Although open surgery is still the gold standard for many pediatric diseases, there is a chance to change this view due to the inherent advantages in reconstructive surgery that can be attained with robot-assisted laparoscopy (81). We fully share this vision and consider that children, like adults, should have the opportunity and receive the benefits of RALTS.

CONCLUSION

RALTS is safe and effective in children. An enormous variety of surgeries can be safely performed including complex surgical cases, even in small children. There are few published prospective series describing pediatric RALTS, since most are only urological.

This technology has only been slowly adopted for use in children. Pediatric Surgeons must advocate for the benefit of our patients and overcome the obstacles to increase the adoption and more widely disseminate its use.

The present prospective series reporting pediatric robotic surgery is the first in Latin America, and its results are very satisfactory, which allows us to affirm that we have accumulated favorable experiences and that we can offer our pediatric patients the benefits and advantages of robotic surgery.

It is possible to implement a robust program of pediatric robotic surgery where multiple procedures are performed.

AUTHOR CONTRIBUTIONS

MNA contributed to the prospective registration of all the information, designed the data spreadsheet for Microsoft Office Excel 2013 version, performed 154 procedures, performed patient follow-up, analyzed the published information (references), analyzed the experimental results, and compared them with the published data, and wrote the manuscript. FGG contributed information to the prospective registry pertaining to the 32 procedures that he performed, and also obtained follow-up information from the patients.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fped.2019.00200/full#supplementary-material

REFERENCES

1. Atug F, Castle EP, Woods M, Srivastav SK, Thomas R, Davis R. Transperitoneal versus extraperitoneal robotic-assisted radical prostatectomy: is one better than the other? *Urology.* (2006) 68:1077–81. doi: 10.1016/j.urology.2006.07.008
2. Mikhail AA, Orvieto MA, Billatos ES, Zorn KC, Gong EM, Brendler CB, et al. Robotic-assisted laparoscopic prostatectomy: first 100 patients with one year of follow-up. *Urology.* (2006) 68:1275–9. doi: 10.1016/j.urology.2006.08.1060
3. Khaira HS, Bruyere F, Malley PJ, Peters JS, Costello AJ. Does obesity influence the operative course or complications of robot-assisted laparoscopic prostatectomy. *Brit J Urol Int.* (2006) 98:1275–8. doi: 10.1111/j.1464-410X.2006.06488.x
4. Tseng TY, Kuebler HR, Cancel QV, Sun L, Springhart WP, Murphy BC, at al. Prospective health-related quality-of-life assessment in an initial cohort of patients undergoing robotic radical prostatectomy. *Urology.* (2006) 68:1061–6. doi: 10.1016/j.urology.2006.06.017

5. Meehan JJ, Sandler A. Robotic surgery: a single- institutional review of the first 100 consecutive cases. *Surg Endosc.* (2008) 22:177–82. doi: 10.1007/s00464-007-9418-2
6. de Lamberg G, Fourcade L, Centi J, Fredon F, Braik K, Szwarc C, et al. How to successfully implement a robotic pediatric surgery program: lessons learned after 96 procedures. *Surg Endosc.* (2013) 27:2137–44. doi: 10.1007/s00464-012-2729-y
7. Sinha SK, Haddad M. Robot-assisted surgery in children: current status. *J Robotic Surg.* (2008) 1:243–6. doi: 10.1007/s11701-007-0054-6
8. Alqahtani A, Albassam A, Zamakhshary M, Shoukri M, Altokhais T, Aljazairi A, et al. Robot-assisted pediatric surgery: how far can we go? *World J Surg.* (2010) 34:975–8. doi: 10.1007/s00268-010-0431-6
9. Al-Bassam A. Robotic-assisted surgery in children: advantages and limitations. *J Robot Surg.* (2010) 4:19–22. doi: 10.1007/s11701-010-0181-3
10. Camps JI. The use of robotics in pediatric surgery: my initial experience. *Pediatr Surg Int.* (2011) 27:991–6. doi: 10.1007/s00383-011-2901-9
11. Marhuenda C, Giné C, Asensio M, Guillén G, Martínez Ibáñez V. Robotic surgery: first pediatric series in Spain. *Cir Pediatr.* (2011) 24:90–2.
12. Ballouhey Q, Villemagne T, Cros J, Szwarc C, Braik K, Longis B, et al. A comparison of robotic surgery in children weighing above and below 15.0 kg: size does not affect surgery success. *Surg Endosc.* (2015) 29:2643–50. doi: 10.1007/s00464-014-3982-z
13. Bütter A, Merritt N, Dave S. Establishing a pediatric robotic surgery program in Canada. *J Robot Surg.* (2017) 11:207–10. doi: 10.1007/s11701-016-0646-0
14. Mattioli G, Pini Prato A, Razore B, Leonelli L, Pio L, Avanzini S, et al. Da Vinci robotic surgery in a pediatric hospital. *J Laparoendosc Adv Surg Tech A.* (2017) 27:539–45. doi: 10.1089/lap.2016.0390
15. Cundy TP, Shetty K, Clark J, Chang TP, Sriskandarajah K, Gattas NE, et al. The first decade of robotic surgery in children. *J Pediatr Surg.* (2013) 48:858–86. doi: 10.1016/j.jpedsurg.2013.01.031
16. Lee RS, Retik AB, Borer JG, Peters CA. Pediatric robot assisted laparoscopic dismembered pyeloplasty: comparison with a cohort of open surgery. *J Urol.* (2006) 175:683–67. doi: 10.1016/S0022-5347(05)00183-7
17. Passerotti CC, Nguyen HT, Eisner BH, Lee RS, Peters CA. Laparoscopic reoperative pediatric pyeloplasty with robotic assistance. *J Endourol.* (2007) 21:1137–40. doi: 10.1089/end.2007.9929
18. Volfson IA, Munver R, Esposito M, Dakwar G, Hanna M, Stock JA. Robot-assisted urologic surgery: safety and feasibility in the pediatric population. *J Endourol.* (2007) 21:1315–8. doi: 10.1089/end.2007.9982
19. Peters CA. Robotically assisted surgery in pediatric urology. *Urol Clin North Am.* (2004) 31:743–52. doi: 10.1016/j.ucl.2004.06.007
20. Lee RS, Passerotti CC, Cendron M, Estrada CR, Borer JG, Peters CA. Early results of robot assisted laparoscopic lithotomy in adolescents. *J Urol.* (2007) 177:2306–10. doi: 10.1016/j.juro.2007.01.178
21. Franco I, Dyer LL, Zelkovic P. Laparoscopic pyeloplasty in the pediatric patient: hand sewn anastomosis versus robotic assisted anastomosis: is there a difference? *J Urol.* (2007) 178:1483–6. doi: 10.1016/j.juro.2007.06.012
22. Yee DS, Shanberg AM, Duel BP, Rodriguez E, Eichel L, Rajpoot D. Initial comparison of robotic-assisted laparoscopic versus open pyeloplasty in children. *Urology.* (2006) 67:599–602. doi: 10.1016/j.urology.2005.09.021
23. Casale P. Robotic pediatric urology. *Curr Urol Rep.* (2009) 10:115–8. doi: 10.1007/s11934-009-0021-z
24. Christman MS, Casale P. Robot-assisted bladder diverticulectomy in the pediatric population. *J Endourol.* (2012) 26:1296–300. doi: 10.1089/end.2012.0051
25. Bansal D, Cost NG, Bean CM, Riachy E, Defoor WR Jr, Reddy PP, et al. Comparison of pediatric robotic-assisted laparoscopic nephroureterectomy and laparoendoscopic single-site nephroureterectomy. *Urology.* (2014) 83:438–42. doi: 10.1016/j.urology.2013.08.066
26. Mason MD, Anthony Herndon CD, Smith-Harrison LI, Peters CA, Corbett ST. Robotic-assisted partial nephrectomy in duplicated collecting systems in the pediatric population: techniques and outcomes. *J Pediatr Urol.* (2014) 10:374–9. doi: 10.1016/j.jpurol.2013.10.014
27. Liu DB, Ellimoottil C, Flum AS, Casey JT, Gong EM. Contemporary national comparison of open, laparoscopic, and robotic-assisted laparoscopic pediatric pyeloplasty. *J Pediatr Urol.* (2014) 10:610–5. doi: 10.1016/j.jpurol.2014.06.010
28. Esposito C, Masieri L, Steyaert H, Escolino M, Cerchione R, La Manna A, et al. Robot-assisted extravesical ureteral reimplantation (revur) for unilateral vesico-ureteral reflux in children: results of a multicentric international survey. *World J Urol.* (2018) 36:481–8. doi: 10.1007/s00345-017-2155-9
29. Kawal T, Srinivasan AK, Chang J, Long C, Chu D, Shukla AR. Robotic-assisted laparoscopic ureteral re-implant (RALUR): can post-operative urinary retention be predicted? *J Pediatr Urol.* (2018) 14:323.e1–5. doi: 10.1016/j.jpurol.2018.05.010
30. Varda BK, Wang Y, Chung BI, Lee RS, Kurtz MP, Nelson CP. Has the robot caught up? National trends in utilization, perioperative outcomes, and cost for open, laparoscopic, and robotic pediatric pyeloplasty in the United States from 2003 to 2015. *J Pediatr Urol.* (2018) 14:336.e1–8. doi: 10.1016/j.jpurol.2017.12.010
31. Garcia I, Salas de Armas IA, Pimpalwar A. Current trends in pediatric robotic surgery. *Bangladesh J Endosurg.* (2014) 2:15–28. doi: 10.3329/bje.v2i1.19589
32. Monn MF, Bahler CD, Schneider EB, Whittam BM, Misseri R, Rink RC, et al. Trends in robot-assisted laparoscopic pyeloplasty in pediatric patients. *Urology.* (2013) 81:1336–41. doi: 10.1016/j.urology.2013.01.025
33. Sukumar S, Roghmann F, Sood A, Abdo A, Menon M, Sammon JD, et al. Correction of ureteropelvic junction obstruction in children: national trends and comparative effectiveness in operative outcomes. *J Endourol.* (2014) 28:592–8. doi: 10.1089/end.2013.0618
34. Varda BK, Johnson EK, Clark C, Chung BI, Nelson CP, Chang SL. National trends of perioperative outcomes and costs for open, laparoscopic and robotic pediatric pyeloplasty. *J Urol.* (2014) 191:1090–5. doi: 10.1016/j.juro.2013.10.077
35. Cundy TP. *Clinical Application and Evaluation of Robot-Assisted Surgery in Children* (Thesis 2014). Avaliable online at: https://spiral.imperial.ac.uk/bitstream/10044/1/.../1/Cundy-TP-2015-PhD-Thesis.pdf
36. Meininger D, Byhahn C, Markus BH, Heller K, Westphal K. Total endoscopic Nissen fundoplication with the robotic device "da Vinci" in children. Hemodynamics, gas exchange, and anesthetic management. *Anaesthesist.* (2001) 50:271–5. doi: 10.1007/s001010051001
37. Meininger DD, Byhahn C, Heller K, Gutt CN, Westphal K. Totally endoscopic Nissen fundoplication with a robotic system in a child. *Surg Endosc.* (2001) 15:1360. doi: 10.1007/s00464-001-4200-3
38. Westebring-van der Putten EP, Goossens RHM, Jakimowicz JJ, Dankelman J. Haptics in minimally invasive surgery—a review. *Minimally Invas Ther.* (2008) 17:3–16. doi: 10.1080/13645700701820242
39. Braumann C, Jacobi CA, Menenakos C, Ismail M, Rueckert JC, Mueller JM. Robotic-assisted laparoscopic and thoracoscopic surgery with the da Vinci system: a 4-year experience in a single institution. *Surg Laparosc Endosc Percutan Tech.* (2008) 18:260–6. doi: 10.1097/SLE.0b013e31816f85e5
40. Vereczkel A, Bubb H, Feussner H. Laparoscopic surgery and ergonomics: it's time to think of ourselves as well. *Surg Endosc.* (2003) 17:1680–2. doi: 10.1007/s00464-003-9020-1
41. Najmaldin A, Antao B. Early experience of tele-robotic sugery in children. *Int J Med Robot Comp Assist Surg.* (2007) 3:199–202. doi: 10.1002/rcs.150
42. Gattas N, Smith C, Alizai NK, Wyk V, Sellors J, Whiteley S, et al. Short and long term complications of robotic abdominal surgery in children. In: *Presented at the 5th Hamlyn Symposium on Medical Robotics*, London, United Kingdom, July 1–2, (2012), 11. Avaliable online at: http://ubimon.doc.ic.ac.uk/Hamlyn2012/public/Hamlyn_2012_proceedings_2.pdf
43. Bansal D, Defoor WR Jr, Reddy PP, Minevich EA, Noh PH. Complications of robotic surgery in pediatric urology: a single institution experience. *Urology.* (2013) 82:917–20. doi: 10.1016/j.urology.2013.05.046
44. Cribbs RK, Wulkan ML, Heiss KF, Gow KW. Minimally invasive surgery and childhood cancer. *Surg Oncol.* (2007) 16:221–8. doi: 10.1016/j.suronc.2007.09.002
45. Cundy TP, Marcus HJ, Clark J, Hughes-Hallett A, Mayer EK, Najmaldin AS, et al. Robot-assisted minimally invasive surgery for pediatric solid tumors: a systematic review of feasibility and current status. *Eur J Pediatr Surg.* (2014) 24:127–35. doi: 10.1055/s-0033-1347297
46. Bentas W, Wolfram M, Bräutigam R, Binder J. Laparoscopic transperitoneal adrenalectomy using a remote-controlled robotic surgical system. *J Endourol.* (2002) 16:373–6. doi: 10.1089/089277902760261419
47. Meignan P, Ballouhey Q, Lejeune J, Braik K, Longis B, Cook AR, et al. Robotic-assisted laparoscopic surgery for pediatric tumors: a bicenter experience. *J Robot Surg.* (2018) 12:501–8. doi: 10.1007/s11701-017-0773-2

