Journal of Pediatric Urology (2026) 22, 105630

Original Research

Laparoscopic Mitrofanoff procedure in children: Feasibility and outcome analysis over 18 years in a single centre

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Keywords
Laparoscopy; Mitrofanoff; Appendicovesicostomy; Catheterizable conduit; Urinary diversion; Robotic surgery

Abbreviations
APV, appendicovesicostomy; CIC, clean intermittent catheterization; IQR, interquartile range; LMA, laparoscopic Mitrofanoff appendicovesicostomy; MIS, minimally invasive surgery; UPJ, ureteropelvic junction; UTI, urinary tract infection; VUDS, video-urodynamic studies; VUR, vesicoureteral reflux

Received 10 May 2025
Revised 27 September 2025
Accepted 30 September 2025
Available online 10 October 2025

Summary

Background
Since the first description procedure in 1980, the Mitrofanoff procedure involving appendicovesicostomy has become a widely adopted method for continent urinary diversion in children and adults.

Objective
This study aims to evaluate the feasibility and outcomes of employing a technically challenging minimally-invasive (MIS) approach in pediatric patients.

Study design
A retrospective analysis of the prospective institutional database was conducted (2003–2020). Patients were categorized into two cohorts: (i) those who underwent surgery before 2013 (Group 1) and (ii) those who underwent surgery after 2013 (Group 2). Prior to surgery, urodynamic studies were performed to assess bladder compliance, capacity, and detrusor activity. Outcome measures included complications, revisions, stenosis, and stomal incontinence, with the latter classified according to the Schulte-Baukloh score.

Results
A total of 29 children (Group 1, n = 15; Group 2, n = 14) with a median (IQR) age of 8 years (6–13) underwent a MIS Mitrofanoff procedure. Median (IQR) follow-up was 60 months (17–88). The procedure was completed by laparoscopy in 26 cases. Three laparoscopic surgeries were converted to an open procedure due to tearing of the bladder mucosa (n = 2) or appendix ischemia (n = 1). All conversions occurred before 2013 (p = 0.23). Median (IQR) operative time was 310 min (250–360) (295 (245–330) *vs.* 324 (273–351) min for Group 1 *vs.* Group 2, respectively; p = 0.44). Social continence was achieved in 21 patients (72 %) (n = 10/15 (67 %) *vs.* 11/14 (79 %), respectively; p = 0.68). Stomal urinary leakage was reported by nine (31 %) patients (6 (40 %) *vs.* 3 (21 %), respectively; p 0.68, no cases in robotic subgroup) of whom five (63 %) were managed successfully by hyaluronic acid/dextranomer injection and four required an open revision of the appendicovesical anastomosis (Group 1: n = 3; Group 2: n = 1). No patient developed stenosis of the catheterizable channel. One patient subsequently had a bladder augmentation. There was an improvement in outcomes with regards to continence and complications as the surgical team gained in experience: revision surgeries: Group 1 (n = 3; 20 %) *vs.* Group 2 (n = 1; 7 %) p = 0.61; conversions: Group 1 (n = 3; 20 %) *vs.* Group 2 (n = 0) (p = 0.23). The last three cases were performed robotically without any complications or conversion, and with stomal continence, in a shorter median operative time (300 min (293–330) *vs.* 338 min (245–344) laparoscopically, p = 0.70).

Conclusion
The laparoscopic Mitrofanoff procedure is a safe and feasible option in children. A trend toward improved continence and fewer revisions was observed in the later cohort, although these differences did not reach statistical significance. None of the patients developed channel stenosis. Previous pediatric literature suggests that minimally invasive approaches may offer additional benefits such as reduced postoperative pain and improved cosmetic outcomes, although these were not assessed in our series. The robotic approach was feasible in our limited experience, with no conversions and short-term continence achieved, but longer follow-up is required to draw firm conclusions.

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https://doi.org/10.1016/j.jpurol.2025.09.036

Introduction

The Mitrofanoff appendicovesicostomy was first described in 1980 and was created to provide a continent and easily catheterizable access for children with urethral disease or neurological disorders lacking to the urethral meatus [1]. The technique consists of using the appendix as a catheterizable channel, connecting the bladder to the abdominal wall. Continence is achieved by attachment of the appendix to a low-pressure urine storage reservoir through an antireflux mechanism that functions like a flap valve. The procedure can be used for isolated clean intermittent catheterization (CIC) or, depending on the patient's characteristics, combined with bladder augmentation or additional bladder surgery. Historically, the Mitrofanoff procedure has been performed by an open approach. A fully laparoscopic procedure, while technically challenging, offers several advantages, including a potentially shorter hospital stay, reduced postoperative pain by avoiding a large Pfannenstiel incision, and improved cosmetic outcomes with minimal scarring [2]. Despite the first robotic bladder augmentation with Mitrofanoff appendicovesicostomy being described in 2008, the adoption of the robotic approach has progressed slowly, largely due to the availability of robotic systems and the experience of the surgical team, in addition to the challenges posed by the small working space in children [3,4]. Moreover, few studies have analyzed the outcomes of a fully laparoscopic Mitrofanoff procedure in children, whether performed via laparoscopy or robotics, and the long-term outcomes remain unclear [4–10].

