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Ten years of paediatric robotic surgery: Lessons learned

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Abstract

Background: Costs and a low total number of cases may be obstacles to the successful implementation of a paediatric robotic surgery programme. The aim of this study was to evaluate a decade of paediatric robotic surgery and to reflect upon factors for success and to consider obstacles.

Materials and Methods: All children operated on with robotic-assisted laparoscopic surgery between 2006 and 2016 were included in a retrospective, single-institutional study in Lund, Sweden.

Results: A total of 152 children underwent robotic surgery during the study time with the most frequent procedures being fundoplication (n = 55) and pyeloplasty (n = 53). Procedure times decreased significantly during the study period. Overall, 18 (12%) of the operations were converted to open surgery, and seven (5%) patients required a reoperation.

Conclusions: Despite a low volume of surgery, we have successfully introduced robotic paediatric surgery in our department. Our operative times and conversion rates are continuously decreasing.

KEYWORDS

abdominal, digestive system, kidney

1 | INTRODUCTION

Today, robotic surgery is well established in adults. However in contrast to this, in paediatric health care progression has been slower although with generally promising results.[1–4] The introduction of robotic surgery has even made it possible to perform procedures that have not been performed laparoscopically in children before and studies have shown repeatable that robotic surgery is safe and that the results are on par with open and laparoscopic surgery in the paediatric population.[5–9] Some of the most important goals at follow-up of an introduction of robotic surgery are feasibility, security and patient outcomes.[10,11] Proving fulfilment of these goals statistically can be a challenge for paediatric surgery centres which are often defined as small volume centres. Therefore, the aim of this study was to evaluate the implementation and continuation of a paediatric robotic programme at a single institution, with focus on description of feasibility, safety, learning curves, and outcome in a variety of procedures in children. Furthermore, we reflect on factors for success and obstacles for the introduction of a robotic surgery programme in a small volume centre. This paper could hopefully serve as a comparative guide for other paediatric centres wanting to introduce robotic surgery in their clinical practice.

2 | MATERIALS AND METHODS

The study was approved by the regional Ethics Committee (no. 2010/49).

2.1 | Settings and children

All children operated on with robotic-assisted laparoscopic surgery between 2006 and 2016 at a single tertiary centre for paediatric surgery in Lund, Sweden were eligible for inclusion in the study. The centre covers an area with around 2 million inhabitants, all with free access to health care. The paediatric surgery department is part of a robotic centre and shares the hospital's four da Vinci® Surgical Systems from Intuitive Surgical® (Sunnyvale CA, USA) with six other adult surgery departments: two da Vinci® Si systems (third generation) and two da Vinci® Xi-systems (fourth generation). One simulator, placed in a skill centre, is used for teaching and practice.

The evaluation cut-off date of 2016 was selected following when a change from the da Vinci Si to the da Vinci Xi in paediatric surgery took place. During the study period, the Department of Paediatric Surgery had a fixed slot for using the robot every other week, except during the summer, which resulted in availability of the robotic system for 15–20 days per year. One operation was planned per operation day. Since the robot is situated in the adult surgery hallway next door to the Children's hospital, children are transported from the paediatric department to the operating room, accompanied by the paediatric surgical- and anaesthetic team. During the decade described, mainly two surgeons were operating. In addition, one senior surgeon acted as a supervisor from when the department first started introducing the robot, and one surgeon was in training. The two main surgeons were specialised in paediatric urology and gastroenterology, respectively.

2.2 | Surgical techniques

Fundoplication was performed *ad modum* Nissen without division of the small vessels of the gastric ventricle. Pyeloplasty was performed as an adaptation of the Anderson-Hynes type with either a retroperitoneal (June 2006 to June 2011) or after that, a transabdominal approach. The details surrounding the surgical techniques are further described in the dissertation by Anderberg from 2010.[12]