48. Varda BK, Cho P, Wagner AA, Lee RS. Collaborating with our adult colleagues: a case series of robotic surgery for suspicious and cancerous lesions in children and young adults performed in a free-standing children's hospital. *J Pediatr Urol*. (2018) 14:182.e1–8. doi: 10.1016/j.jpurol.2018.01.003
49. Secin FP, Coelhjo R, Gardiner JM, Salcedo JGC, Puente R, Martínez L, et al. Robotic surgery in public hospitals of Latin-America: a castle of sand? *World J Urol.* (2018) 36:595–601. doi: 10.1007/s00345-018-2227-5
50. Terra RM. Thymic minimally invasive surgery: state of the art across the world: Central-South America. *J Vis Surg.* (2017) 14:124. doi: 10.21037/jovs.2017.07.13
51. Mota Filho FHA, Sávio LF, Sakata RE, Ivanovic RF, Nunes da Silva NA, Soares MR, et al. Robot-assisted single port radical nephrectomy and cholecystectomy: description and technical aspects. *Int Braz J Urol.* (2018) 44:202–3. doi: 10.1590/s1677-5538.ibju.2016.0560
52. Poffo R, Toschi AP, Pope RB, Montanhesi PK, Santos RS, Teruya A, et al. Robotic cardiac surgery in Brazil. *Ann Cardiothorac Surg.* (2017) 6:17–26. doi: 10.21037/acs.2017.01.01
53. Machado MA, Makdissi FF, Surjan RC, Abdalla RZ. First robotic-assisted laparoscopic liver resection in Latin America. *Arq Gastroenterol.* (2009) 46:78–80. doi: 10.1590/S0004-28032009000100019
54. Machado MA, Makdissi FF, Surjan RC, Abdalla RZ. Robotic resection of intraductal neoplasm of the pancreas. *J Laparoendosc Adv Surg Tech A*. (2009) 19:771–5. doi: 10.1089/lap.2009.0164
55. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg.* (2004) 240:205–13. doi: 10.1097/01.sla.0000133083.54934.ae
56. Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick, et al. The Clavien-Dindo classification of surgical complications: five-year experience. *Ann Surg.* (2009) 250:187–96. doi: 10.1097/SLA.0b013e3181b13ca2
57. Cundy TP, Harling L, Marcus HJ, Athanasiou T, Darzi AW. Meta-analysis of robot-assisted versus conventional laparoscopic fundoplication in children. *J Ped Surg.* (2014) 49:646–52. doi: 10.1016/j.jpedsurg.2013.12.014
58. Baek M, Koh ChJ. Lessons learned over a decade of pediatric robotic ureteral reimplantation. *Investig Clin Urol.* (2017) 58:3–11. doi: 10.4111/icu.2017.58.1.3
59. Gundeti MS, Boysen WR, Shah A. Robot-assisted laparoscopic extravesical ureteral reimplantation: technique modifications contribute to optimized outcomes. *Eur Urol.* (2016) 70:818–23. doi: 10.1016/j.eururo.2016.02.065
60. Bach Ch, Miernik A, Schönthale M. Training in robotics: the learning curve and contemporary concepts in training. *Arab J Urol.* (2014) 12:58–61. doi: 10.1016/j.aju.2013.10.005
61. De Naeyer G, Schatteman P, Carpentier P, Mottrie A. Learning curve in robotic surgery: review of the literature (RALP, RAPN, and RARC). *World J Urol.* (2013) 31:455–61.
62. Gundeti MS, Acharya SS, Zagaja GP, Shalhav AL. Paediatric robotic-assisted laparoscopic augmentation ileocystoplasty and Mitrofanoff appendicovesicostomy (RALIMA): feasibility of and initial experience with the University of Chicago technique. *BJU Int.* (2011) 107:962–9. doi: 10.1111/j.1464-410X.2010.09706.x
63. Famakinwa OJ, Rosen AM, Gundeti MS. Robot-assisted laparoscopic mitrofanoff appendicovesicostomy technique and outcomes of extravesical and intravesical. *Eur Urol*. (2013) 64:831–6. doi: 10.1016/j.eururo.2013.05.007
64. Gargollo PC, Granberg C, Gong E, Tu D, Whittam B, Dajusta D. Complex robotic lower urinary tract surgery in patients with history of open surgery. *J Urol.* (2019) 201:162–8. doi: 10.1016/j.juro.2018.06.017
65. Murthy P, Cohn JA, Selig RB, Gundeti MS. Robot-assisted laparoscopic augmentation ileocystoplasty and mitrofanoff appendicovesicostomy in children: updated interim results. *Eur Urol.* (2015) 68:1069–75. doi: 10.1016/j.eururo.2015.05.047
66. Grimsby GM, Jacobs MA, Gargollo PC Comparison of complications of robot-assisted laparoscopic and open appendicovesicostomy in children. *J Urol.* (2015) 194:772–6. doi: 10.1016/j.juro.2015.02.2942
67. Dangle PP, Akhavan A, Odeleye M, Avery D, Lendvay T, Koh CJ, et al. Ninety-day perioperative complications of pediatric robotic urological surgery: a multi-institutional study. *J Pediatr Urol.* (2016) 12:102.e1–6. doi: 10.1016/j.jpurol.2015.08.015
68. Chang EY, Hong YJ, Chang Hk, Oh JT, Han SJ. Lessons and tips from the experience of pediatric robotic choledochal cyst resection. *J Laparoendosc Adv Surg Tech.* (2012) 22:609–14. doi: 10.1089/lap.2011.0503
69. Alizai NK, Dawrant MJ, Najmaldin AS. Robot-assisted resection of choledochal cysts and hepatojejunostomy in children. *Pediatr Surg Int.* (2014) 30:291–4. doi: 10.1007/s00383-013-3459-5
70. Lee H, Hirose S, Bratton B, Farmer D. Initial experience with complex laparoscopic biliary surgery in children: biliary atresia and choledochal cyst. *J Pediatr Surg.* (2004) 39:804–7. doi: 10.1016/j.jpedsurg.2004.02.018
71. Woo R, Le D, Albanese CT, Kim SS. Robot-assisted laparoscopic resection of a type I choledochal cyst in a child. *J Laparoendosc Adv Surg Tech.* (2006) 16:179–83. doi: 10.1089/lap.2006.16.179
72. Kim NY, Chang EY, Hong YJ, Park S, Kim HY, Bai SJ, et al. Retrospective assessment of the validity of robotic surgery in comparison to open surgery for pediatric choledochal cyst. *Yonsei Med J.* (2015) 56:737–43. doi: 10.3349/ymj.2015.56.3.737
73. Wang XQ, Xu SJ, Wang Z, Xiao YH, Xu J, Wang ZD, et al Robotic-assisted surgery for pediatric choledochal cyst: case report and literature review. *World J Clin Cases*. (2018) 6:143–9. doi: 10.12998/wjcc.v6.i7.143
74. Meehan JJ. Robotic surgery for pediatric tumors. *Cancer J.* (2013) 19:183–8. doi: 10.1097/PPO.0b013e318289486c
75. Hu MG, Xiao YH, Song DD, Zhao GD, Liu YZ, Wang Z, et al. First experience of robotic spleen-preserving distal pancreatectomy in a child with insulinoma. *World J Surg Oncol*. (2017) 15:199. doi: 10.1186/s12957-017-1265-6
76. Liang M, Jiang J, Dai H, Hong X, Han X, Cong L, et al. Robotic enucleation for pediatric insulinoma with MEN1 syndrome: a case report and literature review. *BMC Surg.* (2018) 18:44. doi: 10.1186/s12893-018-0376-5
77. Lalli R, Merritt N, Schlachta CM, Bütter A. Robotic-assisted, spleen-preserving distal pancreatectomy for a solid pseudopapillary tumour in a pediatric patient: a case report and review of the literature. *J Robot Surg.* (2019) 13:325–9. doi: 10.1007/s11701-018-0835-0
78. Herron DM, Marohn M. A *Consensus Document on Robotic Surgery.* SAGES, (2007). Avaliable online at: https://www.sages.org/publications/guidelines/consensus-document-robotic-surgery/
79. Bruns NE, Soldes OS, Ponsky TA. Robotic surgery may not "make the cut" in pediatrics. *Front Pediatr.* (2015) 3:1–3. doi: 10.3389/fped.2015.00010
80. Chaussy Y, Becmeur F, Lardy H, Aubert D. Robot-assisted surgery: current status evaluation in abdominal and urological pediatric surgery. *J Laparoendosc Adv Surg Tech.* (2013) 23:530–8. doi: 10.1089/lap.2012.0192
81. Kibar Y, Yalcin S, Kaya E, Kopru B, Ebiloglu T, Ergin G, et al. Our experiences with robot- assisted laparoscopic surgery in pediatric patients: the first case series from Turkey. *Turk J Urol.* (2017) 43:355–60. doi: 10.5152/tud.2017.88303

Conflict of Interest Statement: MNA declares to be Proctor of the da Vinci Surgical System and sometimes receives salary for advice to Surgeons in their first robotic procedures, from the marketing company in my country, as part of the support in the training of Surgeons by this company. But, in relation to the treatment of patients and the execution of this manuscript, no economic financing was received from commercial companies.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Pediatrics

REVIEW
published: 02 July 2019
doi: 10.3389/fped.2019.00259

Check for updates

The Future of Robotic Surgery in Pediatric Urology: Upcoming Technology and Evolution Within the Field

Kunj R. Sheth [1,2] *and Chester J. Koh* [1,2]*

[1] *Division of Urology, Department of Surgery, Texas Children's Hospital, Houston, TX, United States,* [2] *Scott Department of Urology, Baylor College of Medicine, Houston, TX, United States*

Since the introduction of the Da Vinci Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA) in 1999, the market for robot assisted laparoscopic surgery has grown with urology. The initial surgical advantage seen in adults was for robotic prostatectomy, and over time this expanded to the pediatric population with robotic pyeloplasty. The introduction of three-dimensional visualization, tremor elimination, a 4th arm, and 7-degree range of motion allowed a significant operator advantage over laparoscopy, especially for anastomotic suturing. After starting with pyeloplasty, the use of robotic technology with pediatric urology has expanded to include ureteral reimplantation and even more complex reconstructive procedures, such as enterocystoplasty, appendicovesicostomy, and bladder neck reconstruction. However, limitations of the Da Vinci Surgical Systems still exist despite its continued technological advances over multiple generations in the past 20 years. Due to the smaller pediatric market, less focus appears to have been placed on the development of the smaller 5 mm instruments. As pediatric urology continues to utilize robotic technology for minimally invasive surgery, there is hope that additional pediatric-friendly instruments and components will be developed, either by Intuitive Surgical or one of the new robotic platforms in development that are working to address many of the shortcomings of current systems. These new robotic platforms include improved haptic feedback systems, flexible scopes, easier maneuverability, and even adaptive machine learning concepts to bring robotic assisted laparoscopic surgery to the next level. In this report, we review the present and upcoming technological advances of the current Da Vinci surgical systems as well as various new robotic platforms, each offering a unique set of technological advantages. As technology progresses, the understanding of and access to these new robotic platforms will help guide pediatric urologists into the next forefront of minimally invasive surgery.

Keywords: robotic, laparoscopic, pyeloplasty, heminephrectomy, ureteroureterostomy, children, pediatric, urology

Edited by:
Miguel Alfedo Castellan,
University of Miami, United States

Reviewed by:
Simona Gerocarni Nappo,
Bambino Gesù Children Hospital (IRCCS), Italy
Roberto Luis Vagni,
Hospital Italiano de Buenos Aires, Argentina

***Correspondence:**
Chester J. Koh
cxkoh@texaschildrens.org

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *24 January 2019*
Accepted: *06 June 2019*
Published: *02 July 2019*

Citation:
Sheth KR and Koh CJ (2019) The Future of Robotic Surgery in Pediatric Urology: Upcoming Technology and Evolution Within the Field. Front. Pediatr. 7:259. doi: 10.3389/fped.2019.00259

INTRODUCTION

The introduction of laparoscopy for children with non-palpable testicles in the 1960s has led to widespread adoption within the field of pediatric urology, and even replaced open surgery in some situations as the gold standard (1). Although laparoscopy enabled smaller surgical scars and decreased hospital stays, widespread use in complex reconstructive cases did not occur due to limitations on surgeon dexterity with available laparoscopic instruments, visualization, and sensory feedback (2, 3). Specifically in pediatrics, the need for more delicate tissue handling and adaptation to a smaller operative working space posed a further challenge in minimally invasive surgery (4). The introduction of the da Vinci Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA) in 1999 addressed many of the basics compromises encountered in laparoscopy (5). Some key components included the 4th arm for retraction, 3-D visualization, 7-degree range of motion and tremor elimination. Furthermore, with progressing editions (S, Si, Xi, and X), Intuitive Surgical has advanced the system's visualization and instrumentation, as well as its teaching capabilities with dual-console systems and skill simulators.

INTEGRATION OF THE DA VINCI SYSTEM INTO PEDIATRIC UROLOGY

Adaptation of the robot into adult urology first occurred for prostatectomy (6), and pediatric urology soon followed with the first robotic pyeloplasty (7). Pyeloplasty was first performed laparoscopically in adults in 1993 (8, 9) and in children in 1995 (10). In comparison to open surgery, laparoscopic pyeloplasty demonstrated better postoperative pain control and decreased length of hospital stays (11), but the intracorporeal suturing carried a steep learning curve, limiting widespread adaptation (2, 3). Compared to conventional laparoscopic pyeloplasty, robot-assisted laparoscopic pyeloplasty demonstrated a lower complication rate (OR 0.56, 95% CI 0.37–0.84, $p = 0.005$) and higher success rate (OR 2.76, 95% CI 1.30–5.88, $p = 0.008$) with reductions in average operative times of 27 mi ($p = 0.003$) and reductions in length of hospital stays of 1.2 days ($p = 0.003$) (12).

Despite these advantages, the higher associated costs of robotic surgery do remain a concern. In comparison to open pyeloplasty, costs of laparoscopic pyeloplasty were very similar, but robotic pyeloplasty increased the total median cost from $7,221 to $10,780 in a population-based study. For all approaches, operating room costs were the greatest contributor, but with robotic pyeloplasty, the supplies costs were also much higher (13). Another report showed an 1.2-day improvement in length of stay with robotic vs. open pyeloplasty, amounting to an average savings of parental wages of $90.01 and hospital expenses of $612.80 when excluding amortization robot costs. However, this benefit was lost when amortization costs were included (14). Similarly, Rowe et al. broke down robotic costs into direct costs for the individual case and indirect costs of robot purchase and maintenance, finding that the inclusion of only direct costs showed an 11.9% savings for robotic surgery mostly due to shorter length of stay. Since the inclusion of indirect robotic costs tip the scales in the other direction, they concluded that high surgical volume and potential competition could reduce overall robotic surgery costs (15).