In 2015, our initial experience (2003–2013) in patients undergoing a laparoscopic Mitrofanoff appendicovesicostomy (LMA) was published [11]. Our first results were fairly disappointing, with a high rate of stoma incontinence (33 %). In the current study, we aimed to extend our series of patients until 2020 and to evaluate the feasibility and outcome over a 18-year period. We hypothesized that increased experience would enable to reduce both operative time and the complications rate.

Material and methods

Study design and patients

The study was approved by our local institutional review board.

To evaluate the indication for the Mitrofanoff procedure, bladder compliance, bladder capacity and detrusor activity were measured by urodynamic studies. All children had significant bladder dysfunction. Children were considered for a Mitrofanoff procedure when urethral catheterization was impossible due to either anatomical difficulties or refusal of the child or their parents. A Mitrofanoff channel was created using the appendix or, occasionally, the ureter in conjunction with a nephrectomy. Children with a combined bladder augmentation or by using an ileal stoma (Monti) were excluded from the study.

All patients and their parents were prepared before the surgery by the educational nurses' team, using simulating tools (dolls) or by meeting families who had previously had a Mitrofanoff procedure.

Surgical procedure

Patients were placed in the supine position and a urinary catheter was placed in the sterile field.

Laparoscopic approach. A transperitoneal approach with four trocars and a 30° downwards pointing camera was used. A 5-mm laparoscopic camera port was used which was placed via an open technique on the midline half way between the xiphoid and the umbilicus. Three additional ports were placed respectively in the right subcostal region, the left lower quadrant and the right lower quadrant. The appendix was first exposed and ligated at its base (2/0 absorbable, braided suture) under preservation of the vascular supply. For its implantation into the bladder, the patient was placed in a Trendelenburg position and the bladder was filled through the catheter. The bladder was incised vertically and down to the mucosa along its posterior wall over 5 cm using a monopolar hook. The appendix was positioned between the posterior wall of the bladder and the umbilicus. Either the base or the tip of the appendix was used for suturing to the bladder according to the best way to avoid tension on the anastomosis. The proximal part of the appendix was excised and then spatulated over 1 cm using scissors and without coagulation. A small cystostomy was then created at the caudal apex of the detrusor muscle by a sharp incision of the bladder mucosa over 1 cm. Appendicovesical anastomosis was accomplished with two circumferential running sutures (5/0 monofilament, resorbable suture, 3/8 circle needle). The first two sutures anchored the detrusor muscle along with the bladder mucosa. After suturing the anastomosis, the appendix was placed in the prepared detrusor muscle and covered by the seromuscular layer of the bladder. The sutures were made through the mesentery to avoid compression by the mesentery creating an antireflux mechanism (4/0 absorbable, braided suture). Absence of twisting or tension on the appendiceal mesentery was ensured. The appendix tip was then brought up to the umbilicus and the length of the appendix was adapted by excision to avoid kinking. An arcuate incision was created in the caudal part of the umbilicus. The appendix was spatulated and its tip anastomosed to the umbilicus (5/0 monofilament, resorbable and interrupted suture). Neither the bladder nor the appendix were fixed to the abdominal wall. Bladder anastomosis was eventually checked by bladder filling. In selected cases, the ureter was used as the catheterizable channel in the context of concomitant nephrectomy. The ureter was isolated below the ureteropelvic junction with careful preservation of its vascular supply. If there was no history of urinary tract infection and no vesicoureteral reflux (VUR) identified preoperatively on video-urodynamic studies (VUDS), reimplantation was not required. However, in cases with known VUR, an extravesical reimplantation was performed according to the Lich-Gregoir technique. The distal end of the ureter was then brought out laterally to the abdominal wall to create the stoma. Continence and catheterization were tested, and a Fr12 feeding tube was inserted into the