2.3 | Study design

A retrospective study was conducted using data from a prospectively collected database of all robotic operations performed at the department. Data regarding complications, and results from follow up, were collected retrospectively from patients' charts until 2021 corresponding to at least 5 years' follow up postoperatively. Patient demographics, type of procedure, operative time and docking time, conversions, length of hospital stay, and re-operations, were evaluated for all patients. Learning curves and long-term results were evaluated for the two most frequently performed surgical procedures: fundoplication and pyeloplasty. Evaluation of the outcome after fundoplication was carried out by comparison of 24-h pH measurement, deMeester score, and the use of proton pump inhibitors (PPI) and asthma medication, pre- and postoperatively. During the whole study period, all patients were assessed clinically by their post-operative symptoms and medications at a scheduled outpatient visit at 12–18 months postoperatively. Evaluation of the outcome after pyeloplasty was made by comparing hydronephrosis, renal function, and pain, pre- and postoperatively. For comparison of hydronephrosis and renal function, the last preoperative anterior-posterior (AP) measurement, and mercaptoacetyltriglycine (MAG3) or dimercaptosuccinic acid (DMSA) measurement were compared to the latest postoperative AP-measurement and MAG3/DMSA.

2.4 | Definitions

Surgery time was defined as the time from skin incision (port placement) to skin closure. For surgery time, time for the open procedure after conversion was included. Docking time was defined as the time used to position the patient and dock the robotic arms, and console time as surgery time minus docking time. pH was defined as the measured duration in percent of 24-h $pH < 4$ and was, together with deMeester score, retrieved from a BRAVO® (Medtronic, Shoreview, MN, USA) capsule monitoring test. Hydronephrosis was defined as an AP-value of the renal pelvis of $\geq$10 mm. Normal split renal function was defined as 45%–55% on MAG3/DMSA scintigraphy. Flank pain was reported subjectively by the patient or by parental proxy. A successful outcome after pyeloplasty was defined as improved or stable renal function, together with improvement of the hydronephrosis and relief of flank pain at follow up. The error margin of MAG3 was $\pm$3%; hence a difference in split renal function of more than 3% was considered to be significant. Follow-up time was defined as the number of months elapsed between surgery and the latest renal ultrasonography (US) or MAG3/DMSA. Hospital stay was calculated from the day of surgery, to the day of discharge from hospital.

2.5 | Statistical analysis

Calculations were made using the Statistical Package of Social Sciences (SPSS) version 25. Fisher's two-tailed exact test was used for dichotomous variables and the Mann–Whitney *U*-test was used for continuous, nonparametric results. Linear regression was used for evaluation of learning curves over time. Missing data were excluded from all calculations. Significance level was set to a *p*-value of <0.05.

2.6 | Aspects of management evolution

Procedure management has evolved with team experience gained over the years. Initially a 10 mm balloon port was used for the camera for all cases, which is especially important in retroperitoneal surgery in small children to maximize the limited space. Then 8 mm robotic ports became the standard in the latest of the four versions of the DaVinci system that we have used. Patient positioning has changed as the DaVinci system became slimmer and the setup in the OR was standardized following more distinct routines. The Xi version now offers a dual console and a built-in simulator, which is an advantage for the training of new console surgeons, thereby increasing safety for the patient.

2.7 | Fundoplication

Initially we used four working ports but have changed to three in most cases, with the one assistant port in the epigastrium. Most of our patients had a gastrostomy button at the time of surgery, hence port placement had to be adapted individually and the need for a nasogastric tube postoperatively is no longer mandatory. Cruroplasty is performed only when needed, and not regularly, and we perform less dissection around the oesophagus than initially since a floppy fundoplication can be accomplished anyway. Gore-Tex® sutures have worked very well which is why we have continued using them.

2.8 | Pyeloplasty

The initial reason for changing from retro-to the transperitoneal approach was a case with a very large renal pelvis (AP-measurement of 60 mm) which left no manoeuvring space for instruments retroperitoneally. The transabdominal surgery seemed more straightforward, by virtue of fewer collisions of instruments, compared to the retroperitoneal approach and is now our preferred technique for pyeloplasties. We use resorbable 5-0 or 6-0 multifilament sutures instead of monofilament ones for easier handling. Surgery is performed with a DeBakey grasper and monopolar scissors and only one needle driver which reduces costs. The JJ-stent is placed over an antegrade guide wire after the first part of the anastomosis is completed and we use methylene blue to confirm its correct position in the bladder. A percutaneous trans-anastomotic stent is an option when the ureteral orifice is small or office removal of the stent is preferred. With a catheter in the bladder overnight no drains are used any more. Our follow-up has changed based on our previous studies.[13]

3 | RESULTS

None of the parents of the children selected for robotic laparoscopic surgery declined the robotic approach. A total of 152 children (66% boys, median age 7.3 years, median weight 24 kg) underwent 153 robotic-assisted procedures with an annual frequency of 9–20 procedures, including 13 different procedures with the most frequent ones being fundoplication (36%, $n = 55$), pyeloplasty (35%, $n = 53$), nephrectomy (12%, $n = 19$), and heminephrectomy (7%, $n = 10$) (Table 1).