Fortunately, the rate of robotic pyeloplasty has increased annually at a rate of 29%, accounting for 40% of all cases in the US in 2015 (13). However, in comparison to adult robotic volumes, the pediatric volumes are still quite low, deterring some children's hospitals from individually purchasing a robot. Each institution evaluates the pros and cons of purchasing a da Vinci system due to implied maintenance costs, and some have found creative solutions, such as purchasing the robotic system at the children's hospital but subsidizing costs by allowing adult surgeons to also perform robotic procedures in the children's hospital for a set fee per patient (16). While such alternatives help decrease to costs, it does not remove the other extra robotic costs due to the built-in obsolescence of the robotic instruments, which have a preset number of uses that are programmed into the memory chip of each instrument. This essential monopoly with higher costs provided by the da Vinci surgical system begs for alternative platforms that will bring competition to the market and ideally drive down prices (16).

In addition to cost, the use of the da Vinci surgical system in pediatric patients holds certain other concerns, especially related to the smaller patient size and working space in young children and infants (4). With surgeon experience, tricks to maximize the smaller working space have been developed, such as a more linear, less triangulated trocar placement, delicate cushioning to protect the patient, and intussusception of trocars during placement to prevent injuries (17). Furthermore, careful padding, and port placement to avoid collisions are critical to protect small pediatric patients where the robotic arms are sometimes larger than the patient's body (18). Keeping these nuances and complexities in mind, infant robotic pyeloplasty cases have been performed with similar outcomes (19, 20). Thus, the utilization of robotic technology has grown in pediatric urology, and likely will continued to do so in the future to potentially even become the gold standard for certain reconstructive cases (21).

After pyeloplasty, the robotic platform has been applied to other reconstructive procedures, including extravesical ureteral reimplantation (22), appendicovesicostomy (23), and even bladder augmentation (24). It remains unclear if robotic ureteral reimplantation can provide superior, or even equivalent outcomes to the open correlate due to the high success rates of open surgery, but no significant differences in success rates or complication rates were seen in a recent multi-institutional study after the initial 30-case learning curve (22). The more complex reconstructive procedures still require further studies to determine the benefits of robotic assistance for these cases.

In addition to progressive technologic advances in the da Vinci robotic system in its evolving generations, incorporation of robotic technology with single site surgery has led to robot-assisted laparoendoscopic single site surgery (LESS) to allow

Abbreviations: 3D, Three-dimensional; CI, Confidence Interval; DOF, Degrees of Freedom; FDA, Food and Drug Administration; HD, High Definition; LESS, Laparoendoscopic Single Site; NOTES, Natural Orifice Transluminal Endoscopic Surgery; OR, Odds Ratio.

for surgery to be performed through a single albeit slightly longer incision. This technique has shown success in laparoscopic surgery for extirpative procedures, such as nephrectomy (25, 26), but no reports of robot-assisted LESS in pediatric patients have been published to date. It is possible that the adaptation of the newer robotic platforms may lead to new opportunities in pediatric reconstruction. The da Vinci surgical robot can be combined with Intuitive Surgical's own single-site port platform or with other port platforms, including GelPoint (Applied Medical, Rando Santa Margarita, CA (27). Recent reports of the da Vinci single-site platform for donor nephrectomy noted that the procedure was safe, but without any clear tangible benefit (28). Again, this serves as one example of the need for better articulating instruments and energy sources that could be the key for expanding robotic technology to single site surgery on a larger scale. The most recent da Vinci SP platform is compatible with the Xi system and has an articulating endoscope with up to three fully-wristed, elbowed instruments, all through a single 2.5 cm port (29). While this device shows promise for use in pediatric urology, no such reports have yet been published. One immediate criticism of the device is the amount of working space needed internally to allow the usage and articulation of the instruments. Thus, while single-port robotic surgery is on the horizon, it is not yet been adapted in the field of pediatric urology.

Annually the Da Vinci Surgical robot is used to perform more than 750,000 procedures world-wide (30), but there remains vast areas for technological improvements, especially for pediatric patients. Smaller working spaces restrict surgeon dexterity and ability to perform task with the robot. One study noted that no surgical task could be performed in a space smaller than a 40 mm cubic box due to severe external robotic arm collisions (31). In smaller patients, 5 mm instruments offer the advantage of a smaller diameter incisions and finer needle forces for tissue handling (32). However, while there is a large variety of instruments available in the 8 mm size, only a limited selection is available in the 5 mm that would be better suited for children. While these limited number of 5-mm instruments are sufficient to successfully perform a pediatric robotic pyeloplasty (33), the limited selection of instruments has led many pediatric surgical specialists to use the 8 mm instruments despite its larger sizes, especially when the robot is shared with adult urology colleagues. Furthermore, use of a 5 mm lens removes the advantageous 3-D image and the 5 mm instruments require more working space due to typical joint kinematics (31, 34). On the other hand, the da Vinci 8 mm instruments require less space for articulation and in a head-on comparison the 8 mm robotic instruments demonstrated better efficacy and safety in smaller workspaces (35). It is possible that better 5 mm instruments with the same articulation abilities of the 8 mm instruments would overcome this hurdle, however at present such options are not available from Intuitive Surgical. Unfortunately, with a smaller pediatric market and limited profit potential, the business case often keeps manufacturers from devoting resources and time toward the development of further pediatric-sized instruments.

Lastly, the da Vinci surgical system lacks haptic feedback which can pose some difficulty in both transitioning to and learning robotic surgery. With the advent of new robotic systems, there is hope for application of haptic technology, utilization of more and improved pediatric-sized instruments, and ideally a decrease in cost with increasing competition as many of the Da Vinci patents expire in 2019 (36).

NEW ROBOTIC PLATFORMS

There are many different robotic platforms at various stages of development, and some are even commercially available. As of yet, none of these new technologies have been utilized in pediatric urology, but here we focus on the platforms that could potentially be useful in the field of pediatric urology specifically. **Table 1** compares the various features available in the current da Vinci Surgical System and these new upcoming robotic platforms.

Senhance Surgical Robotic System

An Italian company named Sofar first developed the ALF-X system that was later renamed to Senhance Surgical Robotic System (TransEnterix, Morrisville, NC) after being purchased by this US-based company. In October 2017, the FDA approved the system for both gynecologic and colorectal procedures (37). Both safe and successful outcomes in human subjects undergoing hysterectomy (38–41) and colorectal surgery (42) have been described in the literature. However, within the field of urology, only porcine studies have been previously reported (43).

The key components of this system include the "cockpit" that serves as a remote-control station unit, up to 4 manipulator arms, and HD-3D-technology camera, as well as a connection node. Instead of the bulky single cart used by the Da Vinci system, the Senhance system robotic arms each have their own individual carts, allowing for easy maneuverability. Furthermore, the use of magnets to attach the instruments to the individual robotic arm carts enables more rapid exchanges intraoperatively. All instruments are compatible with a 5 mm port except the camera and articulating needle holder, which require a 10 mm port (44). Unlike the Da Vinci robot, no articulating cutting tool is currently available, with plans for future development (45). In addition to carrying the same 7 degrees of freedom currently available in other systems, all of these robotic arms use haptic sensing to enhance surgical dissection and suturing. The haptic feedback includes 1:1 scaled force feedback, tissue consistency perception and translation of instrument stress. The surgeon controls the robotic arms and eye-tracking camera from the cockpit, which includes comfortable ergonomic positioning (44). By tracking the surgeon's eye movements, the camera image is automatically centered to the surgeon's visual focus point and the amount of magnification can be adjusted by forward and backward head movements. The enhanced HD-3D-technology display is not only provided to the surgeon, but to the entire room. While this new system is promising, the system appears to have disadvantages currently when compared to other systems, including the use of large, bulky, and now multiple separate robotic arms, the need for polarizing glasses for the 3D-monitor eye tracking and the limited selection of articulating instruments (36, 46).

TABLE 1 | Comparison of da Vinci surgical and new robotic systems.

Company	Location	Robotic system	Approach	Status	Camera	Robotic segments	DOF	Haptic feedback	Additional features
Intuitive surgical	Sunnyvale, CA	*Da Vinci Surgical System*	Laparoscopic LESS	Commercially available	2 HD-3D	4	7	None	Tremor filtration
TransEnterix	Morrisville, NC	*Senhance^{TM}*	Laparoscopy	FDA anticipated	HD-3D (eye-tracking)	3	7	Present	Navigation, eye-tracking camera control system, individual robotic carts
Medrobotics Corp	Raynham, MA	*Flex ®*	Transoral	Commercially available	HD-2D (semirigid or flexible)	2	180°	None	Core flexible, steerable scope that becomes rigid once positioned
Cambridge Medical Robotics Ltd.	Cambridge, UK	*Versius*	Laparoscopic	FDA validation	HD-3D	Up to 5 (modular)	7	Present	Force and position measurements > 1000x/second, up to 5 arms, lightweight
Titan Medical Inc.	Toronto, ON	*SPORT^{TM}*	LESS	FDA pending	HD-3D	1	Multiple	None	Singe incisions, multi-articulated instruments, single arm mobile cart
TransEnterix	Morrisville, NC	*SurgiBot^{TM}*	LESS	FDA denied, marketing in China	HD-3D	2	6	None	Internal triangulation
German Aeurospace Center (DLR)	Oberpfaffenhogen-Weßling	*Mirosurge*	Laparoscopy	Commercially available (not US)	HD-3D	3–5	7	Present	Easy adaptation of MIRO arms
Medtronic	Minneapolis, MN	*Hugo*	Laparoscopic	Development	–	–	–	–	Flexible use—mass utilization to decrease cost
Nanyang Technological University	Singapore	*MASTER*	NOTES	Clinical Trial	2D endoscope	2	9	Present	For NOTES allows smaller instruments with larger forces, reconstruction navigation
BIOTRONIK	Berlin, Germany	*ViaCath*	NOTES	Commercially available (not US)	N/A	1	9	None	Use in ureteroscopy and endovascular procedures
Memic Innovative Surgery	Israel	*Hominis^{TM}*	Laparoscopic LESS NOTES	Development	–	Humanoid shaped arms	360°	–	Humanoid shaped robotics arms
Virtual Incision and CAST (Omaha, NA)	Omaha, NA	*Miniature in vivo robot (MIVR)*	Advanced	Development	HD—flexible tip	2	6	None	Miniaturized unit artificial intelligence + machine learning
J&J/Alphabet	Mountain View, CA	*Verb Surgical*	Advanced	Development	–	–	–	-	"Surgery 4.0"—digital surgery combining robotics with data-driven machine learning

Flex Robotic System

The Flex Robotic System, FDA-approved in July 2015, was developed by Medrobotics Corporation (Raynham, MA) for transoral robotic surgery (47). The system is comprised of a single-port operator-controlled flexible endoscope. The endoscope is guided by an outer robotic joystick with a touchscreen and magnified HD 2D visual display. An inner and outer segment with a single articulation point between the two comprises the endoscope, which through this mechanism, either can be semi-rigid or flexible, enabling passage of flexible instruments. Two endoscopic lumens provide a path for both fluid irrigation and electrical wiring. In addition, flexible instruments with 180-degree articulation and as small as 3 mm in size can be passed through the two External Accessory Channels (EAC).

In the world of oral surgery, the system has successfully and safely been used for the removal of lesions in the supraglottic larynx, hypopharynx, and oropharynx in human subjects (48–50). Based on these promising outcomes, in January 2018, the use of the Flex Robotic system was approved for other procedures including thoracic, gynecologic, and general surgical procedures in the thorax and abdomen via skin incisions rather than natural orifices (51). Due to the advantageous ease of setup and transport along with the smaller surgical footprint, it is possible that the expanded FDA approval may lead to more widespread use.

Versius Robotic System

CMR Surgical (Cambridge, UK) has developed a new surgical robotic system, Versius, that recently launched its first U.S. training program in partnership with Florida Hospital Nicholson Center. The system features a lightweight robot for transabdominal surgeries, including general, colorectal, gynecologic, and urologic procedures. After successful cadaveric trials for electrocautery, needle driving, tissue handling, and suturing, the company proceeded to 9 weeks of FDA validation studies in Florida with plans for a U.S. launch in 2019 (52). This anticipated introduction may lead to a worthwhile competing system to the current Da Vinci robotic system.

Through a modular design, the system offers diversity and flexibility when it comes to operating room positioning. Up to 5 different robotic arms can be used with several available 5 mm instruments, including electrocautery electrodes, needle drivers, graspers, and scissors (53). Joystick controllers at the robotic console are used to manipulate the modular wristed robotic arms, and the console monitor can be visualized with HD-3D glasses. Furthermore, the robotic arms can transmit haptic feedback with force and position measurements occurring 1,000 times per second (46).

SPORT™ Surgical System

Through integration of the LESS approach to a console-based platform, a Toronto-based company has created the Single Port Orifice Robotic Technology (SPORT) Surgical System (Titan Medical Inc.). The design utilizes multi-articulated instruments with disposable and replaceable tips. For the single port, the incision can be as small as 2.5 cm, and via this port, the entire collapsible system can be placed intracorporeally (54). The ergonomic open workstation includes a variety of hand controllers, foot pedals, and a 3D HD flat touchscreen monitor. With the single port orifice, only one single-arm mobile patient cart is needed, thus improving the ease of use. Animal models for single port nephrectomy have shown significant success to date (36) and in 2019, an application for FDA approval is anticipated (55).

SurgiBot™

TransEnterix (Morrisville, NC) is also developing another surgical robotic system named the SurgiBot™ specifically for underserved populations by requiring a minimal acquisition investment. All flexible instruments are placed through a single channel in a single-incision site (46). Similar to many other robotic platforms, the SurgiBot includes 3D vision, ergonomic control with internal triangulation, and precision movement with scaling-incision site via a single channel. The pre-clinical trials at Baptist Health Medical Group in Miami consisted of two cholecystectomy and two nephrectomy procedures in a porcine model in 2015 (56). Thereafter, the platform did not receive FDA approval in 2016 as it failed to show equivalence to devices on the market. Since then, TransEnterix transferred the ownership of SurgiBot System assets to Great Belief International Limited with the option to distribute the product outside of China. The future of SurgiBot remains yet to be seen (57).