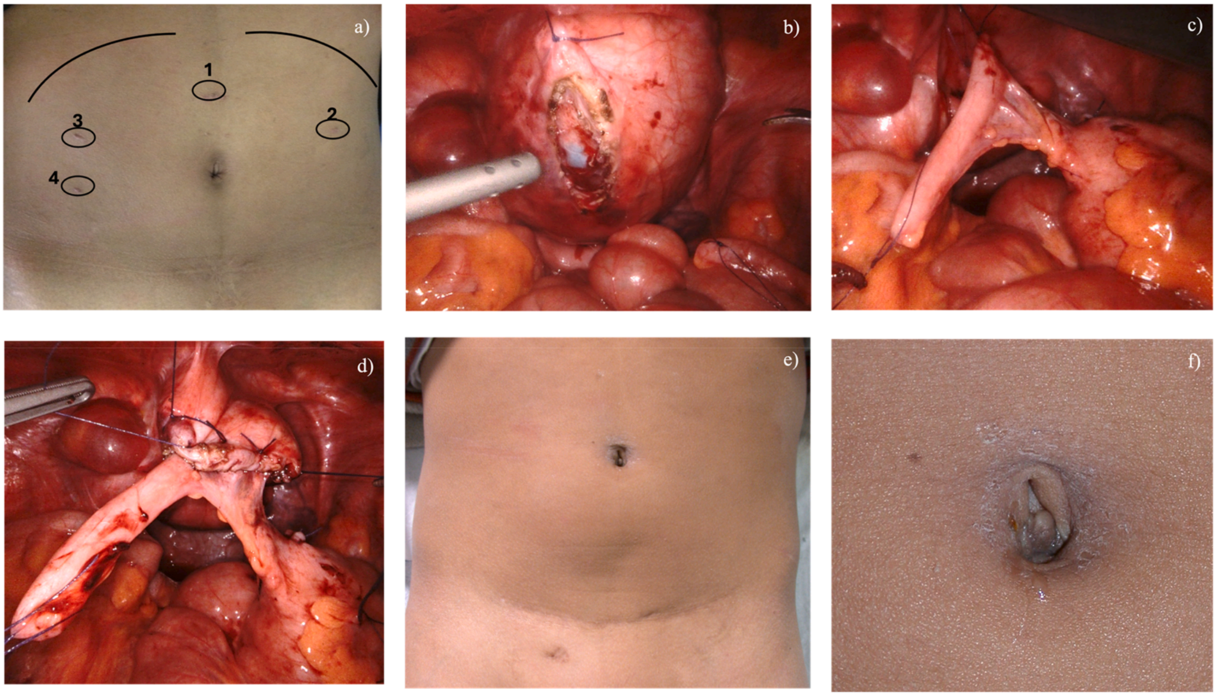

Fig. 1 Surgical steps and cosmetic outcomes of the laparoscopic Mitrofanoff procedure. a) Port placement for the laparoscopic approach: camera trocar (1) and working trocars (2—4). b) Vertical incision of the bladder wall to prepare the site for appendicovesical anastomosis. c) Mobilization and preparation of the appendix for implantation. d) Appendicovesical anastomosis with placement of traction sutures to facilitate exposure and avoid torsion. e) Long-term cosmetic result showing minimal scarring and umbilical stoma. f) Close-up view of the umbilical stoma used for clean intermittent catheterization.

conduit, safely secured to the periumbilical skin by a permanent suture. The feeding tube was left in place for two weeks. A Foley catheter was also introduced through the urethra to drain the bladder. No abdominal drain was used.

After the first seven patients, the series was continued by a modified technique to decrease the rate of conversion due to early opening of the mucosa or difficult anastomosis. From the eighth patient onwards, a transabdominal traction suture was systematically applied to suspend and stabilize the bladder wall during anastomosis, in order to improve exposure and reduce the risk of mucosal tearing. For better visualization, 5 mm trocars were also used to change the laparoscope position from the left to the right subcostal area. The anastomosis was suspended at its two ends during suturing to facilitate access (hitch stitch).

For the ***robotic-assisted approach*** using the da Vinci Xi©, an 8 mm camera port was placed by an open technique on the midline half way between the xiphoid and the umbilicus. Two additional robotic ports were placed in the right and left hypochondriac regions. An additional trocar with the Air Seal® device was placed between the right robotic trocar and the camera port, and was used for accessory instruments by the assistant. The robot was then docked. Subsequent steps were similar to the laparoscopic technique. The Mitrofanoff channel was catheterized at the end of the surgery with a Fr12 dry catheter without balloon. This catheter remained indwelling for at least ten days, then the child came back to the outpatient clinic for starting CIC (Fig. 1).

All procedures were performed by two senior pediatric urologists with extensive experience in reconstructive surgery, ensuring consistency of surgical technique throughout the study period.

