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Single-Site Laparoscopy and Robotic Surgery in Pediatric Urology

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Abstract

Purpose of Review In this review, we summarize research that has evaluated the role of laparoendoscopic single-site (LESS) and robotic surgery in pediatric urology, highlighting new and/or controversial ideas.

Recent Findings The newest research developments over the last several years are studies that address generalizability of these techniques, ideal patient factors, extrapolation to more complex surgeries, and comparative studies to more traditional techniques to define the associated costs and benefits, as well as patient-centered outcomes. Specifically in the field of LESS, addressing the limitations of suboptimal vision, instrument crowding, and loss of triangulation have been a focus. The literature is now replete with new applications for robotic surgery as well as descriptions of the specific technical challenges inherent to pediatrics.

Summary Robotic surgery and LESS are areas of growth in pediatric urology that allow continual innovation and expansion of technology within a surgeon's armamentarium.

Keywords Pediatric urology · Laparoendoscopic single-site surgery · Robotic surgery · LESS

Laparoendoscopic Single-Site (LESS) Surgery

Introduction

Laparoendoscopic single-site (LESS) surgery has now been reported in the pediatric urology population for roughly 10 years since the first case reports were published on LESS varicocelectomy and nephrectomy [1, 2]. In the first 5 years after these reports, several institutions published series focused on varicocelectomy, orchiopexy, and extirpative procedures such as simple nephrectomy to demonstrate equivalency with open and traditional laparoscopy in terms of safety, efficacy, and operative time [3–5]. Pyeloplasty was reported in select series but few other reconstructive procedures have been described [6•]. An experienced laparoscopic surgeon can consider LESS as a viable and safe option for surgeries that include hernia repair, gonadectomy, varicocelectomy, orchiopexy, urachal cyst excision, renal cyst ablation, nephrectomy/nephroureterectomy, and heminephrectomy.

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LESS Inguinal Hernia Repair

A multitude of techniques have been described for laparoscopic inguinal hernia repair in the pediatric surgery and urology literature, including LESS, with an overall recurrence rate cited around 4% [7]. The extraperitoneal approach (also described often as single-site laparoscopic percutaneous extraperitoneal closure, or SLPEC) is an established technique and the subject of a recent meta-analysis finding 51 studies with a total of 11,815 patients [8]. This technique involves placing an encirclage suture around the internal ring under laparoscopic guidance and cinching it tight. Recently, it has been suggested that the use of non-absorbable suture greatly reduced the incidence of recurrence compared to absorbable (0.5–4 vs. 19–26%) [8, 9]. This technique has a comparable success rate to open and enjoys widespread use, with the downside that involvement of the extraperitoneal space in the ligature creates the potential for suture granuloma, skin puckering, and/or postoperative pain from involving the nerves and muscles in these layers [10, 11].

Intraperitoneal LESS hernia repair has been described with slight variations as well, the main difference being whether the patent processus is disconnected then the peritoneum closed, or if the ring is simply closed with a purse string. The recently described T-LESS (two-port) procedure utilizes a camera port and closely placed second port in the umbilicus, instead of a multi-channel port, and passes a

suture percutaneously in order to laparoscopically perform a purse-string closure [12]. In contrast, LESS can be performed using the conventional laparoscopic peritoneal leaflet method described by Giseke in 2010 in 525 hernia repairs with a 1% recurrence rate [13]. The transperitoneal division of the hernia sac followed by purse-string closure, with regular suture or alternately a V-lock barbed suture to negate the need for knot-tying, most closely mimics the open repair while allowing for a minimally invasive approach [14]. A prospective randomized controlled study of conventional laparoscopy in hernia repair from Egypt of 132 males addressed the question of leaving the sac intact and found not surprisingly that the group with division of the sac had a slightly longer operative time (27.68 ± 2.58 vs. 20.42 ± 1.78 min for unilateral cases), however had no recurrences vs. two cases (2.6%) in the group where only purse-string suture was performed [15]. In our experience, LESS hernia repair with division of the patent processus and closure with V-lock suture has provided the most durable long-term results [16] (Fig. 1).

LESS Varicocelectomy and Gonadectomy

Varicocele was another early adopted procedure amenable to LESS and thus far 60 cases have been reported [17, 18]. LESS varicocelectomy is performed transperitoneally, and in a 2016 systematic review, the mean operative time of 52 cases was 38.3 min, with one complication reported (1.7%; hydrocele requiring secondary procedure) [17]. Gonadectomy has been performed in cases of Turners syndrome with Y-mosaicism, as well as for other indications [19, 20]. We now routinely use single-site laparoscopic approach for gonadectomy at our institution.