MiroSurge

In Oberpfaffenhofen-Weßling, the Robotics and Medtronics Center (MDR) of the German Aerospace Center (DLR) is developing a telemanipulated minimally invasive robotic surgery (MIRS) system named MiroSurge. Individual minimally invasive robot-assisted (MIRO) arms carrying an instrument can be mounted to the bed rails at various locations (58–60). Anywhere from three to five MIROs can be used with two guiding instruments by left and right manipulation and one for the endoscopic camera (61). Not only does each MIRO arm carry seven DOF with haptic feedback, but it can also adapt to various uses, such as actuated surgical instrumentation [Tobergte; (62)].

The MIRO arms have joints with torque and position sensors, which enable manual shifting and positioning of the arms. In impedance-controlled mode the insertion points are planned preoperatively based on algorithms specific for the robot's kinematics (61). Thus, far the system has been used for endoscopic teleoperated minimally invasive and open abdominal and thoracic surgeries. While it has not been officially announced, there is speculation that the MicroSurge technology has been licensed for use, although FDA approval information is not yet available (60).

Medtronic Robotic Surgery Program

The Minimally Invasive Therapies Group at Medtronic (Minneapolis, MN) has been working to develop a robotic platform for which a name has not been officially released. Previously the name Einstein had been mentioned (46), and now there are rumors that the surgical robot will be named Hugo (63). The development has occurred through multiple partnerships with Mazor Robotics, the German Aerospace Center (DLR) and

Covidien. Many of the details for this system have not been revealed, but the platform has been under development for more than 6 years and is already past its tenth prototype. The system is advertised to be flexible with a wide range of uses in bariatric, thoracic, colorectal, general, and urologic surgeries. In this fashion they hope to decrease costs by enhanced utilization of the robotic technology (64). Per interviews with Medtronic, the system has been trialed by many surgeons and they anticipated an initial system launch in India (65). However, delays in the initial launch, now aimed to be by end of fiscal year 2019, have led to some drops in the Medtronic stock (66, 67).

Master

Natural orifice transluminal endoscopic surgery (NOTES) takes LESS one step further, allowing an abdominal procedure to be performed through an internal incision in the stomach, vagina, bladder, or colon. However, many complicated procedures cannot be performed via conventional endoscopy and tools due to limited dexterity (68–70). The Master and Slave Transulminal Endoscopic Robotic (MASTER) allows for dexterity, triangulation, haptic feedback and a navigation system with real-time 3D reconstruction. opening the door to many new applications of NOTES (71). This platform created by Nanyang Technological University and National University Health System consists of an endoscope and two effector arms—a monopolar hook cautery and graspers. The surgeon operates the effector arms, which can be bimanually steered through a master control device while an endoscopist guides the endoscope to the desire location, controlling suction and inflation (69). In comparison to other technologies the MASTER allows for smaller instruments with larger forces, but additional work is still planned to improve automated movements and haptic feedback (68). While human procedures have yet to be reported, the MASTER system has demonstrated initial success in animal models, specifically by performing endoscopic sub-mucosal dissections for segmental hepatectomies (69).

ViaCath System

BIOTRONIK (Berlin, Germany) has developed another robotic platform for NOTES, the ViaCath system, with haptic feedback and interchangeable instruments, including graspers, scissors, electrocautery knife and needle holders (68). The surgeon at the console steers a standard colonoscope or endoscope with long-shafted instruments running alongside through an articulated flexible overtube (71). The instruments have better flexibility and decreased friction with the stainless steel and Teflon design, each with seven DOF along with the positioning arm (68). Furthermore, the overtube adds another two DOF via two joints, totaling nine DOF (72). Once the overtube is appropriately placed the two working instruments can be triangulated through a nose cone with cable-actuated gripper devices that allow rotary motion (68).

However, the system does lack appropriate spatial orientation with incomplete triangulation due to the parallel instrument orientations (71). Furthermore, the manipulation forces available are smaller than conventional laparoscopic instruments which could impede controlled device manipulation (72). While the robotic design can be catered toward NOTES, no such studies have yet been done. However, the system has been useful in endoscopic cases, such as ureteropyeloscopy on porcine models (73), and may present a new role for endoscopic procedures in pediatric urology.

Hominis™ Surgical System

Memic Innovative Surgery designed the *Hominis™ Surgical System* robotic platform to emulate human dexterity through small humanoid-shaped robotic arms with a novel 360-degree articulation. The system not only allows for both multiport and single port approaches, but also provides a platform for transvaginal access to perform hysterectomy. The Hominis system may provide the potential for improved ergonomics, lower costs, smaller footprint and variability in access with what is described as "seamless" robotic surgery (74, 75). However, this company appears to be in its early stages with no human or animal studies reported as of yet. For a future FDA submission, they are in the process of evaluating usability review.

Miniature *in vivo* Robot (MIVR)

Through a joint venture between The Center for Advanced Surgical Technology (CAST) at the University of Nebraska Medical Center in Omaha and Virtual Incision, a miniaturized *in vivo* robot (MIVR) was developed. This novel platform aims to reduce the robot size as well as improve intraperitoneal maneuverability to enable access to all four quadrants from a single umbilical entry point (76). The miniaturized robotic system is comprised of a novel surgeon-controlled flexible tip laparoscope and two robotic arms with multiple joints. The end effectors of the robotic arms can easily be changed and adapted for different operative needs and instruments. Additionally, the instrument movements are tracked and ultimately guided with a combination of artificial intelligence and machine learning technologies (77, 78). By localizing the drive technology within the small robotic arms, there is no need for larger platforms, further facilitating its use in the operating room (78). In the future, it is envisioned that the use of a combination of miniaturized robots simultaneously will cater to the specific complexity and needs of a particular procedure but with entry of all robots through the same entry site (78).

At present, successful use of a MIVR for colectomy was described in porcine studies (77). This same technology was applied to feasibility and safety human trials in South Africa, again showing successful outcomes for robotic colectomy (79). Further development of the platform is still in progress, with plans for small inexpensive robots for common routine procedures, such as cholecystectomy or hernia repair. Pending the finalization of these designs, an application for FDA approval is planned in the near future (76).

Verb Surgical

A joint venture between Johnson & Johnson's medical device company Ethicon Endo-Surgery and Alphabet's (Google) Verily Life Sciences, led to the creation of Verb Surgical, Inc.

(J&J/Alphabet, Mountain View, CA, USA) (80). This company is striving to create an autonomous surgical robot rather than just a surgeon controlled tool, which they envision as the next advance for the digital age (81). Although the company provided a demonstration to collaborators in January 2017 (80), little information has been released to date about anticipated next steps and plans.

Thus far, the device is said to "democratize surgery" with increased surgeon access to information through advancements in data analytics and machine learning, which they described as one step farther than the basic goals of robotic platforms of advanced visualization, instrumentation and connectivity (82). This new era of "digital surgery" has been coined as surgery 4.0, an advancement from the initial open surgery (1.0) to minimally invasive surgery (2.0) to initial robotic surgery (3.0) (83). Theoretically their prototype works to decrease costs and increase surgeon access through a combinations of robotic technology and data-driven machine learning (82).

Future Directions

Examination of emerging robotic platforms has opened a vast array of possibilities for the future of robotic surgery. With these continued advancements, the trend appears to be moving toward less incisions down to a single port platform, and possibly even no incision in the future. Furthermore, the combination of virtual reality technology and robotic surgery may lead to a completely new era of surgery that may include autonomous robotic surgery in the future.

AUTHOR CONTRIBUTIONS

KS and CK drafted, revised, and approved the final manuscript.

REFERENCES

1. Gobbi D, Midrio P, Gamba P. Instrumentation for minimally invasive surgery in pediatric urology. *Transl Pediatr.* (2016) 5:186–204. doi: 10.21037/tp.2016.10.07
2. Chen RN, Moore RG, Kavoussi LR. Laparoscopic pyeloplasty. Indications, technique, and long-term outcome. *Urol Clin North Am.* (1998) 25:323–30. doi: 10.1016/S.0094-0143(05)70021-5
3. Bauer JJ, Bishoff JT, Moore RG, Chen RN, Iverson AJ, Kavoussi LR. Laparoscopic versus open pyeloplasty: assessment of objective and subjective outcome. *J Urol.* (1999) 162(3 Pt 1):692–5. doi: 10.1097/00005392-199909010-00016
4. Jaffray B. Minimally invasive surgery. *Arch Dis Child.* (2005) 90:537–42. doi: 10.1136/adc.2004.062760
5. Rassweiler JJ, Teber D. Advances in laparoscopic surgery in urology. *Nat Rev Urol.* (2016) 13:387–99. doi: 10.1038/nrurol.2016.70
6. Rassweiler J, Binder J, Frede T. Robotic and telesurgery: will they change our future? *Curr Opin Urol.* (2001) 11:309–20. doi: 10.1097/00042307-200105000-00012
7. Atug F, Woods M, Burgess SV, Castle EP, Thomas R. Robotic assisted laparoscopic pyeloplasty in children. *J Urol.* (2005) 174(4 Pt 1):1440–2. doi: 10.1097/01.ju.0000173131.64558.c9
8. Kavoussi LR, Peters CA. Laparoscopic pyeloplasty. *J Urol.* (1993) 150:1891–4. doi: 10.1016/S0022-5347(17)35926-8
9. Schuessler WW, Grune MT, Tecuanhuey LV, Preminger GM. Laparoscopic dismembered pyeloplasty. *J Urol.* (1993) 150:1795–9. doi: 10.1016/S0022-5347(17)35898-6
10. Peters CA, Schlussel RN, Retik AB. Pediatric laparoscopic dismembered pyeloplasty. *J Urol.* (1995) 153:1962–5. doi: 10.1016/S0022-5347(01)67378-6
11. Klingler HC, Remzi M, Janetschek G, Kratzik C, Marberger MJ. Comparison of open versus laparoscopic pyeloplasty techniques in treatment of uretero-pelvic junction obstruction. *Eur Urol.* (2003) 44:340–5. doi: 10.1016/S0302-2838(03)00297-5
12. 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. doi: 10.1111/bju.14170
13. Varda BK, Wang Y, Chung BI, 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 pediatric pyeloplasty in the United States from 2003 to 2015. *J Pediatr Urol.* (2018) 336:e1–336.e8. doi: 10.1016/j.jpurol.2017.12.010
14. Behan JW, Kim SS, Dorey F, De Filippo RE, Chang AY, Hardy BE, et al. Human capital gains associated with robotic assisted laparoscopic pyeloplasty in children compared to open pyeloplasty. *J Urol.* (2011) 186:1663–7. doi: 10.1016/j.juro.2011.04.019
15. Rowe CK, Pierce MW, Tecci KC, Houck CS, Mandell J, Retik AB, et al. A comparative direct cost analysis of pediatric urologic robot-assisted laparoscopic surgery versus open surgery: could robot-assisted surgery be less expensive? *J Endourol.* (2012) 26:871–7. doi: 10.1089/end.2011.0584
16. Steyaert H, Van Der Veken E, Joyeux L. Implementation of robotic surgery in a pediatric hospital: lessons learned. *J Laparoendosc Adv Surg Tech A.* (2019) 29:136–40. doi: 10.1089/lap.2018.0426
17. Howe A, Kozel Z, Palmer L. Robotic surgery in pediatric urology. *Asian J Urol.* (2017) 4:55–67. doi: 10.1016/j.ajur.2016.06.002
18. Gundeti MS, Kojima Y, Haga N, Kiriluk K. Robotic-assisted laparoscopic reconstructive surgery in the lower urinary tract. *Curr Urol Rep.* (2013) 14:333–41. doi: 10.1007/s11934-013-0328-7
19. Ballouhey Q, Villemagne T, Cros J, Szwarc C, Braik K, Longis B, et al. A comparison of robotic surgery in children weighing above and below 15.0 kg: size does not affect surgery success. *Surg Endosc.* (2015) 29:2643–50. doi: 10.1007/s00464-014-3982-z
20. Baek M, Au J, Huang GO, Koh CJ. Robot-assisted laparoscopic pyeloureterostomy in infants with duplex systems and upper pole hydronephrosis: variations in double-J ureteral stenting techniques. *J Pediatr Urol.* (2017) 13:219–20. doi: 10.1016/j.jpurol.2016.12.008
21. Andolfi C, Kumar R, Boysen WR, Gundeti MS. Current status of robotic surgery in pediatric urology. *J Laparoendosc Adv Surg Tech A.* (2019) 29:159–66. doi: 10.1089/lap.2018.0745
22. Boysen WR, Akhavan A, Ko J, Ellison JS, Lendvay TS, Huang J, et al. Prospective multicenter study on robot-assisted laparoscopic extravesical ureteral reimplantation (RALUR-EV): outcomes and complications. *J Pediatr Urol.* (2018) 14:265–66. doi: 10.1016/j.jpurol.2018.03.004
23. Gundeti MS, Petravick ME, Pariser JJ, Pearce SM, Anderson BB, Grimsby GM, et al. A multi-institutional study of perioperative and functional outcomes for pediatric robotic-assisted laparoscopic Mitrofanoff appendicovesicostomy. *J Pediatr Urol.* (2016) 12:386.e381–386.e385. doi: 10.1016/j.jpurol.2016.05.031
24. Murthy P, Cohn JA, Selig RB, Gundeti MS. Robot-assisted laparoscopic augmentation ileocystoplasty and mitrofanoff appendicovesicostomy in children: updated interim results. *Eur Urol.* (2015) 68:1069–75. doi: 10.1016/j.eururo.2015.05.047
25. Kawauchi A, Naitoh Y, Miki T. Laparoendoscopic single-site surgery for pediatric patients in urology. *Curr Opin Urol.* (2011) 21:303–8. doi: 10.1097/MOU.0b013e3283468d40
26. Luithle T, Szavay P, Fuchs J. Single-incision laparoscopic nephroureterectomy in children of all age groups. *J Pediatr Surg.* (2013) 48:1142–6. doi: 10.1016/j.jpedsurg.2013.01.040
27. Kan HC, Pang ST, Wu CT, Chang YH, Liu CY, Chuang CK, et al. Robot-assisted laparoendoscopic single site adrenalectomy: a comparison of 3 different port platforms with 3 case reports. *Medicine.* (2017) 96:e9479. doi: 10.1097/MD.0000000000009479