Completed robotic procedures were 135 (88%); 12% of operations were converted to open surgery. The most common reasons for conversions were anatomical or patient-related while none of the conversions was due to malfunction of the robotic system (Table 2). Heminephrectomies had the highest rate of conversions (40%), followed by pyeloplasty (17%). The majority of the converted pyeloplasties (88%) were performed during the first 3 years, and they were all performed with a retroperitoneal approach. Hence, 8/22 (36%) retroperitoneal approach surgeries were converted compared to 1/31 (3%) of those with a transabdominal approach. In total, seven (5%) patients required re-operations: three fundoplication (all during the first 5 years), and four pyeloplasties (Table 2). The median operative time was 172 (97–450) min for fundoplication, 255 (165–505) min for pyeloplasty, 194 (97–322) min for nephrectomy, and 243 (195–405) min for heminephrectomy. Median docking time was 8 (1–70) min for all four procedures (Table 2).

The surgery time decreased during the study period for fundoplication from an average of 254 min in 2006 to 181 min in 2016 ($r = 0.45$, $p = 0.0008$), and for pyeloplasty from 347 min in 2006–2007 to 226 min in 2016 ($r = 0.42$, $p = 0.005$) (Figure 1A,B).

No child in the fundoplication group had any complication requiring reoperation or any more severe complication in the short term (Clavien Dindo 3b or more). At follow-up of patients operated on with fundoplication, four patients died due to underlying conditions. Data for 24 h pH measurement and deMeester score were only available during 2006–2010 after which the follow-up programme did not include 24 h pH measurements routinely. For evaluation of PPI and asthma medication use, three (6%) patients were lost to follow-up. The measured duration in percent of 24 h pH < 4, deMeester score, and the use of PPI and asthma medication all improved postoperatively (Table 3).

Regarding short-term complications in the pyeloplasty group, 14 of the 53 patients (26%) had stent dysfunction, and as a result seven of them (13%) had to be anesthetized to either have a nephrostomy or a laparoscopic abdominal drain placement (Clavien Dindo 3b). Length of hospital stay after pyeloplasty was a median 3 (1–19) days for all cases, and a median of 2.5 (1–19) days when converted operations were excluded from calculations.

At long-term follow up, AP measurement decreased from a preoperative mean of 31 mm (±16) to a postoperative mean of 9 mm (±5) ($p < 0.0001$); average split renal function was 41.5% (±11) preoperatively and 44.6% (±10) postoperatively ($p = 0.03$). The success rates were 38/39 (97%) for pain resolution, 48/52 (92%) for improvement of hydronephrosis, and 50/52 (96%) had improvement of or stable renal function. At the end of the study period, four out of 53 patients had undergone a re-operation (three open and one robotic operation) of which all were successful.

TABLE 1 Procedures, demographics, indications, and overall length of hospital stay in 152 children (153 procedures) operated on with robot-assisted laparoscopic surgery