LESS Nephrectomy and Nephroureterectomy

The use of LESS for renal extirpative surgery has seen an increase in total reported cases over the last decade. Gor et al. published a multi-institutional retrospective study involving three surgeons in which almost all procedures were extirpative aside from two Malone antegrade continence enemas. With a median age of 5 years, 41 of a total 59 patients underwent nephrectomy or nephroureterectomy with acceptable OR times and two complications (port site hernia and superficial wound infection) [19]. A systematic review of LESS nephrectomy summarized studies with a cumulative 165 patients who underwent transperitoneal nephrectomy and 19 patients retroperitoneal (RP) nephrectomy/nephroureterectomy [17]. All cases of partial nephrectomy were performed transperitoneal. No RP cases required an additional port, the size of incision ranged from 1.1 to 2.5 cm, and the procedure length ranged from 50 to 90 min.

LESS Reconstructive Procedures

Single-site surgery is thus not limited to transperitoneal surgery, and in particular, a retroperitoneal (RP) approach may be employed or preferred for kidney surgery given the advantages of direct access to the UPJ and eliminating any theoretical peritoneal complications. Pyeloplasty is a candidate procedure for an RP LESS approach; however, with the inherent limitations of smaller working space and an already technically challenging surgery laparoscopically, pushing this further to a single-site approach is controversial [21]. Perhaps combating the idea of smaller space as limiting, Badawy et al. reviewed 15 patients less than 2 years old who underwent conventional retroperitoneoscopic pyeloplasty. Their conversion rate

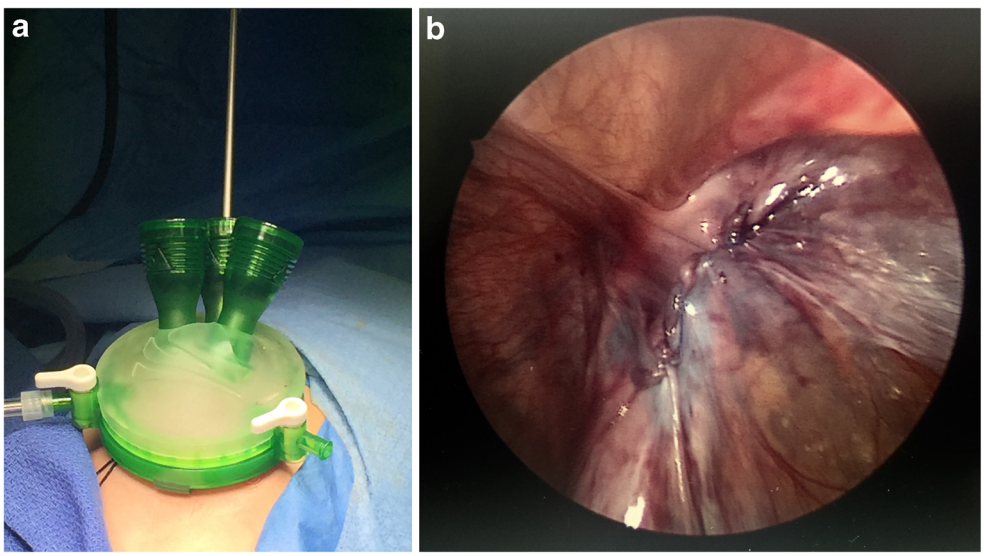

Fig. 1 **a** Gelport for single-site hernia repair. **b** Intraoperative view of peritoneal leaflet procedure for hernia repair

to open was 20% ($n = 3$), for too narrow a space or peritoneal violation, but all three patients were < 3 months old; no statistically significant difference was found for gender or side [22]. To date, Blanc has published the largest series of conventional laparoscopic RP pediatric pyeloplasties at a teaching hospital; a major point of which was the long learning curve which they estimated to be roughly 30 cases [21]. Thus, it could be argued that the learning curve for RP LESS pyeloplasty will no doubt be much longer.

Whether LESS has room for expansion into other reconstructive surgeries and whether this necessitates use of different or more advanced instrumentation remain to be seen. Gor et al. reported two Malone antegrade continence enema (MACE) in their series with a median operative time of 119 min; to the best of our knowledge, this is the first report [19]. Despite scattered ureteral cases in adults, no reports of pediatric LESS ureteral reimplantation or ureteroureterostomy exist in the literature [23, 24].