28. LaMattina JC, Alvarez-Casas J, Lu I, Powell JM, Sultan S, Phelan MW, et al. Robotic-assisted single-port donor nephrectomy using the da Vinci single-site platform. *J Surg Res.* (2018) 222:34–8. doi: 10.1016/j.jss.2017.09.049
29. Intuitive Surgical. *Da Vinci SP: For Narros Access Surgery*. (2019). Available online at: https://www.intuitive.com/en-us/products-and-services/da-vinci/systems/sp (accessed May 2, 2019).
30. Cole AP, Trinh QD, Sood A, Menon M. The rise of robotic surgery in the new millennium. *J Urol.* (2017) 197:S213–5. doi: 10.1016/j.juro.2016.11.030
31. Thakre AA, Bailly Y, Sun LW, Van Meer F, Yeung CK. Is smaller workspace a limitation for robot performance in laparoscopy? *J Urol.* (2008) 179:1138–1142; discussion 1142–1133. doi: 10.1016/j.juro.2007.10.091
32. Ballouhey Q, Villemagne T, Cros J, Vacquerie V, Berenguer D, Braik K, et al. Assessment of paediatric thoracic robotic surgery. *Interact Cardiovasc Thorac Surg.* (2015) 20:300–3. doi: 10.1093/icvts/ivu406
33. Paradise HJ, Huang GO, Elizondo Saenz RA, Baek M, Koh CJ. Robot-assisted laparoscopic pyeloplasty in infants using 5-mm instruments. *J Pediatr Urol.* (2017) 13:221–2. doi: 10.1016/j.jpurol.2016.12.011
34. Pelizzo G, Nakib G, Romano P, Avolio L, Mencherini S, Zambaiti E, et al. Five millimetre-instruments in paediatric robotic surgery: advantages and shortcomings. *Minim Invasive Ther Allied Technol.* (2015) 24:148–53. doi: 10.3109/13645706.2014.975135
35. Ballouhey Q, Clermidi P, Cros J, Grosos C, Rosa-Arsene C, Bahans C, et al. Comparison of 8 and 5 mm robotic instruments in small cavities: 5 or 8 mm robotic instruments for small cavities? *Surg Endosc.* (2018) 32:1027–34. doi: 10.1007/s00464-017-5781-9
36. Rassweiler JJ, Autorino R, Klein J, Mottrie A, Goezen AS, Stolzenburg JU, et al. Future of robotic surgery in urology. *BJU Int.* (2017) 120:822–41. doi: 10.1111/bju.13851
37. U. S. Food and Drug. *FDA Clears New Robotically-Assisted Surgical Device For Adult Patients.* (2017). Available online at: http://news.doximity.com/entries/9699292?authenticated=false (accessed March 26, 2018).
38. Fanfani F, Restaino S, Gueli Alletti S, Fagotti A, Monterossi G, Rossitto C, et al. TELELAP ALF-X robotic-assisted laparoscopic hysterectomy: feasibility and perioperative outcomes. *J Minim Invasive Gynecol.* (2015) 22:1011–7. doi: 10.1016/j.jmig.2015.05.004
39. Fanfani F, Monterossi G, Fagotti A, Rossitto C, Gueli Alletti S, Costantini B, et al. The new robotic TELELAP ALF-X in gynecological surgery: single-center experience. *Surg Endosc.* (2016) 30:215–21. doi: 10.1007/s00464-015-4187-9
40. Fanfani F, Restaino S, Rossitto C, Gueli Alletti S, Costantini B, Monterossi G, et al. Total Laparoscopic (S-LPS) versus TELELAP ALF-X robotic-assisted hysterectomy: a case-control study. *J Minim Invasive Gynecol.* (2016) 23:933–8. doi: 10.1016/j.jmig.2016.05.008
41. Gueli Alletti S, Rossitto C, Cianci S, Restaino S, Costantini B, Fanfani F, et al. Telelap ALF-X vs standard laparoscopy for the treatment of early-stage endometrial cancer: a single-institution retrospective cohort study. *J Minim Invasive Gynecol.* (2016) 23:378–83. doi: 10.1016/j.jmig.2015.11.006
42. Spinelli A, David G, Gidaro S, Carvello M, Sacchi M, Montorsi M, et al. First experience in colorectal surgery with a new robotic platform with haptic feedback. *Colorectal Disease.* (2018) 20:228–35. doi: 10.1111/codi.13882
43. Bozzini G, Gidaro S, Taverna G. Robot-assisted laparoscopic partial nephrectomy with the ALF-X Robot on Pig models. *Eur Urol.* (2016) 69:376–7. doi: 10.1016/j.eururo.2015.08.031
44. TranEnterix. *Senhance^{TM}*. (2018). Available online at: https://www.transenterix.com/overview/ (accessed March 26, 2018).
45. Rao PP. Robotic surgery: new robots and finally some real competition! *World J Urol.* (2018) 36:537–41. doi: 10.1007/s00345-018-2213-y
46. Peters BS, Armijo PR, Krause C, Choudhury SA, Oleynikov D. Review of emerging surgical robotic technology. *Surg Endosc.* (2018) 32:1636–55. doi: 10.1007/s00464-018-6079-2
47. Medrobotics. *Flex® Robotic System: Expanding the Reach of Surgery®*. (2018). Available online at: https://medrobotics.com/gateway/flex-system-int/ (accessed March 26, 2018).
48. Lang S, Mattheis S, Hasskamp P, Lawson G, Guldner C, Mandapathil M, et al. A european multicenter study evaluating the flex robotic system in transoral robotic surgery. *Laryngoscope.* (2017) 127:391–5. doi: 10.1002/lary.26358
49. Mattheis S, Hasskamp P, Holtmann L, Schafer C, Geisthoff U, Dominas N, et al. Flex robotic system in transoral robotic surgery: The first 40 patients. *Head Neck.* (2017) 39:471–5. doi: 10.1002/hed.24611
50. Tan Wen Sheng B, Wong P, Teo Ee Hoon C. Transoral robotic excision of laryngeal papillomas with Flex(R) Robotic System - A novel surgical approach. *Am J Otolaryngol.* (2018) 355–8. doi: 10.1016/j.amjoto.2018.03.011
51. Taylor NP. *FDA Clears Medrobotics' Robotic Surgical Platform for Expanded Use.* (2018). Available online at: https://www.fiercebiotech.com/medtech/fda-clears-medrobotics-robotic-surgical-platform-for-expanded-use (accessed March 26, 2018).
52. CMR Surgical. *CMR Reveals Versius Robotic Surgery System.* (2016). Available online at: https://cmrsurgical.com/cmr-reveals-versius-robotic-surgery-system/ (accessed March 26, 2018).
53. Ellis R. *UK Scientists Create World's Smallest Surgical Robot to Start A Hospital Revolution.* (2017). Available online at: https://www.theguardian.com/society/2017/aug/19/worlds-smallest-surgical-robot-versius-keyhole-hospital-revolution?CMP=share_btn_link (accessed March 26, 2018).
54. Titan Medical Inc. *SPORT^{TM} Surgical System.* (2018). Available online at: https://titanmedicalinc.com/technology/ (accessed March 26, 2018).
55. Idrus AA. *On Track for 2019 Launch, Titan Medical Installs Its First Surgical Robot in Florida (2017).* Available online at: https://www.fiercebiotech.com/medtech/track-for-2019-launch-titan-medical-installs-its-first-surgical-robot-florida (accessed March 26, 2018).
56. Haskins O. *TransEnterix Completes SurgiBot Pre-Clinical FDA Work.* (2015). Available online at: http://www.bariatricnews.net/?q=node/1856 (accessed May 15, 2019).
57. Ohnesorge L. *TransEnterix Announces Global SurgiBot System Agreement.* (2017). Available online at: https://www.businesswire.com/news/home/20171218005245/en/TransEnterix-Announces-Global-SurgiBot-System-Agreement (accessed May 15, 2019).
58. Hagn U, Konietschke R, Tobergte A, Nickl M, Jorg S, Kubler B, et al. DLR MiroSurge: a versatile system for research in endoscopic telesurgery. *Int J Comput Assist Radiol Surg.* (2010) 5:183–93. doi: 10.1007/s11548-009-0372-4
59. Beasley RA. Medical robots: current systems and research directions. *J Robot.* (2012) 2012:401613. doi: 10.1155/2012/401613
60. Henry BN, Santo G. *Peering Behind the Veil of Secrecy in Surgical Robotics & 2016 Market Outlook*. RBC Capital Markets (2017).
61. Konietschke R, Hagn U, Nickl M, Jorg S, Tobergte A, Passig G, et al. The DLR MiroSurge - A robotic system for surgery. In: *2009 IEEE International Conference on Robotics and Automation*. Kobe (2009). p. 1589–90. doi: 10.1109/ROBOT.2009.5152361
62. Tobergte AH, Thielmann P, Grange S, Albu-Schaffer S, Conti A, Hirzinger F. The sigma.7 haptick interface fo MiroSurge: a new bi-manual surgical console. In: *2011 IEEE/RSJ International Conference onf Intelligent Robots and Systems*, San Francisco, CA (2001), p. 3023–30.
63. Medtechy[y]. *Did Medtronic Accidentally Release the Name of Their Robotic Surgery Program?* (2017). Available online at: https://www.medtechy.com/articles/2017/did-medtronic-accidentally-release-the-name-of-their-robotic-surgery-program (accessed May 15, 2019).
64. Thibault M. *Finally, Details on Medtronic's Robotics Platform.* (2016). Available online at: https://www.mddionline.com/finally-details-medtronics-robotics-platform (accessed May 5, 2019).
65. Medtechy[y]. *Medtronic CEO Provides Updated on Robotic Surgery Program.* (2019). Available online at: https://www.medtechy.com/articles/2019/medtronic-ceo-provides-update-on-robotic-surgery-program (accessed May 15, 2019).
66. Gatlin A. *Medtronic Sinks After Its Rival To Intuitive Surgical Delayed.* (2018). Available online at: https://www.investors.com/news/technology/medtronic-rises-after-topping-quarterly-expectations/ (accessed May 15, 2019).
67. Perriello B. *UPDATE: Robotics Delay Pushes Medtronic Down Despite Fiscal Q3 Beats.* (2018). Available online at: https://www.massdevice.com/medtronics-q3-beats-expectations/ (accessed May 15, 2019).
68. Yeung BP, Gourlay T. A technical review of flexible endoscopic multitasking platforms. *Int J Surg.* (2012) 10:345–54. doi: 10.1016/j.ijsu.2012.05.009
69. Lomanto D, Wijerathne S, Ho LK, Phee LS. Flexible endoscopic robot. *Minim Invasive Ther Allied Technol.* (2015) 24:37–44. doi: 10.3109/13645706.2014.996163
70. Kume K. Flexible robotic endoscopy: current and original devices. *Comput Assist Surg.* (2016) 21:150–9. doi: 10.1080/24699322.2016.1242654

71. Klibansky D, Rothstein RI. Robotics in endoscopy. *Curr Opin Gastroenterol.* (2012) 28:477–82. doi: 10.1097/MOG.0b013e328356ac5e
72. Prendergast JM, Rentschler ME. Towards autonomous motion control in minimally invasive robotic surgery. *Exp Rev Med Devices.* (2016) 13:741–8. doi: 10.1080/17434440.2016.1205482
73. Aron M, Haber GP, Desai MM, Gill IS. Flexible robotics: a new paradigm. *Curr Opin Urol.* (2007) 17:151–5. doi: 10.1097/MOU.0b013e3280e126ab
74. Memic Innovation Surgery. *Hominis - Robotic Surgery Made Natural.* (2017). Available online at: https://www.kenes-exhibitions.com/old/biomed2016/wp-content/uploads/2016/05/MEMIC.docx (accessed March 26, 2018).
75. Memic. *Hominis^{TM}- the Smallest, Farthest Reaching Surgical Robot.* (2018). Available online at: https://www.memicmed.com/ (accessed March 26, 2018).
76. Keenan J. *Virtual Incision Reels in $18M in Series B Round To Support Its Surgical Robotics.* (2017). Available online at: https://www.fiercebiotech.com/medtech/virtual-incision-reels-18m-series-b-round-to-support-its-surgical-robotics (accessed March 26, 2018).
77. Wortman TD. *Design, Analysis, and Testing of in vivo Surgical Robots.* (2011). Department of Mechanical Engineering, University of Nebraska—Lincoln. Available online at: https://digitalcommons.unl.edu/mechengdiss/28/ (accessed March 26, 2018).
78. Virtual Incision. *World's First Use of Miniaturized Robot in Human Surgery.* (2016). Available online at: https://www.virtualincision.com/fim-surgery/ (accessed March 26, 2016).
79. Bedem LJ. *Realization of a Demonstrator Slave for Robotic Minimally Invasive Surgery*. Eindhoven: Technische Universiteit Eindhoven (2010).
80. Verb Surgical Inc. *Verb Surgical Delivers Digital Surgery Prototype Demonstration to Collaboration Partners.* (2017). Available online at: https://www.prnewswire.com/news-releases/verb-surgical-delivers-digital-surgery-prototype-demonstration-to-collaboration-partners-300397192.html (accessed March 26, 2018).
81. Simonite T. *The Recipe for the Perfect Robot Surgeon.* (2016). Available online at: https://www.technologyreview.com/s/602595/the-recipe-for-the-perfect-robot-surgeon/ (accessed March 26, 2018).
82. Thibault M. *Here's the Latest From Verb Surgical.* (2016). Available online at: https://www.mddionline.com/heres-latest-verb-surgical (accessed March 26, 2018).
83. Khateeb OM. *Democratizing Surgery Part 1: What Verb Surgical is Creating.* (2016). Available online at: https://www.linkedin.com/pulse/democratizing-surgery-how-verb-surgical-invented-new-category (accessed March 26, 2018).