Follow-up

Follow-up was performed according to our institutional protocol with urinary tract imaging, measurement of serum electrolytes and urodynamic evaluation at regular intervals. The schedule of catheterization was individualized based on bladder capacity, urodynamic findings, clinical status, and the familial environment. Intervals between catheterizations initially ranged from every 2—4 h and were progressively adjusted during follow-up under the supervision of the pediatric urology team and specialized nurses. Anticholinergic therapy was initiated in cases of detrusor overactivity or low bladder compliance identified on urodynamic studies, or in children with persistent urgency or incontinence not fully controlled by catheterization schedule adjustments.

Study endpoint

The primary endpoint was the success rate of LMA in terms of postoperative stomal continence. Stomal incontinence was classified using the Schulte-Baukloh score, a grading system originally described in pediatric patients with neurogenic bladder [12] and defined as urinary leakage reported by the patients or parents and confirmed by the urology nurse and pediatric urologist. A detailed description of the Schulte-Baukloh score is provided in

Table 1 Patientś demographics and outcomes (2003—2013) - Group 1.

No.	Sex	Age [years]	Diagnosis	Previous abdominal or bladder open surgery	Reason for failed urethral CIC	Bladder dysfunction	Surgical approach	Associated intervention	Operative time [min]	Length of stay [d]	FU [m]	Complications (peri- or postoperatively9	Incontinence Quantity Schulte-Baukloh [1—3]	Stenosis Yes = 1 No = 0	Revision Yes = 1 No = 0
1*	F	16	Non-neurogenic neurogenic bladder	0	Pain with CIC	Normal bladder capacity and compliance. Detrusor under-activity	CL after 135 min 8tearing of bladder mucosa during creation of the tunnel)	No	135 + 100	18	Lost to FU	Conversion to open procedure	0	0	0
2*	M	14.5	Posterior urethral valves	0	Pain with CIC	High bladder capacity, Detrusor over activity	Laparoscopy	No	270	6	69	None	0	0	0
3*	M	7.5	Sacral agenesis and anorectal malformation	5	Pain with CIC	Low bladder capacity and compliance, Detrusor over activity	CL after 270 min (tearing of bladder mucosa during the anastomosis)	No	270 + 120	12	137	Conversion to open procedure. Bladder augmentation	0	0	0
4*	M	3.5	Caudal dysplasia syndrome	0	Pain with CIC	Low compliance bladder. Detrusor over activity. Urethral	hypertonicity	Laparoscopy	Deflux injection for bilateral VUR	240	13	140	Stomal incontinence: treatment with one Deflux injection in year 4	3	0
0															
5*	F	3.5	Cloacae	2	Refusal of the child	Normal bladder capacity Low compliance bladder	Laparoscopy	No	195	4	115	Conversion to open procedure. Urinary leak (urethra and stoma). Artificial urinary sphincter and redo of the appendicovesical	3	0	1

												anastomosis			
6*	F	9.5	Bladder dysfunction (ectopic ureterocele)	2	Operated bladder neck	Detrusor-sphincter dyssynergia	CL after 260 min (appendix ischemia)	No	260 + 120	12	118	None	0	0	0
7*	M	13	Sacral agenesis	1	Pain with CIC	Normal bladder capacity. Detrusor over activity. Urethral	Hypertonicity. Detrusor-sphincter dyssynergia	Laparoscopy				Neurostimulator explantation	300	5	23
		None	0	0	0										
8*	M	6	Bladder dysfunction secondary to multiple bladder surgery for primary obstructive megaureter	3	Pain with CIC	Normal bladder capacity. Low compliance bladder No detrusor overactivity	Laparoscopy	No	250	6	58	Stomal incontinence, Dry interval 2 h. Anticholinergic treatment. Capacity limited to 250 mL	1	0	0
9*	M	8	Non-neurogenic neurogenic bladder	5	Pain with CIC	Detrusor under-activity. High compliance bladder	Laparoscopy	No	290	6	37	None	0	0	0
10*	M	7	Incontinent epispadias	4	Reconstructed tight bladder neck	Border line bladder Capacity and compliance	Laparoscopy	No	240	4	101	Stomal incontinence: treatment with one Deflux injection in year 2	3	0	0
11*	M	9	Posterior urethral valves	0	Pain with CIC	Large distended						hypocontractile bladder	Laparoscopy	No	240
5		100	None	0	0	0									
12*	M	17	Posterior	0	Pain	Large and	Laparoscopy	No	310	5	6	None	0	0	0

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Table 1 (*continued*)