Advantages of LESS Surgery

A standard explanation for migration towards minimally invasive surgery (MIS) is in part cosmetic outcomes. In general, the umbilical incision for a transperitoneal LESS procedure in pediatrics is described as anywhere between 1 and 2.5 cm within the umbilicus, depending on the port that is used [19, 25, 26]. At our institution, we have found that the GelPoint Mini (Applied Medical) is suitable for a 1.5-cm incision and can accommodate 5–12-mm instruments. The ability to hide the scar within the umbilicus as opposed to a flank incision has led some authors to conclude that cosmesis is improved with the transperitoneal approach, although objective assessments and patient-centered outcomes have yet to be done [25]. If one of the main drivers of single-site surgery is cosmesis, however, then it would naturally follow that this could be an important factor in choosing transperitoneal versus RP access that would not be hidden.

Another argument in support of LESS surgery aside from cosmesis is that reducing the number of ports will in turn reduce the opportunity for port site complications. Within the pediatric urology literature, the risk of port site hernia is 3.2%, and limiting the sites to one central port with a capacious incision that facilitates vision for closure could theoretically decrease this risk though no studies have addressed this risk comparatively [19].

There are few patient factors that are prohibitive for LESS procedures, aside from established conventional laparoscopic principles of candidacy. The lower age limit of safely performing LESS has been proposed to be 3 years due to the port apparatus; however, numerous reports of patients as young as 2.5 months safely undergoing LESS are in the literature [4, 25, 27].

Recent Innovations

In pediatric urology, LESS technology has certainly advanced from the earliest descriptions of the technique, such as the series by Ham et al. who reported outcomes of 6 patients using a homemade port consisting of a sterile glove through which conventional ports were placed [28]. Currently, there are a large number of commercially available ports and instruments [3, 27]. Our experience has been with the GelPoint and GelPoint mini (Applied Medical) ports, which allow for adequate visualization and instrument spacing using conventional laparoscopic nonarticulating instruments.

Innovation in minimally invasive surgery has come from both device manufacturers and surgeons. Adapting the idea of a single port through the umbilicus, Chiang et al. described a new multi-port technique that utilizes the central theme of an umbilical incision for a central trocar but incorporates adjacent fascial stab incisions for a grasper and telescope. The authors make the case that most LESS procedures (outside of nephrectomy owing to the multiple exchanges of instruments) can be done using this technique with no compromise on cosmetic outcome [29].

Just as port type and placement have been described in various ways, instrumentation is starting to be defined. Articulating instruments are available at the 5-mm size; however, in the vast majority of pediatric urology reviews, standard laparoscopic instrumentation is used for LESS without the addition of articulating or disposable instruments [29, 30]. To date, there is little literature on the cost-effectiveness of LESS as compared to traditional laparoscopy, which would be affected not only by disposable costs but also by operative time [6•, 31]. Over the last several years, many new instruments have been developed and come on the market to help overcome the difficulties of LESS, namely instrument clashing, vision, and difficulty with suturing [32]. Given the cost of robotic surgery and the perceived limited ability of LESS in regard to more complex cases, perhaps there is a role to incorporate the use of articulating instruments and future innovative tools.

Limitations

Intuitively, LESS surgery is an ideal method for extirpative surgery as a single larger incision can be used for specimen extraction yet still provide excellent cosmesis. However, its expansion to and regular use in reconstructive surgery is more controversial. Pyeloplasty was reported early in the LESS literature; however, there have been few comparative studies since then addressing its role versus traditional laparoscopy and robotics [33].

Perhaps one of the most important limiting factors in more generalized LESS adoption is a thorough understanding of the learning curve for these procedures. A steep learning curve is cited for various adult LESS urologic studies, and indeed, the

EAU 2013 guidelines for single-site laparoscopic surgery recommended only expert laparoscopic surgeons perform these surgeries [34]. In experienced hands, Abdel-Karim et al. found at least 30 LESS procedures were required to achieve professional competence in adult patients (the majority upper urinary tract procedures and transperitoneal) [4]. To date, there are no robust learning curve papers in the pediatric urologic LESS literature.

Robotics in Pediatric Urology

Introduction

Robotic surgery has rapidly evolved over the last few decades to become an integral part of pediatric urologic practice and in some cases has evolved to be a new gold standard (e.g., robotic pyeloplasty) [35]. Most of the early literature that naturally followed are technique descriptions; however, there has now been an exponential increase in studies that support the robotic platform, most notably for robotic pyeloplasty (RALP). In addition, studies have been conducted that explore the advantages and potential risks of robotic surgery, as in extravesical reimplantation (RALUR), and descriptions of techniques for more advanced reconstructive procedures such as robotic ureteroureterostomies (R-UU) and lower urinary tract reconstruction.