Conflict of Interest Statement: CK is a course director and consultant for Intuitive Surgical.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

REVIEW
published: 22 August 2019
doi: 10.3389/fped.2019.00351

Robotic Management of Urolithiasis in the Pediatric Population

Natalia Ballesteros[1]*, *Zachary A. Snow*[2], *Paulo R. M. Moscardi*[3], *George A. Ransford*[1], *Pablo Gomez*[4] and *Miguel Castellan*[1,3,5]

[1] Division of Pediatric Urology, Nicklaus Children's Hospital, Miami, FL, United States, [2] Dr. Kiran C. Patel College of Osteopathic Medicine, Nova Southeastern University, Fort Lauderdale, FL, United States, [3] Division of Pediatric Urology, Jackson Memorial Hospital, Miami, FL, United States, [4] Division of Pediatric Urology, Florida Hospital for Children, Orlando, FL, United States, [5] Division of Pediatric Urology, Joe DiMaggio Children's Hospital, Hollywood, FL, United States

A variety of surgical techniques exist for the management of urolithiasis. Minimally invasive techniques have replaced open surgery in the last few decades. For complex stone management, robotic-assisted laparoscopic surgery (RALS) has emerged as a safe and feasible alternative in adults. The literature for RALS for urolithiasis (RALS-UL) in the pediatric population is scarce. Herein, we present a review of the literature in both adult and pediatric patients as well as our experience using RALS-UL at our institutions. Special attention is given to the synchronous management of urolithiasis when surgery is performed for other conditions such as ureteropelvic junction obstruction (UPJO), and a supplemental video is provided.

Keywords: robotic, pyelolithotomy, nephrolithotomy, urolithiasis, renal stones, ureteropelvic junction obstruction, pediatric

OPEN ACCESS

Edited by:
Sajid Sultan,
Sindh Institute of Urology and Transplantation, Pakistan

Reviewed by:
Mohan S. Gundeti,
University of Chicago, United States
Matthieu Peycelon,
Indiana University, United States
Roberto Luis Vagni,
Italian Hospital of Buenos Aires, Argentina

****Correspondence:***
Natalia Ballesteros
natabal4@gmail.com

Specialty section:
This article was submitted to Pediatric Urology, a section of the journal Frontiers in Pediatrics

Received: *04 January 2019*
Accepted: *06 August 2019*
Published: *22 August 2019*

Citation:
Ballesteros N, Snow ZA, Moscardi PRM, Ransford GA, Gomez P and Castellan M (2019) Robotic Management of Urolithiasis in the Pediatric Population. Front. Pediatr. 7:351. doi: 10.3389/fped.2019.00351

INTRODUCTION

Urolithiasis is a very common condition affecting both men and women of all age groups. When surgical management is indicated, there are a variety of minimally invasive techniques that have gradually replaced open surgery as the preferred approach (1). Although most patients with kidney or ureteric stones are treated via ureteroscopy (URS) and retrograde intrarenal surgery (RIRS), percutaneous nephrolithotomy (PCNL) or extracorporeal shock wave lithotripsy (ESWL); the use of laparoscopic surgery in stone disease has increased over the last two decades (2), and open surgical interventions such as anatrophic nephrolithotomy and ureterolithotomy are now rarely done. Besides the significant laparoscopic skills needed, drawbacks to laparoscopic stone surgery include challenges with ureteral stenting and suturing, limited dissection and intracorporal reconstruction, as well as increased risk of urinary leak (3–6). The use of the robotic platform allows for improved ergonomics and visualization (magnified, three-dimensional) as well as ease of instrument dexterity that most closely imitates the open technique maintaining the advantages associated with minimally invasive surgery. Robotic assisted laparoscopic surgery for urolithiasis (RALS-UL) overcomes most of the issues associated with open or laparoscopic urolithiasis surgery and the training curve, like most skills, is attainable. Robot-assisted pyelolithotomy, robot-assisted ureterolithotomy and robot-assisted flexible URS are now part of the urologist's arsenal for the treatment of large volume stones and become particularly useful in conditions requiring simultaneous reconstruction (1, 7). In the pediatric population the incidence of urolithiasis appears to be increasing globally (8). The standard procedures to treat stone disease in children have been similar as those used in the adult population (9). However, there is very limited data regarding the use of robotic-assisted surgery in the management of pediatric urolithiasis.

Lee et al. (10) demonstrated safe and effective use of robotic-assisted pyelolithotomy in 5 adolescent patients with large stone burdens. To our knowledge, this is the only study dedicated to the surgical management of stone disease robotically within the pediatric population. In this literature review, we will highlight the current advances in the field of robotics for stone disease among the general population.

MATERIALS AND METHODS

We performed a review of the major studies in adult and pediatric robotic-assisted laparoscopic surgery for urolithiasis (RALS-UL) from 2005 to 2018. Search words included, but were not limited to: robotic, laparoscopic, urolithiasis, stone, pyelolithotomy, nephrolithotomy, and pediatric.

RESULTS

Since 2005, 22 articles for RALS-UL have been published in the adult population for management of various conditions: concomitant management of UPJO and nephrolithiasis (4), concomitant management of caliceal diverticuli with stones (2), pyelolithotomy (2), pyelolithotomy with nephrolithotomy (1), extended pyelolithotomy (4), ureterolithotomy (1 proximal, 1 distal), anatrophic nephrolithotomy (3), and management of stones when ectopic and other renal anomalies are present (2 pelvic kidney, 1 horseshoe kidney, 1 cross-fused ectopic kidney). Of note, many of these studies did not include detailed information regarding the initial patient stone burden. Additionally, the video section of one journal in 2012 reported a case of anatrophic nephrolithotomy. This video was not available for viewing.

In the pediatric population, an article from 2007 is the only one that describes RALS-UL: 4 pyelolithotomies and 1 concomitant management of UPJO and nephrolithiasis. Furthermore, the video section of one journal in 2014 depicted a technique using intraoperative ultrasound probing during RALS-UL in children. This video and further details of the study were not available for reviewing.

DISCUSSION

According to the American Urological Association (AUA) and Endourological Society guidelines on adult urolithiasis, when surgical intervention is necessary, URS/RIRS and ESWL are considered to be first-line treatment for kidney stones < 2 cm, whereas for > 2 cm, PCNL is the therapy of choice (11). This is also the case for pediatric patients, with the addition that ESWL can be implemented as well when stones are >2 cm (12). Although these guidelines do not include RALS as a standard of treatment for routine patients, they do include open, laparoscopic, or robotic interventions as an option for patients with rare anatomic anomalies and complex stone disease or for those requiring concomitant reconstruction (12). This is further supported by the European Association of Urology (EAU) guideline for the management of urinary stone disease in children which states that open or laparoscopic alternatives may be inevitable in such situations (13). Ample literature has shown that laparoscopic and robotic-assisted approaches to stone disease are both viable options for patients with large stones, abnormal collecting system anatomy, and complex stone burden (14). The earliest report of laparoscopy for the management of stone disease was published in the 1979, when Wickham first documented his results of laparoscopic ureterolithotomy via a retroperitoneal approach (15). Then, over a decade later, clinical trials investigating this minimally-invasive method began to expand largely due to the creation of new laparoscopic technologies and the widespread adoption of laparoscopic surgical skills (2). In 1994, Gaur et al. (16) demonstrated the safe and effective use of retroperitoneal laparoscopic pyelolithotomy in 5 patients with medium-sized pelvic stones not amenable to ESWL or PCNL. Since then, multiple studies have been performed showing that laparoscopic pyelolithotomy is comparable to PCNL for kidney stones > 2 cm in the renal pelvis, with certain advantages such as less blood loss and less post-operative analgesia requirement (14, 17). As for laparoscopic ureterolithotomy, clinical trials comparing this approach to traditional flexible ureteroscopy for large upper tract stones (> 2 cm) show comparable to higher stone-free rates, less need for any additional procedures and lower complication rates (18). The success of conventional laparoscopic techniques in the management of large volume stones in combination with the development of the da Vinci® Surgical System by Intuitive Surgical Inc. eventually gave way to the use of robotic-assisted surgery in the treatment of urolithiasis. The use of RALS-UL was first reported by Atug et al. (19). Since then, RALS-UL has become a great tool in the urologist armamentarium for managing diverse complex and challenging cases of urolithiasis where other known modalities may not be feasible or when multiple prior procedures have been attempted.

General Considerations

Preoperative Urine Culture and Antibiotics

The importance of documented urine sterilization prior to urologic surgical intervention cannot be overstated, especially in the setting of intraperitoneal and/or retroperitoneal urine spillage during robotic cases (20). Likewise, perioperative antibiotic prophylaxis should be used based on urologic guidelines and preoperative culture sensitivity.

Ureteral Stents

In general, placement of ureteral double J (JJ) stents is performed depending on the case and at the surgeon's discretion. They can be conducted antegrade during the procedure in similar fashion as when placed in open cases. In other instances, stents may have been already placed preoperatively to relieve obstruction. For other cases, such as in anatrophic nephrolithotomies, routine ureteral stent placement is not done (20). At one of our institutions, we prefer to perform a retrograde pyelogram (RPG) and JJ stent placement prior to all RAL pyeloplasties; therefore, it is done in this manner for concurrent management of renal stones. At another institution (FHC), retrograde pyelogram is not routinely performed and urinary drainage (JJ stenting or nephrostomy tube) is avoided in the majority of RAL pyeloplasties. Indications for JJ stenting at this institution include massive reduction of the renal pelvis, solitary kidney and age < 6 months. Additionally, for isolated pyelolithotomies, we do not leave a ureteral stent when the ureteropelvic junction (UPJ) is not compromised. On infants, we place 3.7 Fr stents, and in older children we use either 3.7 or 4.8 Fr stents.

Nephroscopy and Stone Retrieval

Regardless of stone location in the upper collecting system, the use of the flexible or rigid ureteroscope is a great addition to the surgical intervention. The scope is deployed through an assistant port, when available, or through a robotic trocar after one of the arms is undocked. A ureteral access sheath can be telescoped through the trocar if multiple stones are found or if a large stone burden warrants it. This maneuver decreases surgical time. At our institutions we prefer the use of a flexible ureteroscope for nephroscopy when multiple stones are present to maximize stone clearance (**Figure 1**). The stones can be retrieved with the ProGrasp forceps (Intuitive Surgical INC, Sunnyvale, CA, USA), when easily visible, or using endoscopic graspers or baskets. Laser lithotripsy can be employed as necessary to break large stones into smaller fragments that are easier to retrieve (21). Furthermore, for removing stones from the abdominal cavity, simultaneous removal through the trocar or the use of a commercially available or homemade bag is possible. One article mentioned the use of the fingers of a sterile glove as retrieval bags (21). Interestingly, the use of a flexible cystoscope has also been described to ease intraperitoneal stone removal after pyelolithotomy is closed (22).

Intraoperative Ultrasonography

The use of the laparoscopic ultrasound probe is an additional tool that can aid in localizing calculi before or after nephroscopy and can also be used to identify hilar vessels when needed, for example in anatrophic nephrolithotomy cases (20, 23, 24).

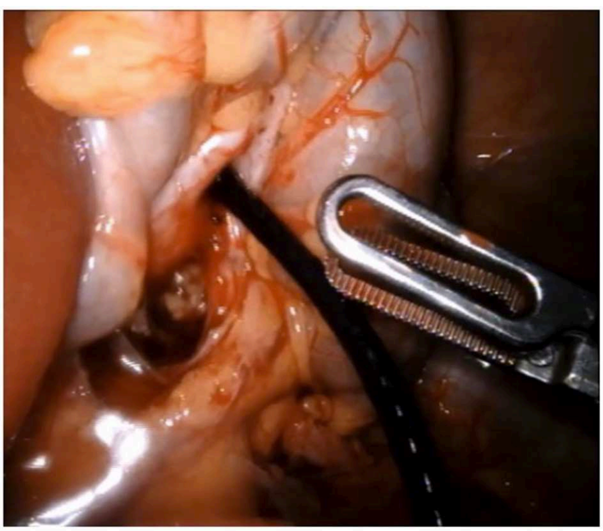

FIGURE 1 | Nephroscopy using a standard digital flexible ureteroscope.

Type of Suture

The collecting system is closed with interrupted or continuous absorbable suture depending on surgeon's preference. In cases of nephrolithotomy, the renal parenchyma can be closed with braided or barbed absorbable suture.

Drain Placement

In many cases, a JP or similar suction drain has been left intraperitoneally for 1–2 days (24–26). At our institutions, for robotic pyeloplasties and other pediatric surgeries, we do not traditionally leave such drain and instead we leave a Foley catheter for 1–2 days. If a JJ stent is left, it is removed 4–6 weeks later. For cases of RALS-UL, we have not had urinary leaks or other complications in this manner.

Urolithiasis and Concomitant UPJO

When presented with cases of UPJO and renal stone disease, options for surgical management are limited. The European Association of Urology guidelines currently recommend that robotic-assisted pyeloplasty (RALP) and surgical intervention for stones be performed in separate procedures (27). However, due to the potential risks of general anesthetics on the brain development of children undergoing multiple and lengthy procedures (28, 29), one should consider as an alternative to perform both surgeries concurrently. Laparoscopic pyeloplasty with pyelolithotomy with or without flexible URS to completely clear stone burden has been widely described in the adult literature. Concomitant RALP and pyelolithotomy (RALP +P) in these patients was first reported by Atug et al. (19). After pyelotomy, flexible renoscopy with stone removal was achieved on 8 patients with 100% stone clearance confirmed on imaging. Since then, 3 more studies looking specifically at RALP + P have emerged supporting the safety and feasibility of the procedure along with high stone-free rates (27, 30, 31). Of these, Zheng et al. (27) reported their experience removing renal calculi with a rigid ureteroscope in 9 patients. The stone-fee rate was 89% with one patient requiring one ESWL session for complete stone clearance. Most recently, in 2017 Jensen et al. (30) demonstrated that although the median operative time for concomitant RALP and RALS-UL was 31 min more than RALP alone, no statistical difference in the blood loss or length of stay were observed.