No.	Sex	Age [years]	Diagnosis	Previous abdominal or bladder open surgery	Reason for failed urethral CIC	Bladder dysfunction	Surgical approach	Associated intervention	Operative time [min]	Length of stay [d]	FU [m]	Complications (peri- or postoperatively9	Incontinence Quantity Schulte-Baukloh [1–3]	Stenosis Yes = 1 No = 0	Revision Yes = 1 No = 0
			urethral valves		with CIC	distended bladder									
13*	M	9	Posterior urethral valves	0	Pain with CIC							Hypocontractile bladder. Low bladder capacity. Low compliance bladder. No Detrusor overactivity	Laparoscopy	No	350
5	12	Stomal	incontinence Failure of Deflux injection Redo of the									appendicovesical anastomosis	3	0	1
14*	M	12	Posterior urethral valves	1	Pain with CIC	Normal bladder capacity. Low compliance bladder. No Detrusor over activity	Laparoscopy	No	260	4	6	None	0	0	0
15*	M	4	Urethral duplication with posterior urethral valves	2	Urethral duplication	Normal bladder capacity. Normal compliance bladder. Detrusor-sphincter dyssynergia	Laparoscopy	No	250	13	4	Stomal incontinence: treatment with one Deflux injection in year 0	3	0	0

Table 2 Patientś demographics and outcomes (2013–2020) - Group 2.

No.	Sex	Age [years]	Diagnosis	Previous abdominal or bladder open surgery	Reason for failed urethral CIC	Bladder dysfunction	Surgical approach	Associated intervention	Operative time [min]	Length of stay [d]	FU [m]	Complications (peri- or postoperatively9	Incontinence Quantity Schulte-Baukloh [1–3]	Stenosis Yes = 1 No = 0	Revision Yes = 1 No = 0
16	M	6	Posterior urethral valves	1	Polyuric/pain	Low capacity, detrusor overactivity, low compliance	Robotic surgery (ureter tunnel)	Nephrectomy, ureteral reimplantation (left)	286	8	4	None	0	0	0
17	M	14	Posterior urethral valves	1	Refusal of the child	Low capacity, hypertrophic, normal compliance and activity	Robotic surgery (ureter tunnel)	Nephrectomy, ureteral reimplantation (left)	360	10	14	None	0	0	0
18	M	15	Myelomeningocele	0	Difficulties in access	Normal compliance, activity and capacity	Robotic surgery	Cystoscopy	300	7	18	None	0	0	0
19	M	15	Posterior urethral valves	1	Pain with CIC	Normal compliance, activity and capacity	Laparoscopy (ureter tunnel)	Nephrectomy, ureter reimplantation (right)	442	8	13	None	0	0	0
20	F	3	Syringomyelia, Kabuki-syndrome	0	Difficulties in access (female hypospadias)	Low compliance	Laparoscopy	No	325	7	45	None	0	0	0
21	M	6	Epispadias	1	Stenosis of bladder neck	Normal compliance, activity and capacity	Laparoscopy	No	372	5	56	None	0	0	0
22	M	13	Posterior urethral valves	0	Stenosis of bladder neck	Low compliance, underactivity	Laparoscopy	No	237	6	73	fUTI 4 days after leaving	0	0	0
23	F	11	Female hypospadias	1	Difficulties in access (female hypospadias)	Detrusor-sphincter-dyssynergia	Laparoscopy	No	433	12	69	False passage by catheterization 2 and 6 years after surgery	0	0	0
24	M	11	Detrusor-sphincter dyssynergia secondary to Hirschsprung disease	1	Refusal of the child	Low compliance, hypertonicity	Laparoscopy	No	380	7	62	None	0	0	0

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Table 2 (*continued*)

No.	Sex	Age [years]	Diagnosis	Previous abdominal or bladder open surgery	Reason for failed urethral CIC	Bladder dysfunction	Surgical approach	Associated intervention	Operative time [min]	Length of stay [d]	FU [m]	Complications (peri- or postoperatively9	Incontinence Quantity Schulte-Baukloh [1–3]	Stenosis Yes = 1 No = 0	Revision Yes = 1 No = 0
24	F	7	Enlarged bladder with bilateral duplex system	1	Difficulties in access, pain	Hyperactivity, mega bladder, hyposensitivity	Laparoscopy	No	310	5	79	None	0	0	0
25	M	5	Posterior urethral valves	1	Difficulties in access (bladder neck stenosis)	Detrusor-sphincter-dyssynergia	Laparoscopy	No	360	5	90	Stomal incontinence: treatment with Deflux injection in year 6	3	0	0
27	M	8	Posterior urethral valves	0	Difficulties in access (urethral stenosis)	Hypo-compliant bladder, low capacity	Laparoscopy	No	410	8	103	Stomal incontinence: treatment with one Deflux injection and revision surgery	3	0	1
28	M	12	Posterior urethral valves	0	Pain with CIC	Hypo-compliant bladder	Laparoscopy	No	323	6	83	None	0	0	0
29	M	3	Urethral duplication	1	Difficulties in access (urethral duplication)	Hypo-compliant bladder	Laparoscopy	No	324	15	83	Stomal incontinence: treatment with one Deflux injection in year 0	3	0	0

Table 3 Comparative demographics and outcomes of laparoscopic Mitrofanoff procedure.