Procedure	*n*	Sex (M/F)	Age (years)	Weight (kg)	Indications/diseases	LOH
Fundoplication	55	37/18	6.2 (0.5–15)	19 (6–81)	GERD with (*n* = 45)/without (*n* = 10) oesophagitis	3 (1–21)
Pyeloplasty	53	37/16	9.3 (0.7–15.1)	29 (10–84)	Ureteropelvic junction obstruction (53)	3 (1–19)
Nephrectomy	19	15/4	4.8 (1.1–15.3)	21 (9–61)	Renal dysplasia (11), UPJ-obstruction (3), Vesico-uretero-renal reflux (2), Posterior urethral valve (1), Distal urethral stenosis (1), Renal artery thrombosis (1)	1 (1–4)
Heminephrectomy	10	1/9	7.6 (1.7–14.9)	27 (11–54)	Ureteral duplication (7), Ureteral duplication with ectopic ureter (3)	3 (2–4)
CDH-repair	4	3/1	1.5 (1.4–13)	11 (8–42)	Morgagni (4)	3 (1–4)
Cholecystectomy	3	1/2	12.6 (8.3–15)	42 (34–49)	Cholecystolithiasis without cholecystitis (3)	2 (1–4)
Hemihysterectomy	3	-/3	15 (14.6–15)	47 (44–58)	Bicornate uterus (2), Endometriosis (1)	3
Malrotation	1	1/0	9.6	35	Malrotation	29
Dor fundoplication	1	0/1	13.2	71	Achalasia	3
Ureterectomy	1	0/1	6.4	25	Ureteral duplication	2
Resection of vaginal remnant	1	-/1	11.1	29	Vaginal remnant	9
Cystoprostatectomy	1	1/-	1.8	9	Rhabdomyosarcoma	10
Kidney biopsy	1	0/1	12.3	31	Chronic kidney disease	1
Total	153	100/53	7.3 (0.5–15.3)	24 (6–84)		3 (1–29)

Note: Numbers presented as median (min–max).

Abbreviations: CDH, Congenital diaphragmatic hernia; F, Female; GERD, Gastroesophageal reflux disease; LOH, length of hospital stay; M, Male.

TABLE 2 Surgery time, conversions and re-operations in 152 children (153 procedures) operated on with robot-assisted laparoscopic surgery

Procedure	Surgery time (min)	Console time (min)	Docking time (min)	Converted and reasons	Re-operation
Fundoplication (*n* = 55) – conversions (*n* = 52)	172 (97–450) 172 (97–450)	110 (50–260) 109 (50–260)	8 (1–35)	3 (5) Adhesions (2), Oesophageal perforation (1)	3 (5)
Pyeloplasty (*n* = 53) – conversions (*n* = 44)	255 (165–505) 244 (169–375	176 (63–315) 179 (100–315	9 (4–50)	9 (17) Inflammatory/fragile tissue (2), Abnormal arterial anatomy (2), Lack of good overview (2), Abnormal kidney anatomy (1), Stent placement impossible (1), Obesity (1)	4 (8)
Nephrectomy (*n* = 19)	194 (97–322)	95 (34–180)	8 (4–70)	0 (0)	0 (0)
Heminephrectomy (*n* = 10) – conversions (*n* = 6)	243 (195–405) 233 (195–355)	95 (34–180) 161 (115–290)	5 (5–10)	4 (40) No space for instruments (1), No clear demarcation line (1), Dense adhesions (1), Bleeding (1)	0 (0)
CDH-repair (*n* = 4)	167 (145–215)	123 (80–168)	9 (7–10)	0 (0)	0 (0)
Other (*n* = 12)	178 (117–345)	123 (20–185)	10 (5–18)	2 (17) Concomitant splenectomy (1) Lack of good overview (1)	0 (0)
Total – conversions	205 (97–505) 205 (97–505)	140 (20–315) 140 (20–315)	8 (1–70)	18 (12)	7 (5)

Note: Values presented as median (min-max) and as the absolute number and percentage of patients, *n* (%).
Abbreviation: CDH, congenital diaphragmatic hernia.