The described advantages of robotic surgery in pediatric urology include a dual-channel telescope that provides a magnified and high-definition three-dimensional image, tremor control, and allowance of delicate maneuvers and many degrees of "wrist" freedom that are generally not possible with laparoscopy. Pediatric robotic cases, as a generality, will involve a smaller working space than adult which may lead to instrument interference and require careful port site considerations. The use of 5-mm ports and instrumentation has eased this burden and also allowed for even better cosmesis in younger patients [36].

Commonly described disadvantages of robotics are higher cost and longer operative time. While likely multifactorial, many authors are now suggesting technical modifications or nuances to chip away at operative time. A reduction in surgical fog with a warm humidified gas management protocol was recently described and shortened the operative time in 26 patients undergoing a variety of robotic procedures [37]. The learning curve in robotics is also a target for reducing operative time; however, most graduating residents and fellows will now have had robotics training and one study showed that fellowship-trained surgeons can quickly attain competency within established robotic surgical programs [38].

Cosmesis in Robotic Surgery Cosmesis was assumed to be better in the early years of robotics given the smaller nature of the incisions, but robust unbiased studies of pediatric patients with true patient- and parent-reported outcomes have been elusive. Barbosa et al. found that robotic scars were perceived as cosmetically superior to open scars, and this was a highly relevant factor affecting patient and parent decisions [39]. This preference was more pronounced for robotic bladder augmentation and RALUR. In an attempt to improve upon cosmetic outcomes further, Gargollo employed the hidden incision endoscopic surgery (HIdES) trocar placement for RALP in 29 patients [40]. By placing two port sites at the level of a Pfannenstiel incision and the third within the umbilicus, this technique is purported to have improved satisfaction with cosmetic outcome by patients and parents. A larger study was recently performed by Hong et al. directly comparing outcomes of traditional port placement and HIdES for RALP and found that outcomes at a median follow-up of 42 months, including length of surgical time and postoperative complications, were not compromised [41].

Age in Robotic Surgery

In particular, age becomes an important consideration as robotic surgery was initially thought to be only appropriate for older children. This idea has been challenged by several series for patients aged < 12 months. Bansal et al. reviewed 10 infants (8 RALP, 2 R-UU) with an age range of 3–12 months old, found there were no intraoperative complications, and concluded that robotic upper urinary tract reconstruction is technically feasible and safe in this age group [42]. Expanding upon this, Avery et al. performed a retrospective review across multiple institutions of infant RALP, the largest published series at 60 patients operated on by 6 experienced robotic surgeons. They found a 91% success rate and an 11% complication rate, equivalent to modern series, and concluded that infant RALP is safe and efficacious [43]. However, no prospective randomized comparisons exist in the literature to show equivalent outcomes in this age group [44].

Specific Procedures

Innovation abounds in robotic surgery with continual expansion of its application, including reports on pediatric retroperitoneal lymph node dissection, renal transplant ureteral reconstruction, and redo RALP with buccal mucosa graft for recurrent UPJO with significant fibrosis or stricture [45–47].

Robotic Pyeloplasty

The most robust data for efficacy and safety is undeniably in RALP, which is the most commonly performed robotic surgery in pediatric urology. The earliest surgery to be described

as the most suitable to robotic technology, its success has been replicated in multiple large multicenter studies [35, 48, 49]. The success rate is > 90% and has reached equivalence with open, and many consider RALP to now be the gold standard for surgical reconstruction of UPJ obstruction [35, 50]. Indeed, there has been a trend towards minimally invasive pyeloplasty and away from open surgery in national database studies [51, 52]. Chan et al. found using a University Health Consortium of 102 academic institutions, there was a trend away from laparoscopic pyeloplasty and towards RALP; and of the 633 RALP cases, the mean patient age had decreased significantly [48]. RALP also appears to be safe and often the preferred choice for reoperative pyeloplasty, with acceptable operative times, lengths of stay, and complication rates [53, 54]. At our institution, reoperative pyeloplasty is performed robotically, allowing identification of crossing vessels and giving maximal exposure.