Variable	Total (2003–2020)	Group 1 (2003–2013)	Group 2 (2014–2020)	Robotic Subgroup	p-value (Group 1 vs 2)
Patients, N	29	15	14	3	–
Sex (M/F)	23/6	13/2	10/4	3/0	1.0
Median age [years] (IQR)	8 (6–13)	8 (4–12)	9 (6–13)	10 (7–14)	0.64
Median follow-up [months] (IQR)	60 (17–88)	83 (34–102)	54 (18–71)	18 (13–26)	0.15
Social continence, n (%)	21 (72 %)	10 (67 %)	11 (79 %)	3 (100 %)	0.68
Stomal incontinence, n (%)	9 (31 %)	6 (40 %)	3 (21 %)	0 (0 %)	0.68
Schulte-Baukloh score I	1	1	0	0	–
Schulte-Baukloh score III	8	5	3	0	–
Stenosis, n (%)	0	0	0	0	–
Revision, n (%)	4 (14 %)	3 (20 %)	1 (7 %)	0	0.61
Conversion to open, n (%)	3 (10 %)	3[a] (20 %)	0	0	0.23
Median operative time [min] (IQR)	310 (250–360)	295 (245–330)	324 (273–351)	300 (293–330)	0.44
Median length of stay [days] (IQR)	6 (5–10)	5 (5–12)	7 (6–8)	8 (7–9)	0.30

[a] **Note:** Three patients in Group 1 required conversion to open surgery (2 for bladder mucosa tears, 1 for appendix ischemia). Only one of these patients developed stomal incontinence (grade III), while the others remained continent. All 29 attempted laparoscopic cases were retained in the cohort to reflect feasibility and outcomes.

Supplementary Table S1. Operative time, complications, surgical revisions, and stomal stenosis were further endpoints. Social continence was recorded as a descriptive secondary outcome, recognizing its dependence on bladder and outlet management rather than on the Mitrofanoff procedure itself.

Data collection

The data for the patients were divided into two groups: (i) patients undergoing surgery between 2003 and 2013 (Group 1: n = 15); and (2) those undergoing surgery between 2013 and 2020 (Group 2: n = 14).

Statistical analysis

Statistical analyses were performed using the Mann–Whitney test and Fisher's exact test. All statistical analyses were carried out using R-version i386 4.0.3 (The R foundation). A p-value <0.05 was considered significant.

Results

Study population

A total of 29 children underwent LMA, between 2003 and 2020, including 23 boys, with a median (IQR) age of 8 years (6–13). The baseline characteristics of these patients are summarized in Tables 1 and 2.

Surgical outcomes

Between 2003 and 2013 (Group 1), 12/15 patients had a successful LMA which was completed by laparoscopy only; however, in three children (20 %) conversion to an open procedure was necessary. Conversely, between 2013 and 2020 all interventions were fully completed by MIS (Group 2, n = 14/14 (100 %)). The reasons for failure in period 1 were tearing of the bladder mucosa (during creation of the tunnel (n = 1), during suturing (n = 1)) or appendix ischemia (n = 1). The median (IQR) operative time for totally LMA was 310 min (250–360) (period 1: 295 min (245–330) *vs.* period 2: 324 min (273–351); p = 0.44). The three last cases of Group 2 were performed robotically in a median (IQR) time of 300 min (293–330) (*vs.* 338 min (245–344) laparoscopically, p = 0.70). Estimated blood loss was <20 mL. No anastomotic leakage was reported. The median (IQR) hospital stay was 6 days (5–10) (period 1: 5 days (5–12) *vs.* period 2: 7 days (6–8); p = 0.30). The median (IQR) follow-up was 60 months (17–88). At the last follow-up, all patients were still using their Mitrofanoff channel for clean intermittent catheterization, and no cases of channel abandonment were observed, even among those who required secondary procedures.