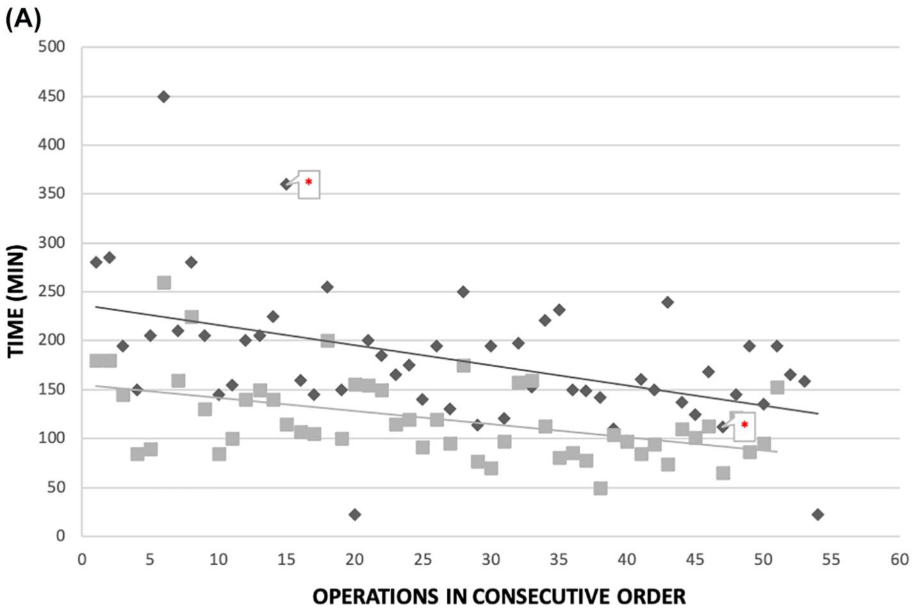
4 | DISCUSSION

We hereby report on one of the largest cohorts of paediatric robotic surgery from a single institution, illustrating that robotic surgery has been slowly but securely established since its introduction in our centre. We showed that selected procedures in selected patients can be performed safely on a variety of paediatric patients and conditions. Despite being a low-volume centre, learning curves and outcomes after robot-assisted laparoscopic pyeloplasty and fundoplication at our department are comparable to those of larger centres.

Our overall conversion rate was 12%, and a majority of those were pyeloplasties with the retroperitoneal approach. Other centres have reported conversion rates ranging from 0% to 10%.[7,14–16] After switching to the abdominal pyeloplasty approach, the overall conversion rate decreased from 36% (retroperitoneal) to 3%. No conversions had to be made due to material failure, whereas other authors have reported material failure as being responsible for between 0%[17] and 0.5% of conversions.[18] In adult robotic urology the reported device failure rates were as high as 11%.[19] Heminephrectomies had a conversion rate of 40% in our centre, and they were all performed with a retroperitoneal approach. For comparison, a follow-up study by Mason et al showed no conversions to open surgery during trans-peritoneal robotic heminephrectomies in children.[20] Our results and approach need further evaluation and comparison with outcome after laparoscopic surgery in a future study.

Patient obesity was the reason for one of our conversions. Acquired experience from both laparoscopic and robotic surgery has taught us that if a patient has large amounts of fragile, subcutaneous fat it might obstruct vision, interfering with the minimally invasive procedure. It is important to be aware that obesity in children might also mean complicated surgery with the robotic minimally invasive technique, and not just in open surgery. Sometimes obesity makes conversion necessary and sometimes it requires repositioning of the patient, or the addition of an extra port. To plan and take decisions safely concerning robotic surgery we therefore propose patient body mass index (BMI) calculations as a future evaluation tool and we will hereinafter collect prospectively not only patient weight, but also length/height.

There were three (5%) patients in need of reoperation after fundoplication within the first 2 years, which is slightly more than reported by Meehan et al: 2%.[21] One of the patients was re-operated using the robot after 6 months but had to be re-operated openly after another 8 months. The two other patients were re-operated after approximately 1 year, and 1.5 years, respectively, due to relapse of symptoms and slacking wraps. However, it is difficult to compare patients undergoing fundoplication with patients from other centres; while many have debilitating comorbidities with severe neurological impairment, some are completely free of such conditions. This makes generalisation hard to apply and could be one of the reasons for the difference in reported ‘redo’ operations. A total of 44 (80%) of our fundoplication patients had an underlying neurological condition and none had oesophageal atresia or congenital diaphragmatic hernia. After pyeloplasty the frequency of