Ureteral Reimplantation

A more controversial use of robotic surgery is in ureteral reimplantation with wide-ranging reported success rates for robotic extravesical ureteral reimplant (RALUR). Despite the controversy in the literature, RALUR is a technique that appears to be gaining traction according to national databases such as the HCUP Kids Inpatient Database (KID), showing that although the total number of ureteral reimplantations had decreased from 2000 to 2012 by 14.3%, the proportion performed in a minimally invasive fashion increased from 0.6 to 6.3% with the vast majority being robotic (81.2%) [55]. However, there are conflicting data in the literature regarding safety and efficacy as compared to the open procedure, with most available literature coming from small, single-institution series. A recent comparative analysis addressed voiding dysfunction following bilateral RALUR and found that it was not associated with an increased risk of postoperative urinary retention compared to unilateral surgery [56]. Regarding efficacy, a 2015 multi-institutional retrospective review of 61 patients (93 ureters) found a 72% success rate at a mean follow-up of 11.7 months with six complications (10%) [57•]. Subsequently, a 2017 multi-institutional study combining data from nine academic centers found that of 280 ureters (170 patients) with available postoperative dynamic imaging, 87.9% demonstrated radiographic resolution. There were 25 complications overall (9.6%) and four patients (3.9%) with transient urinary retention following bilateral RALUR [58]. Given these findings that do fall slightly short of the gold standard, continued attempts to refine specific techniques and patient factors associated with success are critical.

Dismembered ureteral reimplants for UVJ obstruction and bladder diverticula can also be performed robotically [59]. Different techniques have been described and surgeons have various methods for performing intracorporeal ureteral tailoring and a tunneled reimplantation [60, 61].

Ureteroureterostomy and Heminephrectomy

The initial literature for R-UU and robotic heminephrectomy (RHN) was limited to a handful of case reports and technique descriptions; however, in the last 3 years, several larger series and retrospective comparative analyses have been published, importantly attempting to establish safety and efficacy [62–64]. R-UU appears to have equivocal mean operative times and complication rates as open, and in comparing R-UU to RHN, although RHN may carry a small risk of lower pole function loss, both have similar overall complications rates [63, 64]. Malik et al. reported on RHN as compared to open and laparoscopic series and found that mean renal function loss in RHN was 2.6% in 7 patients, with 1 patient experiencing loss over 10% [65]. An interesting addition to the robotic repertoire is selective arterial mapping with indocyanine green (ICG)-induced near-infrared fluorescence (NIRF) using Firefly TM infrared system on the da Vinci to aid in dissection and separation of duplex parenchyma [66]. The hope is that use of this technology will allow for more accurate surgical technique and further limit damage to normal parenchyma.

Lower Urinary Tract Reconstruction

Robotic appendicovesicostomy (APV) creation has become increasingly popular, and just recently, a few important studies have been published to bolster the literature. A multicenter retrospective study of 88 patients characterized functional and perioperative outcomes—short-term complications occurred in 29.5% of patients (most commonly ileus) and 12.5% required eventual APV revision with an 85.2% initial continence rate [67]. In a comparison of 28 open and 39 robotic APVs at a single institution, the authors found no significant difference in 30-day complications or reoperations (33 vs. 29%) at a mean of 2.7 years follow-up [68]. One interesting difference to note is that the reasons for reoperation differed—robotic APV patients were more likely to be revised due to incontinence versus stomal prolapse or stenosis in the open group. The reason behind this is unclear, although the authors speculate it is related to tunnel length [68].

Studies in other areas of pediatric robotic complex reconstruction are extremely limited, though. Robotic intracorporeal enterocystoplasty remains a challenging but feasible operation and the literature contains technique descriptions and case series, often as part of APV series [69, 70]. Similarly, bladder neck (BN) reconstruction has had a dearth of robust studies following initial descriptions in 2008, with one large single-institution series of 38 patients undergoing robotic APV with concomitant Mitchell/

Leadbetter BN reconstruction and bladder neck sling, showing feasibility [71–73].

Conclusions and Future Directions

Both LESS and robotic surgery have seen an expansion in the last decade, fueled by advances in technology and innovation to push surgical limits. Advanced instrumentation may come in the form of robotic laparoendoscopic single-site (R-LESS) surgery. Proponents of R-LESS tout improved cosmesis and reduced incidence of postoperative complications such as incisional hernias, as well as the enhancements in optics and ergonomics that have addressed previous deficits in single-site surgery [74]. The first urologic report of R-LESS was in 2009 describing three adult patients and thus far the pediatric literature is sparse [75]. The introduction of the endowrist da Vinci technology in 2015 to further ease difficulties with triangulation for surgeries with extensive suturing has the potential to increase utilization [74].

Compliance with Ethical Standards

Conflict of Interest Diana K. Bowen, Jason P. Van Batavia, and Arun K. Srinivasan each declare no potential conflicts of interest.

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

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