Social continence was achieved in 21 patients (72 %) (Group 1: 10/15, 67 %; Group 2: 11/14, 79 %; including 3/3 patients in the robotic subgroup, 100 %; p = 0.68) (Table 3). Stomal urinary leakage was reported in 9 patients (31 %) (Group 1: 6/15, 40 %; Group 2: 3/14, 21 %; no cases in the robotic subgroup; p = 0.68), of whom 5 (63 %) had a Schulte-Baukloh score of 3 and were successfully managed with hyaluronic acid/dextranomer injection into the catheterizable channel (Tables 1–3). One patient needed another hyaluronic acid/dextranomer injection six years after the first one for new onset incontinence and remained continent afterwards. Three patients needed revision surgery in the first postoperative year after failure of hyaluronic acid/dextranomer injections or in the third year after to failure of hyaluronic acid/dextranomer injections (Tables 1 and 2). One patient who had also undergone conversion to open surgery was treated directly by revision surgery for important incontinence. One patient had a Schulte-Baukloh score = 1 and gained continence by adapting the intervals of catheterization and anticholinergic treatment. Among the three converted patients in Group 1, one had a bladder augmentation three years after the Mitrofanoff procedure for persistent bladder dysfunction. No patient developed stenosis of the catheterizable channel and none reported severe difficulties in catheterization requiring an intervention or catheter placement. One patient had recurrent difficulties with catheterization two and six years after LMA and was successfully handled by counselling.

Although a lower revision rate was observed in Group 2 compared to Group 1 (1/14, 7 % vs. 3/15, 21 %), this difference was not statistically significant ($p = 0.61$). Similarly, the conversion rate decreased from 3/15 patients (20 %) in Group 1 to 0/14 in Group 2, but this difference was also not statistically significant ($p = 0.23$).

Discussion

Reconstructive urological surgery in children has conventionally been performed using an open approach. The Mitrofanoff procedure, historically performed via a midline or Pfannenstiel incision, exposes children to significant morbidity and postoperative pain.

While MIS techniques have rapidly been incorporated and used for other urological surgeries, they have slowly developed for lower urinary tract reconstruction. Several articles have described laparoscopic or robot-assisted surgery with mobilization of bowel segments by laparoscopy and continuation of complex reconstruction through a small open incision [2,13].

A complete intracorporeal appendicovesicostomy (APV) by laparoscopy is challenging and requires high technical skills and surgical experience. The first complete laparoscopic Mitrofanoff procedure was described by Hsu et al. in 2004 [9]. The potential benefits of MIS procedures include lower postoperative pain scores, a shorter hospital stay and better cosmetic results. Despite initial concerns about the small working space, the robotic approach in children has gained widespread acceptance for pediatric urological surgery in recent years. The first intracorporeal robot-assisted Mitrofanoff appendicovesicostomy was reported by Gundeti et al., in 2008 as a single case report, with an updated series of 18 patients published in 2013, with or without a bladder augmentation [3,4]. They compared the outcome of an extravesical anastomosis of the appendix on the anterior wall of the bladder with an intravesical anastomosis on the posterior wall. Extravesical anterior anastomosis was reported to be a feasible and safe option, exhibiting good continence rates (94.4 %) [6]. In our practice, the anastomosis of the appendix is performed on the posterior wall of the bladder, to keep the anterior wall free for any potential further bladder surgery. Nevertheless, this approach presents technical challenges, particularly when suturing the appendicovesical anastomosis in this location. Our first cohort published in 2015 included three patients who needed a conversion, possibly due to this difficult step [11]. Subsequently, our technique was modified by using a traction suture on each end of the anastomosis. The following eight patients in the cohort were operated on successfully via a laparoscopic approach without conversion as were all other patients who underwent surgery in period 2 ($n = 14$). The robotic approach facilitates intracorporeal suturing and access to the anastomosis due to the greater degrees of freedom in instrument movement and three-dimensional viewing. However, the restricted working space remains a challenge. Outcomes have been reported to be similar to the open procedure in terms of efficacy and safety [10].

With the results of our cohort between 2003 and 2013 published in 2015, we concluded that the procedure in children was not satisfactory in terms of stoma incontinence in the cases of patients with high-pressure bladder [11]. However, with time and experience, there was a trend to improve patients' outcomes in period 2 concerning social continence (21/29; 72 %) (period 1: 10/15, 67 % vs. period 2: 11/14, 79 %; $p = 0.68$). The rate of revision surgery was reduced from 21 % in period 1—7 % in period 2. Pediatric series generally report continence rates of 88—97 % after continent catheterizable channels, with no significant differences between open and robotic approaches. Galansky et al. [14] reported continence of 91.4 % (open) and 91.2 % (robotic) in a decade-long pediatric cohort, while Juul et al. [15] confirmed similar continence rates in a systematic review but noted shorter hospital stays with robotic surgery. In comparison, our continence rate of 72 % lies at the lower end of this range, likely reflecting the inclusion of patients with challenging bladder dynamics and the use of isolated APV in some cases. These findings highlight both the feasibility of the minimally invasive approach and the need for standardized definitions of continence in future studies.

Furthermore, all procedures performed during period 2 were fully completed by laparoscopy while three patients (20 %) underwent a conversion in period 1. There was no significant difference in median length of hospital stay in period 1 (6 days), period 2 (7 days) or for robotic surgery patients (6 days), but there was a greater range in period 1 (IQR 7 *vs.* IQR 2 in period 2).