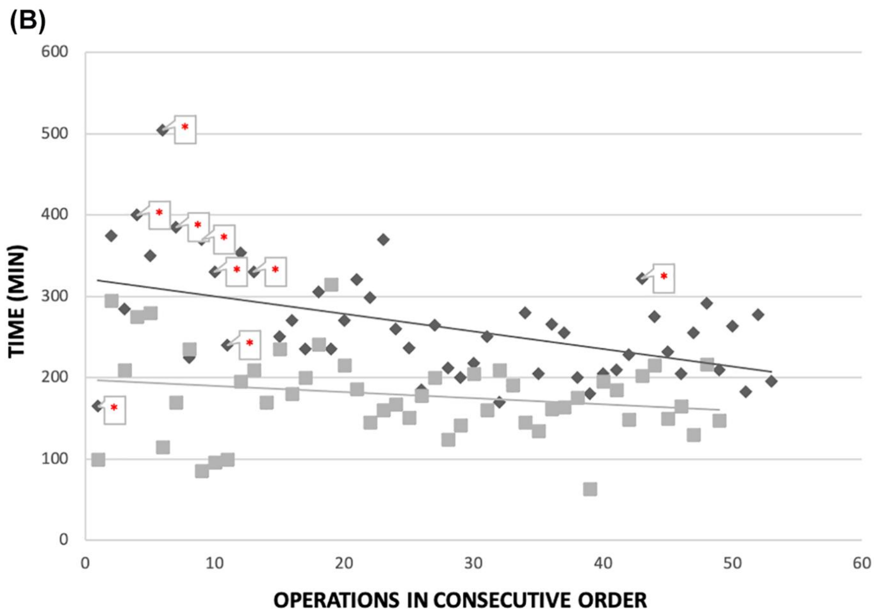


FIGURE 1 (A) Learning curve for robotic-assisted laparoscopic fundoplication in 55 children with specified operative time (skin-to-skin) (◆) (r^2 = 0.2, p = 0.0008) and console time (□) (r^2 = 0.2, p = 0.0004); * = converted to open surgery (one missing data not included). (B) Learning curve for robotic-assisted laparoscopic pyeloplasty in 53 children with specified operative time (skin-to-skin) (◆) (r^2 = 0.2, p = 0.0003) and console time (r^2 = 0.04, p = 0.1624); * = converted to open surgery

re-operation was 8%, which is similar to other studies reporting numbers between 3 and 6%.[22,23]

The operative time for fundoplication was a median of 172 min, mimicking results of other centres who report operative times from 143 to 145 min[11,17] to 262 min (Zeus system).[24] The median operative time for pyeloplasty was 244 min not counting converted operations, which is much longer compared to the report from Volfson et al: 175 min,[15] but similar to the data reported by de Lambert: 251 min.[11] There is a point in excluding converted operations since extra time is spent on docking off the robotic arms, remaking the sterile area, and the operation per se is not finished by robot. It is important to note that operative times were never so long as to cause immobility complications.

Our learning curves show that both robotic operating times and docking times are decreasing with experience and that our operative times are close to those of other centres, while in most cases still being significantly longer when compared to open surgery.[25,26] Our earlier study showed that operative times for pyeloplasty were 1 h longer than for open surgery while the average patient hospital stay was 1–2 days shorter.[9] Docking times have not only improved during the study time but are also in general fairly low. Gutt et al report a docking time of an average of 23 min,[16] compared to our docking times of 5–10 min. Our robotic operative times for fundoplication have improved to such a degree that they are now better than our laparoscopic operative times.[27] With the new da Vinci® Surgical System it is possible to record successful operations and use them for

TABLE 3 Long-term outcome after robot-assisted laparoscopic fundoplication in 55 children

	Preoperative (*n* = 42°)	Postoperative (*n* = 25*)	*p*-value
24-h pH < 4	11.7 (0.1–39)	0.6 (0–14.4)	<0.001[b]
DeMeester score	40.9 (0.8–137.1)	3.8 (0.3–54.9)	0.002[b]
Follow-up (months)	19 (6–117)		
	Preoperative (*n* = 55)	**Postoperative (*n* = 46°)**	
PPI	53 (96)	14 (30)	<0.0001[a]
Asthma medication	29 (53)	13 (28)	0.016[a]
Follow-up (months)	22 (1–117)		

Note: Values presented as absolute number and percentage of patients, *n* (%), or median (min–max); PPI: Proton Pump Inhibitors; a: Mann-Whitney *U*-test, b: two-tailed Fisher's exact test-two tailed; °missing data excluded from calculations; *conversions and reoperations (*n* = 6), and missing data (*n* = 24) excluded from calculations.