In the pediatric population, only one case has been described of concomitant RALP and pyelolithotomy on an adolescent. Further details regarding the stone burden was not reported but the patient was rendered stone free with a single procedure (10). At our institutions, over the last 5 years we have performed concomitant RALP + P on 10 patients from 5 to 26 years of age (supplementary video: https://doi.org/10.6084/m9.figshare.8799269.v1). All cases had preoperatively been diagnosed with UPJO and ipsilateral nephrolithiasis. As above mentioned, after pyelotomy, nephroscopy and stone removal was performed (**Figure 2**). Length of stay was 1 day in 7 cases. The extra day spent by the remaining patients was for pain control or for observation. Nine of 10 patients were rendered stone free with robotic intervention. In 2 patients, no stone was found. One of them had a punctate stone recognized on preoperative computed tomography (CT) and was believed to have been flushed out

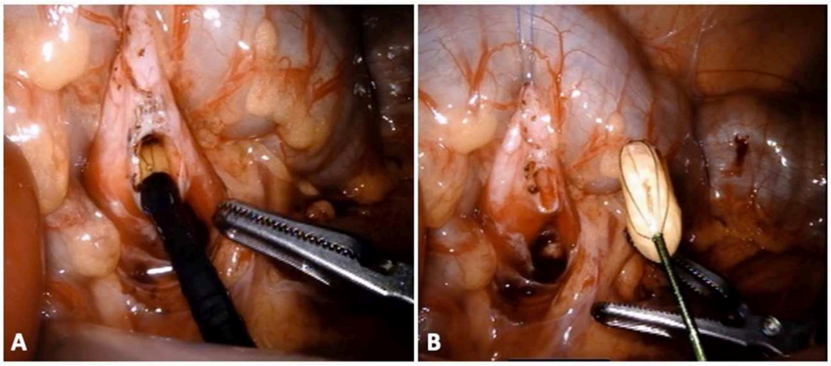

FIGURE 2 | Patient with UPJO and nephrolithiasis undergoing pyeloplasty and concomitant nephrolithotomy. Through the flexible ureteroscope **(A)**, a standard basket device is used for stone extraction **(B)**.

with irrigation as it was not visualized later on postoperative imaging. The other patient had a history of a small lower pole calculus. This was missed during nephroscopy and shortly after the pyeloplasty he passed the stone spontaneously. Of note, this patient later underwent other interventions for recurrent urolithiasis, including on the contralateral kidney.

Pyelolithotomy, Extended Pyelolithotomy, and Nephrolithotomy

With the above-mentioned success of concurrent RALP + P, robotic pyelolithotomy has become the most common approach in the RALS-UL literature and further applications have been explored to include nephrolithotomy and extended pyelolithotomy procedures. Pyelolithotomy involves incision of the renal pelvis with subsequent stone extraction. Further involvement of the calyceal system calls for an extended approach. Nephrotomy and nephrolithotomy is performed to allow stone extraction when there is a narrow infundibulum or part of the calculus is attached to the parenchyma. In 2006, Badani et al. (32) reported their experience with robotic extended pyelolithotomy (REP). The patient is positioned in modified lateral decubitus with minimal to no flexion and without kidney rest elevation. After adequate exposure of the renal pelvis, a pyelotomy is performed away from the UPJ. The authors demonstrated complete stone removal and minimal blood loss in 12 patients with partial staghorn calculi. Of note, a 13th patient with complete staghorn stones was unsuccessfully cleared, leading to the conclusion that REP is not a suitable technique for full staghorn calculi. Other authors have described REP with similar experiences (33–35), with the latest one being a case report of a 31-year-old non-diabetic woman with emphysematous pyelonephritis caused by on a 6.5 cm gas-containing calculus (35). In 2015, Rajiv et al. (25) described a case of bilateral large stone disease managed with simultaneous bilateral robot-assisted pyelolithotomy, showing minimal morbidity, a short hospital course and the avoidance of adjuvant procedures. A multi-center evaluation of robotic pyelolithotomy and robotic nephrolithotomy in 27 patients between 2008 and 2014 concluded that both techniques are safe (minimal bleeding and low risk of sepsis) and effective (maximum stone free clearance and infrequent retreatment rates) for patients with large renal pelvis and calyceal stones (36). Cystine stones account for 1–2% and 6–8% of urolithiasis in the adult and pediatric population, respectively (21). Although cystinuria is best treated medically for stone prevention, the surgical management of large stones can be quite a challenge and may require multiple endourologic procedures. On the other hand, robotic pyelolithotomy is a feasible alternative. In 2017, Megiatto et al. (21) reported a case of a 20-year-old woman who was poorly compliant with medical treatment and had undergone several procedures through the years for her disease. On one side, there was a single stone that required both URS and ESWL to clear. For her large, multiple stone burden contralaterally (36 stones), she underwent robotic pyelolithotomy with concomitant renoscopy and laser lithotripsy. In the only published report of RALS-UL in the pediatric population, 4 patients, between the ages of 10 and 23, underwent robotic-assisted laparoscopic lithotomy for the treatment of large cystine stones 2–7 cm in size (10). These stones had been refractory to previous PCNL and ESWL. Additionally, one patient required open conversion due to an intrarenal pelvis and inability to remove the stone. This patient required 3 additional procedures (ESWL and 2 URS) to become stone free. In 2014, Ghani et al. (23) published a video that depicts a technique for using intraoperative ultrasound probing during RALS-UL in 4 children to aid in stone localization. This video was not available for viewing but is worth mentioning as an additional tool that can be applied to RALS-UL. At one of our institutions, we performed metachronous bilateral pyelolithotomies in a 15-year-old girl with bilateral staghorn calculi and a new diagnosis of cystinuria (**Figure 3**). In both cases, no ureteral stents were left indwelling as the UPJs were not compromised. She had a 1-night hospitalization per each surgery. There were no overall complications and she was 100% stone free following the procedures.

Calyceal Diverticular Calculi

Another example of approaching urolithiasis concomitantly with the management of another condition is in the treatment of

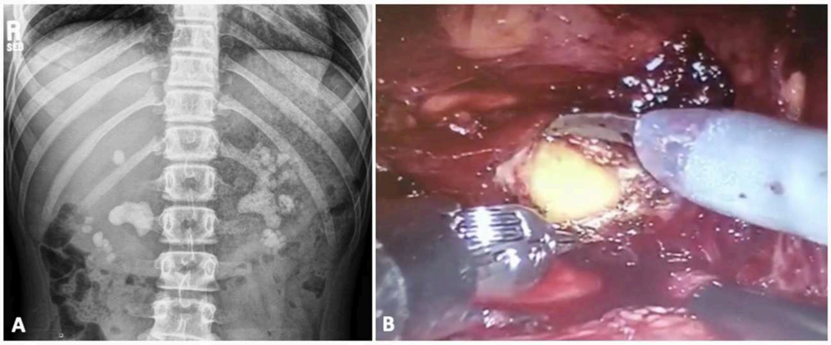

FIGURE 3 | Patient with bilateral staghorn calculi and cystinuria **(A)** undergoes metachronous bilateral pyelolithotomies **(B)**.

calyceal diverticular calculi. The incidence of stones within a calyceal diverticulum ranges from 1 to 10% (37). Although these are managed primarily with ESWL, RIRS and PCNL; laparoscopic and robotic assisted interventions are feasible alternatives. Furthermore, laparoscopic intervention has been proposed to be the approach for management of anteriorly-located calyceal diverticuli that have failed prior endourologic attempts or for anteriorly-located stones $>$ 3 cm (38). In 2014, Torricelli et al. (37) reported the first case managed robotically in a 33-year old obese woman with a symptomatic 2 cm, anterior mid polar calyceal diverticular calculus. She had undergone two prior failed URS attempts: one with diverticular laser incision but inability to remove stone fragments after lithotripsy and the second had found the diverticular neck to be obliterated. After RALS-UL, the diverticulum was managed with fulguration. The patient was in a 45-degree lateral decubitus position with the table flexed, and the ports were placed in similar fashion as for robotic-assisted laparoscopic partial nephrectomy (RALPN). As in RALPN, the renal vasculature was clamped for warm ischemia. Likewise, an intraperitoneal drain was left in place for 2 days. More recently, Verbrugghe et al. (39) described their similar experience with an anterior calyceal diverticulum with stone burden in the lower pole of a 55-year old woman with an additional history of pyelonephritis. In the first case, the use of a robotic ultrasound probe was used for identification of the diverticulum while in the second case a CT-guided puncture of the calyx was done with a harpoon left in place for localization.

Congenital Renal Anomalies

Ectopic pelvic and horseshoe kidneys are a surgical challenge in the management of ureterolithiasis. They are located in close proximity to the bony pelvis and are surrounded by important visceral organs. In addition to abnormal vasculature, they have intrinsic anatomical anomalies such as malrotation, anteriorly displaced renal pelves, and high ureteral insertions. These often lead to partial or complete urinary obstruction and hydronephrosis. UPJO is found in 70% of ectopic kidneys with hydronephrosis (5). Concomitant urolithiasis poses a challenge for endourological interventions, including PCNL requiring modified renal access. RALS-UL is an alternative that has been demonstrated in the literature to be safely feasible. Pyeloplasty with concomitant pyelolithotomy on an ectopic pelvic kidney with UPJO and nephrolithiasis was first described in 2010 by Zheng et al. (27). The patient was a 55-year old man who presented with abdominal pain, a serum creatinine (Cr) of 2.3 mg/dL, and the aforementioned renal anomalies. Six months after surgical intervention, the patient was doing well, Cr had significantly improved, and renal function had increased from 19 to 24%. In the management of isolated large-burden urolithiasis in these anomalous kidneys, the traditional surgical modalities have been employed in the past such as RIRS, ESWL, and PCNL. However, due to the above-mentioned anatomic challenges, these surgeries are often difficult and unsuccessful for complete stone clearance (24). In these cases, endopyelotomy with subsequent pyelolithotomy can be accomplished. Examples described in the literature include an ectopic pancake, or fused lumped kidney, with a 2.5 cm stone in one of the moieties (40) and a horseshoe kidney with multiple pelvicalyceal calculi (25). In most cases, patient positioning and robotic port placement were done in a prostatectomy-like configuration. In the pediatric population, this would be comparable to positioning and port placement for bilateral vesicoureteral reimplantations. A transmesenteric approach was utilized for endopyelotomy and subsequent pyelolithotomy thus avoiding mobilization of the colon and its increased operative time and potential risk for injury (22, 25).

Ureterolithiasis

RALS-UL is also helpful in the setting of complex ureteral calculi and prior surgical interventions. It's use in the upper urinary tract with good outcomes has been previously reported (41). In 2015 Olvera-Posada et al. (3) reported the case of a 66-year-old female with a history of recurrent ureterolithiasis, recurrent urinary tract infections (UTIs), two large obstructing right proximal ureteral calculi, and a right split renal function of 37%. Despite a remote successful ureteroscopy in the past on that same kidney, the patient underwent failed attempts at antegrade or retrograde access to the stone in this instance; partially due to ureteral tortuosity and significant inflammatory changes. She underwent robotic assisted ureteropyelostomy for the stone removal followed by pyeloplasty for closure. At 1-year follow up renogram the right renal function was 42% and there was good drainage. Likewise, RALS-UL has been performed successfully in the lower ureters. In 2013 Dogra et al. (4) published outcomes on 16 patients (mean age 27) treated with robotic-assisted distal ureterolithotomies for impacted stones over 2 cm in size. Their mean operative time was 45.3 min with a mean console time of 20.3 min, which was significantly shorter when compared with a traditional endoscopic approach. Additionally, they demonstrated greater clearance rates and a lower incidence of complications compared to URS. Of note, all patients underwent urethral catheterization, intraperitoneal ureteral stenting, and placement of intraperitoneal drain. The drain was removed on postoperative day (POD) 1 and the Foley on POD 2, with the ureteral stents removed around 4 weeks later.

Robotic Anthropic Nephrolithotomy

Open anatrophic nephrolithotomy is done now rarely despite its high rate of stone clearance due to the morbidity of the procedure. In the majority, the laparoscopic method has been performed with warm ischemia, due to the difficulties achieving renal icing intraperitoneally (24). This modality is not ideal for preservation of renal function. Sotelo (42) was the first to report a case of robotic-assisted anatrophic nephrolithotomy (RANL). This was done via video submission and it was not available for viewing at this time. They reported implementation of vascular control with early unclamping and controlled hypotension. Like in the laparoscopic approach, warm ischemia was replicated with a time of 26 min. The patient required intraoperative blood transfusion, a residual 1 cm stone was later identified, and furosemide renogram showed 10% renal function loss at 1 month of follow up. In 2013, using their practice with cold ischemia for partial nephrectomies, Ghani et al. (24) then reported their experience performing RANL on three patients. They described their technique which includes initial cystoscopic placement of a JJ ureteral stent and the patient is then placed in a traditional flank position. Port placement includes a gel port placed in the midline, with a camera and assistant port through it, two more robotic arm ports and an additional assistant port. Renal hypothermia was achieved with ice slush which was introduced through the gel port. Following this, Mannitol was administered, and the hilum was clamped. The incision was made through the avascular plane and after nephrolithotomy, the collecting system was closed with monofilament suture and running barbed suture was used for the renal parenchyma. The mean cold ischemia time was 57 min. The authors achieved a stone-free rate of 33%, with intraoperative knowledge that 2 of the 3 patients had incomplete stone clearance, despite having used intraoperative ultrasonography. These 2 patients required PCNL to remove the residual calculi. One patient had a drain placed as a nephrostomy tube for drainage of pyonephrosis at the time of stone removal. There were no complications including no need for blood transfusion. Renal function preservation was corroborated upon follow up based on creatinine clearance. Another study of RANL in 2014 was performed by King et al. (26) on 7 patients, 5 with complete staghorn calculi. The mean warm ischemia time was 35 min. They demonstrated a 29% stone-free rate with minimal hospital length of stay and few post-operative complications, including a blood transfusion and continuous bladder irrigation in one patient for hematuria. Although these studies failed to demonstrate significant stone-free rates as compared to the open technique, both studies highlight the successful debulking of large staghorn stones in a traditionally difficult to manage population and with improved morbidity. Also, further research needs to be done to determine if there is a significant long-term difference in renal function with regards to the use of cold vs. warm ischemia. Another advantage of performing this surgery robotically, is the application of intraoperative near infrared fluorescence (NIRF) with indocyanine green (ICG) dye. Although not performed in humans, NIRF has been assessed in porcine models to detect the avascular renal plane for proper demarcation of the site of nephrolithotomy (43). Madi et al. (20) described their use of NIRF intraoperative to assess if there is any residual renal perfusion after vascular clamping perhaps from an accessory or unclamped vessel. They do not mention if a dose of ICG was given before obtaining vascular control for use on the kidney to identify the avascular plane.