Regarding operative time, the median (IQR) operative time was longer in period 2 (period 1: 295 (245—330) vs. period 2: 324 (273—351); $p = 0.44$), which can be explained by the optimization of our technique and using a technical tip by adding a traction suture. Interestingly, the best results concerning the operative time were observed for the three robot-assisted Mitrofanoff procedures with a median time of 300 min, even though traction sutures were also used during the robotic approach. Nevertheless, with only three robotic approaches, our results only give a first impression of the feasibility and there is a need for further experience and long-term outcome results. Operative time in our series remained longer than that reported for the open approach. This reflects both the technical demands of a fully laparoscopic Mitrofanoff and the slow learning curve inherent to procedures with limited indications. The longer time observed in period 2 compared to period 1 is related to the introduction of traction sutures, which increased suturing time but improved safety of the anastomosis and reduced the risk of conversion. The effect of prolonged general anesthesia duration on long-term outcomes in children is not yet clearly understood in the literature. Nevertheless, we always aim to minimize operative and anesthesia times, as some studies have suggested that longer exposure to general anesthesia could be a potential risk factor for neurodevelopmental delay in newborns and children [16].

The limitations of this study include the relatively small cohort size, reflecting the rarity of this procedure, as well as the heterogeneity of underlying pathologies and ages.

In addition, the long inclusion period, 18 years, represents a limitation, as surgical expertise, perioperative care, and patient selection criteria inevitably evolved during this timeframe and may have influenced the results. Furthermore, the differing duration of follow-up between groups limits our ability to draw firm conclusions about long-term revision or complication rates. Future studies with larger cohorts should incorporate time-to-event analyses to better address this issue.

The robotic-assisted approach seems to be a safe and effective procedure but requires further data and follow-up. To our knowledge, our study still represents the largest cohort published analyzing LMA and is the first with a long-term follow-up of 5 years. Our astonishing observation was the absence of channel stenosis in any of our patients whereas the literature describes channel stenosis with open approach in 11.2—17.5 % of cases [17,18]. This low rate of stenosis may be due to multifactorial reasons in surgical steps: 1) the umbilical skin stoma was not used for laparoscopic ports (to keep the skin in optimal conditions for the anastomosis); 2) the careful handling of the appendix without using electrocoagulation or energy devices in cutting the edges of the appendix, the skin or the bladder mucosa, and; 3) long and strong preparation by our educational nursing staff of the children and their families for the surgery and for CIC compliance. Although cosmetic and pain-related outcomes were not measured in our series, recent pediatric studies indicate that minimally invasive approaches, including laparoscopic and robotic Mitrofanoff procedures, can yield improved cosmetic appearance, reduced postoperative pain, and faster recovery compared to open techniques. Specifically, Gander et al., in 2022 [19] demonstrated better cosmesis and less pain with laparoscopic Mitrofanoff in children, while Di Giuseppe et al., in 2024 [20] conducted a pediatric systematic review that highlighted benefits of the robotic approach in pain, cosmesis, and recovery.

Conclusions

The laparoscopic Mitrofanoff procedure is a safe and effective approach for minimizing postoperative complications, stenosis and incontinence. There was a trend toward fewer revisions and improved stomal continence in the later cohort, although these differences did not reach statistical significance. None of the patients who underwent a MIS Mitrofanoff procedure developed channel stenosis. Although operative times remained relatively long overall, technical refinements and robotic assistance improved safety and reduced conversions; longer follow-up is required to confirm durability. These findings support the role of minimally invasive techniques in pediatric reconstructive urology, while highlighting the need for larger comparative studies with standardized outcome measures. Previous pediatric literature also suggests potential benefits of MIS approaches, such as reduced postoperative pain, improved cosmesis, and faster recovery, although these outcomes were not assessed in our series.

Author contributions

Sylvia Weis: Protocol/project development, Data collection or management, Data analysis, Manuscript writing/editing.

Ugo Maria Pierucci: Protocol/project development, Data analysis, Manuscript writing/editing.

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Declaration of Generative AI and AI-assisted technologies in the writing process

Generative AI and AI-assisted technologies were NOT used in the preparation of this work.

Declarations of interest

Disclosure of potential conflicts of interest: The authors have no relevant financial or non-financial interests to disclose. Research involving Human Participants and/or Animals: As this was a retrospective study, it did not contain any contact with human participants or animals performed by any of the authors. Local law does not require ethics committee approval or informed consent for retrospective data collection. Informed consent: Local law does not require ethics committee approval or informed consent for retrospective data collection.

Acknowledgements

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jpurol.2025.09.036.