simulation exercises, something we are about to introduce to accelerate learning curves. Meanwhile, robotic surgery has already resulted in a rapid learning curve for new surgeons where they gain independence faster compared to the use of traditional techniques.[28]

There are also other, difficult to quantify and measure, learning curves taking place in the surgical setting. The value of having the same operating team where everyone knows what they should do and what is expected from them, increases the team-learning curve. To experience the unexpected multiple times together creates a team in which the assisting surgeon knows how to best perform close to the patient and the assisting nurses know how to position the robot optimally relative to the type of procedure and the physiology of the patient. For a low-volume robotic paediatric centre, it is crucial to gain experience across the speciality borders as well as sharing the costs associated with robotic surgery. If the department could manage to perform more than one operation per day this could decrease the cost per surgery. The lack of qualified operation nurses has made it necessary to cancel a few operations, despite having available operation slots, surgeons and suitable patients. This is an unacceptable bottle-neck that needs to be looked into by hospital management and regional council.

The measured outcomes after fundoplication show that the majority of the operated children had a good result overall. Both PPI use and asthma medication decreased significantly. A possible source of error could be that a few of the children, apart from those with gastro-oesophagial reflux disease, also had allergic asthma in which case the prescribed steroid inhalers post-operatively could have been intended for the indication of asthma instead of reflux disease. We did not specifically check the indications for the prescribed medicines for our patients, by doing so we would have probably improved our numbers. Neither did we discriminate between doses or varieties: all regular prescriptions were counted in our calculations. It is therefore possible that a few of the children could have had a positive result with respect to being able to lower their doses of medication or switch to a less potent medication. This was not evaluated. The 24 h pH and deMeester score measurements were also successful with a significant result and in line with our earlier studies. Apart from pH and deMeester results we have also demonstrated previously that robotic surgery is comparable to laparoscopic surgery and superior to open surgery with regard to the use of postoperative analgesics with morphine and post-operative hospital stay.[29] Although scheduled, not all children had their follow-up measurements at the same postoperative point of time, which might have influenced the results. Due to the non-ethical approach of putting patients under anaesthesia just to confirm a good operative result with deMeester or pH-measuring we changed our practice in follow-up, and we now only perform postoperative objective measurements in patients reporting symptoms of reflux.

The outcomes after pyeloplasty show that there is a significant improvement in hydronephrosis and pain after robotic surgery. A possible source of error to the AP measurements is that some US technicians interpret extrarenal hydronephrosis components as part of the AP measurement. To secure certain measurements it would be preferable to perform all pre- and post-operative measurements at the same centre, which unfortunately is not possible today since patients are referred to us from other hospitals in the region. There was no statistically significant worsening in renal function after surgery. We did not expect any amelioration though, consistent with McAleer and Kaplan's study comparing renal function before and after pyeloplasty where they found no postoperative statistical improvement in renal function.[30] Essentially, since renal function does not improve significantly after surgery it is important to consider pyeloplasty before renal function starts to deteriorate. There are, however, other studies which did report a significant improvement in postoperative renal function. Even if their limits differed from ours, we stipulated a stable condition as a change of <3% while they set a significant change at <5%[31]; this might be something to re-evaluate in the future. Only four (8%) patients had an impaired renal function at the last follow-up, even if the change was not statistically significant.

Apart from being safe, an investment in a new technology must be economically justifiable for ethical, as well as political, reasons. An often-overlooked point when making economic calculations of the feasibility of robotic surgery is the lack of a total cost-of-care analysis. Shorter hospital stays after surgery, and fewer readmissions and complications, all lead to cost-cutting in terms of hospitalisation expenses.[13] But when hospital stay is shortened it also leads to savings of lost parental wages and reimbursements from insurance companies—in the long run leading to societal gains and lower insurance contingents for all patients.[30] This study, as well as our previous studies, showed few serious complications and a shorter hospital stay for the pyeloplasty patients when compared to their openly operated counterparts.[9,31] de Lambert et al report a median hospital stay after robotic pyeloplasty of 8 days, including the day of admission to hospital 1 day prior to surgery. That would mean 6 days according to our way of calculating, making it double the time of stay compared to our openly operated patients.