CONCLUSION

Minimally invasive management of stones in general has evolved in the last few decades.

Although URS, RIRS, ESWL, and PCNL are still first line treatment in the management of pediatric and adult urolithiasis, RALS-UL has been demonstrated to be safe, effective, and with high stone-free rates in some specific cases. Although all authors stated encouraging results, no study compared the robotic approach to first-line minimally-invasive surgery. RALS-UL is a viable option for patients in whom the above minimally invasive techniques are not applicable or in circumstances where their use is hampered: complex urinary tract calculi, failed prior procedures, or abnormal genitourinary anatomy. Furthermore, concomitant RALS-UL can be performed when other reconstructive interventions are planned. For example, RALP + P should constitute the first choice of treatment for concomitant renal stones and UPJO. The use of flexible URS aids in localizing and extracting stone burden. We have successfully performed RALS-UL at our institution and though the pediatric literature is scarce, this area continues to be one that needs further research.

AUTHOR CONTRIBUTIONS

NB and ZS contributed to the conception and design of the study. NB, GR, and PG contributed to database acquisition and analysis. NB and ZS co-wrote the first drafts of the manuscript. PM, PG, and MC wrote sections of the manuscript. All authors contributed to manuscript revision, read and approved the submitted version, and agree to be accountable for all aspects of the work.

ACKNOWLEDGMENTS

We are grateful to all the personnel that was involved in the medical and surgical treatment of these patients.

REFERENCES

1. Müller PF, Schlager D, Hein S, Bach C, Miernik A, Schoeb DS. Robotic stone surgery—Current state and future prospects: a systematic review. *Arab J Urol*. (2018) 16:357–64. doi: 10.1016/j.aju.2017.09.004
2. Humphreys MR. The emerging role of robotics and laparoscopy in stone disease. *Urol Clin North Am*. (2013) 40:115–28. doi: 10.1016/j.ucl.2012.09.005
3. Olvera-Posada D, Dion M, Alenezi H, Razvi H, Pautler SE. Robotic proximal ureteropyelostomy after unsuccessful endourologic management of complicated proximal ureteral stone disease. *J Endourol Case Rep*. (2015) 1:30–2. doi: 10.1089/cren.2015.29012.dop
4. Dogra PN, Regmi SK, Singh P, Saini AK, Nayak B. Lower ureteral stonesrevisited: expanding the horizons of robotics. *Urology*. (2013) 82:95–9. doi: 10.1016/j.urology.2013.02.059
5. Nayyar R, Singh P, Gupta NP. Robot-assisted laparoscopic pyeloplasty withstone removal in an ectopic pelvic kidney. *JSLS*. (2010) 14:130–2. doi: 10.4293/108680810X12674612015102
6. Gaur DD, Trivedi S, Prabhudesai MR, Madhusudhana HR, Gopichand M. Laparoscopicureterolithotomy: technical considerations and long-term follow-up. *BJU Int*. (2002) 89:339–43. doi: 10.1046/j.1464-4096.2001.01562.x
7. Siddiqui KM, Albala DM. Robotic-assisted surgery and treatment of urolithiasis. *Int J Surg*. (2016) 36 (Pt D):673–5. doi: 10.1016/j.ijsu.2016.11.031
8. Hwang K, Mason MD, Peters CA. Clinical practice: surgical approaches to urolithiasis in children. *Eur J Pediatrics*. (2011) 170:681–8. doi: 10.1007/s00431-010-1373-6
9. Aydogdu O, Karakose A, Celik O, Atesci YZ. Recent management of urinary stone disease in a pediatric population. *World J Clin Pediatrics*. (2014) 3:1–5. doi: 10.5409/wjcp.v3.i1.1
10. Lee RS, Passerotti CC, Cendron M, Estrada CR, Borer JG, Peters CA. Early results of robot assisted laparoscopic lithotomy in adolescents. *J Urol*. (2007) 177:2306–9; discussion 2309–10. doi: 10.1016/j.juro.2007.01.178
11. Assimos D, Krambeck A, Miller NL, Monga M, Murad MH, Nelson CP, et al. Surgical management of stones: American Urological Association/Endourological Society Guideline, Part I. *J Urol*. (2016) 196:1153–60. doi: 10.1016/j.juro.2016.05.090
12. Assimos D, Krambeck A, Miller NL, Monga M, Murad MH, Nelson CP, et al. Surgical management of stones: American Urological Association/Endourological Society Guideline, Part II. *J Urol*. (2016) 196:1161–9. doi: 10.1016/j.juro.2016.05.091
13. Radmayr C, Bogaert G, Dogan HS, Kocvara R, Nijman JM, Stein R, Tekgul S, et al. *European Association of Urology Guidelines on Paediatric Urology: Urinary Stone Disease*. (2018). Available online at: https://uroweb.org/guideline/paediatric-urology/#3_14 (accessed April 8, 2019).
14. Pedro RN, Buchholz N. Laparoscopic and robotic surgery for stone disease. *Urolithiasis*. (2018) 46:125–7. doi: 10.1007/s00240-017-1014-x
15. Wickham JE. The surgical treatment of renal lithiasis. In: Wickham JE, editor. *Urinary Calculous Disease*. Edinburg: Churchill Livingstone (1979).
16. Gaur DD, Agarwal DK, Purohit KC, Darshane AS. Retroperitoneal laparoscopic pyelolithotomy. *J Urol*. (1994) 151:927–9. doi: 10.1016/S0022-5347(17)35124-8
17. Singh V, Sinha RJ, Gupta DK, Pandey M. Prospective randomized comparison of retroperitoneoscopic pyelolithotomy versus percutaneous nephrolithotomy for solitary large pelvic kidney stones. *Urol Int*. (2014) 92:392–5. doi: 10.1159/000353973
18. Kumar A, Vasudeva P, Nanda B, Kumar N, Jha SK, Singh H. A prospective randomized comparison between laparoscopic ureterolithotomy and semirigid ureteroscopy for upper ureteral stones >2 cm: a single-center experience. *J Endourol*. (2015) 29:1248–52. doi: 10.1089/end.2013.0791
19. Atug F, Castle EP, Burgess SV, Thomas R. Concomitant management of renalcalculi and pelvi-ureteric junction obstruction with robotic laparoscopicsurgery. *BJU Int*. (2005) 96:1365–8. doi: 10.1111/j.1464-410X.2005.05819.x
20. Madi R, Hemal A. Robotic pyelolithotomy, extended pyelolithotomy,nephrolithotomy, and anatrophic nephrolithotomy. *J Endourol*. (2018) 32:S73–81. doi: 10.1089/end.2017.0718
21. Meggiato L, Cattaneo F, Zattoni F, Dal Moro F, Beltrami P, Zattoni F. Complex cystine kidney stones treated with combined robot-assisted laparoscopicpyelolithotomy and intraoperative renoscopy. *Urologia*. (2018) 85:76–8. doi: 10.5301/uro.5000215
22. Al-Yousef R, Almarzouq A, Aldousari S. Robotic pyelolithotomy in a congenital pelvic kidney: side docking and robotic prostatectomy port - site approach. *Int Braz J Urol*. (2017) 43:374. doi: 10.1590/s1677-5538.ibju.2016.0059
23. Ghani KR, Trinh QD, Jeong W, Friedman A, Lakshmanan Y, Omenon M, et al. Robotic nephrolithotomy and pyelolithotomy with utilization of the roboticultrasound probe. *Int Braz J Urol*. (2014) 40:125–6; discussion 126. doi: 10.1590/S1677-5538.IBJU.2014.01.19
24. Ghani KR, Rogers CG, Sood A, Kumar R, Ehlert M, Jeong W, et al. Robot-assisted anatrophic nephrolithotomy with renal hypothermia for managing staghorn calculi. *J Endourol*. (2013) 27:1393–8. doi: 10.1089/end.2013.0266
25. Rajiv Y, Kumar A, Poonam Y. Bilateral simultaneous robot-assistedpyelolithotomy for large (>6 cm) kidney stones: technique and review ofliterature. *J Robot Surg*. (2015) 9:263–6. doi: 10.1007/s11701-015-0524-1
26. King SA, Klaassen Z, Madi R. Robot-assisted anatrophic nephrolithotomy: description of technique and early results. *J Endourol*. (2014) 28:325–9. doi: 10.1089/end.2013.0597
27. Zheng J, Yan J, Zhou Z, Chen Z, Li X, Pan J, et al. Concomitant treatment ofureteropelvic junction obstruction and renal calculi with robotic laparoscopicsurgery and rigid nephroscopy. *Urology*. (2014) 83:237–42. doi: 10.1016/j.urology.2013.08.008
28. FDA. *FDA Drug Safety Communication: FDA Review Results in New Warnings about Using General Anesthetics and Sedation Drugs in Young Children and Pregnant Women*. Available online at: https://Www.Fda.Gov/Drugs/Drugsafety/Ucm532356.Htm (accessed April 8, 2019).
29. FDA. *FDA Drug Safety Communication: FDA Approves Label Changes for Use of General Anesthetic and Sedation Drugs in Young Children*. https://www.fda.gov/Drugs/DrugSafety/ucm554634.htm (accessed April 8, 2019).
30. Jensen PH, Berg KD, Azawi NH. Robot-assisted pyeloplasty and pyelolithotomy inpatients with ureteropelvic junction stenosis. *Scand J Urol*. (2017) 51:323–8. doi: 10.1080/21681805.2017.1300188
31. Mufarrij PW, Woods M, Shah OD, Palese MA, Berger AD, Thomas R, et al. Robotic dismembered pyeloplasty: a 6-year, multi-institutional experience. *J Urol*. (2008) 180:1391–6. doi: 10.1016/j.juro.2008.06.024
32. Badani KK, Hemal AK, Fumo M, Kaul S, Shrivastava A, Rajendram AK, et al. Robotic extended pyelolithotomy for treatment of renal calculi: a feasibility study. *World J Urol*. (2006) 24:198–201. doi: 10.1007/s00345-006-0099-6
33. Nayyar R, Wadhwa P, Hemal AK. Pure robotic extended pyelolithotomy: cosmeticreplica of open surgery. *J Robot Surg*. (2007) 1:207–11. doi: 10.1007/s11701-007-0039-5
34. Sotelo R, Astigueta JC, Giedelman C, de Andrade R, Carmona O, Ramirez D, et al. Robotic extended pyelolithotomy for complete staghorn calculus. *J Robot Surg*. (2010) 4:99–102. doi: 10.1007/s11701-010-0192-0
35. Manny TB, Manny JS, Hemal AK. Transmesocolic robotic extended pyelolithotomyof a large gas-containing renal stone: case report and review of the literature. *Urol Ann*. (2013) 5:126–8. doi: 10.4103/0974-7796.110015
36. Swearingen R, Sood A, Madi R, Klaassen Z, Badani K, Elder JS, et al. Zero-fragment nephrolithotomy: a multi-center evaluation of robotic pyelolithotomy and nephrolithotomy for treating renal stones. *Eur Urol*. (2017) 72:1014–21. doi: 10.1016/j.eururo.2016.10.021
37. Torricelli FC, Batista LT, Colombo JR Jr, Coelho RF. Robotic-assistedlaparoscopic management of a caliceal diverticular calculus. *BMJ Case Rep*. (2014) 2014:bcr2014205437. doi: 10.1136/bcr-2014-205437
38. Koopman SG, Fuchs G. Management of stones associated with intrarenal stenosis: infundibular stenosis and caliceal diverticulum. *J Endourol*. (2013) 27: 1546–50. doi: 10.1089/end.2013.0186
39. Verbrugghe A, Gaillandre L, Mouton D, Deschildre F, Koenig P, Ballereau C, et al. Robot-assisted laparoscopic management of caliceal diverticular calculi. *Urol Case Rep*. (2017) 13:133–6. doi: 10.1016/j.eucr.2017.04.004

40. Kumar S, Bishnoi K, Panwar VK, Kumar A, Sharma MK. Stone in ectopic pelvicpancake kidney: a surgical challenge overcome by robotic surgery. *J Robot Surg*. (2018) 12:181–3. doi: 10.1007/s11701-017-0704-2
41. Hemal AK, Nayyar R, Gupta NP, Dorairajan LN. Experience with robotic assisted laparoscopic surgery in upper tract urolithiasis. *Can J Urol*. (2010) 17:5299–305.
42. Sotelo R. Robotic assisted laparoscopic anatrophic nephrolithotomy: first case report. J Endourol (2012) 26:P1–572. doi: 10.1016/S1569-9056(13)61621-8
43. Sood A, Hemal AK, Assimos DG, Peabody JO, Menon M, Ghani KR. Robotic anatrophic nephrolithotomy utilizing near-infrared fluorescence image-guidance: idea, development, exploration, assessment, and long-term monitoring (IDEAL) stage 0 animal model study. *Urology*. (2016) 94:117–22. doi: 10.1016/j.urology.2016.04.051

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer MG is currently organizing a research topic with one of the authors MC and confirms the absence of any other collaboration.

Advantages of publishing in Frontiers

OPEN ACCESS
Articles are free to read for greatest visibility and readership

FAST PUBLICATION
Around 90 days from submission to decision

HIGH QUALITY PEER-REVIEW
Rigorous, collaborative, and constructive peer-review

TRANSPARENT PEER-REVIEW
Editors and reviewers acknowledged by name on published articles

Frontiers
Avenue du Tribunal-Fédéral 34
1005 Lausanne | Switzerland

Visit us: www.frontiersin.org
Contact us: info@frontiersin.org | +41 21 510 17 00

REPRODUCIBILITY OF RESEARCH
Support open data and methods to enhance research reproducibility

DIGITAL PUBLISHING
Articles designed for optimal readership across devices

FOLLOW US
@frontiersin

IMPACT METRICS
Advanced article metrics track visibility across digital media

EXTENSIVE PROMOTION
Marketing and promotion of impactful research

LOOP RESEARCH NETWORK
Our network increases your article's readership