However, there are more than monetary ways to estimate value. If open surgeries can be transformed successfully to laparoscopic ones by the help of the robot, the patient benefits are immense. Meehan et al reported being able to complete 20 different procedures that were never performed laparoscopically or thoracoscopically before, with the aid of the robot.[3] We share the same experience in our department: apart from fundoplication, pyeloplasty and cholecystectomy, all other operations have not been performed laparoscopically before. Other centres have also managed novel operations by robot or have successfully completed robotic 'redo' operations after failed open surgeries,[32–34] making robotic surgery suitable for the clinic and society. Our results in terms of feasibility, security and patient outcomes are comparable with the experience of other paediatric centres that have introduced robotic surgery.[3,11–15] We managed to perform robotic surgery on a variety of patients: our smallest patient was an infant undergoing fundoplication, weighing 6 kg at 6 months of age. At the other end of the scale, we performed a pyeloplasty successfully in a 15-year old patient weighing 84 kg.

Another important aspect in choosing surgical approach is patient and parent satisfaction. Lifelong scarring can decrease overall quality of life and scar appearance has been proven to be an important decision factor for parents and patients.[35,36] Many of our patients and their parents mentioned the quick healing and minimal scarring as an important factor for satisfaction after surgery, making this an interesting perspective to look into in future research.

A drawback in the study design is that the same parameters were not used for all procedures which makes them hard to relate to each other and difficult to analyse. At the same time, it is not possible to measure outcome in an equivalent way for all procedures, making this approach necessary. The outcomes after fundoplication and pyeloplasty have to be put into context with a 2014 report from Sahlgrenska University Hospital, Sweden stating that no clear benefits could be seen by using robot-assisted surgery for paediatric fundoplication and pyeloplasty.[37] However, according to Friedmacher et al, and contradicting the report from Sahlgrenska University Hospital, fundoplication and pyeloplasty have OCEBM (Oxford Centre for Evidence-Based Medicine) level 3 evidence.[4] Clearly, the knowledge base needs further evaluations. We firmly believe that there is a place for robotic surgery in our paediatric centre; if not for all procedures, at least for our two most commonly performed ones as well as the technically difficult procedures that can be turned from open-to robotic surgery.

There are also a few possible sources of error regarding the calculation of learning curves. First and foremost, all procedures were performed according to the medical needs of the patients, with the result that the same procedure was not done consecutively. During the study time, we have also trained two new surgeons and other medical staff. Additionally, the robots used have been upgraded during the study time, which might have influenced the surgeons' and the surgical team's collective performance and therefore the calculated learning curves. In pyeloplasty, the learning curves were also slowed in the middle of the study by switching from a retroperitoneal to a transabdominal approach.

There are several sources of error when comparing and calculating operative times. Some of our calculations are based on anaesthetic journals and not skin-to-skin times, which might have extended our calculated operative time. Another source of error is how different paediatric centres classify operative time when multiple procedures are performed during theatre time. For fundoplication patients, these additional procedures could be a gastrostomy tube placement, a hiatal hernia repair, or a pyloroplasty. In our calculations, all extended and advanced procedures are included, and not just pure fundoplications and pyeloplasties. Meehan et al report operative fundoplication times in a range from 122 min for a simple fundoplication, to 225 min for a fundoplication with a hiatal hernia.[22] It might be advantageous for future studies to investigate theatre times thoroughly to fully understand how time is spent.

During the past decade, we have introduced a robotic surgery programme successfully in our paediatric centre. Our operative times and conversion rates decreased continuously during the study period. Despite being a low-volume robotic paediatric centre, our outcomes after robot-assisted laparoscopic pyeloplasty and fundoplication are similar to those of other earlier studies. Robotic surgery is ideal in situations where there is an increased risk of bleeding or need for exact dissection. The patients who benefit the most from robotic surgery are those in whom surgery is most difficult to execute and those who require many procedures during their lifetime. More controlled trials and evaluations as well as further long-term outcome studies are necessary in the future. To implement a robotic programme offers constant development for the surgical profession, eventually translating into a better result for patients.

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CONFLICT OF INTEREST

All authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

Specific data such as operation time and type of surgery is available upon request. Age and sex and year of surgery, and other variables that potentially can identify a single patient, is not available.

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