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Review

Robotic surgery for paediatric neurogenic lower urinary tract dysfunction: a systematic review

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Objective

To evaluate in a systematic review the outcomes, benefits, and limitations of robot-assisted surgeries for paediatric neurogenic lower urinary tract dysfunction (LUTD), as robot-assisted techniques have emerged as a potential alternative, offering enhanced precision, dexterity, and visualisation.

Methods

This review was registered in the International Prospective Register of Systematic Reviews (PROSPERO identifier CRD42023464849) and adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. We included studies of paediatric patients (aged <18 years) with neurogenic LUTD undergoing robot-assisted continence surgery, assessing safety and efficacy. Literature searches in the Medical Literature Analysis and Retrieval System Online (MEDLINE), Excerpta Medica dataBASE (EMBASE), and Scopus were conducted until 12 July 2024. Data extraction included surgical procedures, complications, operative times, lengths of stay, and bladder function outcomes.

Results

A total of 42 studies (20 case reports, 10 case series, six cohort studies, six comparative cohort studies) were included. Robotic procedures for continent catherisable channel construction, augmentation cystoplasty, and bladder neck reconstruction showed comparable peri- and postoperative outcomes. Meta-analysis of five studies comparing robotic vs open appendicovesicostomy indicated a significant reduction in length of stay for robotic groups, while operative time, complications, and re-intervention rates were not significantly different. Conversions to open surgery were rare, indicated by adhesions or small appendices during channel constructions.

Conclusions

Robot-assisted surgeries for paediatric neurogenic LUTD demonstrate potential benefits, including reduced hospital stays and comparable complication rates to open surgery in certain contexts. However, the available evidence is limited by heterogeneity in study designs, small sample sizes, and single-centre experiences, which constrain generalisability. Standardised reporting of complications and outcomes, alongside multicentre studies, is essential to clarify the long-term efficacy and broader applicability of these techniques.

Keywords

neurogenic bladder, neurogenic lower urinary tract dysfunction, robotics, cystoplasty, appendicovesicostomy, reconstruction, review

Introduction

Neurogenic lower urinary tract dysfunction (LUTD) is a condition characterised by impairment of the lower urinary system due to neurological injury, affecting the ability to store and empty urine safely. Neurogenic LUTD in paediatrics often arises from congenital or acquired diseases, including spina bifida, cerebral palsy, spinal cord injuries, among other neurological disorders. The incidence of neurogenic LUTD varies, with spina bifida alone affecting approximately four in 10 000 live births in the United States [1]. Management is multi-faceted, using behavioural modifications including clean intermittent catheterisation and pharmacotherapy like anticholinergics aimed at improving bladder function and preventing complications [2]. When conservative treatments are insufficient, surgical interventions are necessary to enhance bladder capacity, treat high-pressure bladders, and prevent renal deterioration.

The introduction of robotic systems has revolutionised the surgical landscape by offering enhanced precision, improved dexterity, and better visualisation. Technological progression has paved the way for exploring the potential benefits of robotic surgery in neurogenic LUTD. Early experiments from the 2000s showcased robot-assisted augmentation cystoplasty (AC) and appendicovesicostomy (APV) in children [3,4]. Since then, surgeons across the globe have utilised robotic assistance for procedures including continent appendicostomy or antegrade continence enema (ACE) and bladder neck reconstruction (BNR). Accordingly, a 2023 narrative review by Upasani et al. [5] outlines recent and technical updates for robotic lower urinary tract reconstruction in children.

Despite these advancements, controversy persists regarding functional bladder outcomes and comparative efficacy of robot-assisted surgeries in this context. Factors such as increased operative time, the learning curve for new procedures, and cost–benefit considerations for acquiring and maintaining robotic systems in paediatric centres pose barriers have been cited as barriers widespread adoption [6,7]. Additionally, challenges like limited abdominal space in paediatric patients alongside variations in port configurations for smaller patients complicate standardisation and raise questions about optimal approaches for specific procedures [8]. For patients with neurogenic LUTD, early series point to comparable functional outcomes and complications, but heterogeneity in reported procedures and mainly single-centre or single-surgeon experiences limits interpretability [9]. Overall, the limited number of studies and varying results have led to ongoing debates among paediatric surgeons.

To address these uncertainties and provide a clear understanding of the impact and utility of robotic surgery in treating paediatric neurogenic LUTD, a comprehensive systematic review of the literature from the past 20 years is essential. We hypothesised that robot-assisted techniques yield comparable or superior outcomes to traditional open surgical methods in terms of bladder function and surgical complications, while demonstrating feasibility across a variety of reconstructive procedures. We also aimed to evaluate recovery metrics like length of stay alongside procedural details including operative time and port usage that are important for practical adaptation.

Methods

Study Registration

The protocol for this research was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the identifier CRD42023464849. This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [10].

Eligibility Criteria

We included studies that met all the following criteria: paediatric patients (aged <18 years) diagnosed with neurogenic LUTD, undergoing bladder surgery with a robot-assisted approach, and reported outcomes in terms of safety, efficacy, and/or surgical outcomes like continence or leakage among others. No exclusions were made based on the cause of neurogenic LUTD, including various conditions like spina bifida, spinal cord injuries, or prior pelvic surgeries among others. We included case reports, case series, and cohort studies from both published articles and conference abstracts. We excluded narrative reviews, scoping reviews, systematic reviews, and meta-analyses.

Information Sources and Screening Process

Three independent reviewers (I.A., P.Y., and D.A.) conducted both electronic and manual literature searches up to 12 July 2024, using the following databases: the Medical Literature Analysis and Retrieval System Online (MEDLINE), Excerpta Medica dataBASE (EMBASE), and Scopus. Search terms included 'robotic' or 'robotic assisted', 'paediatric' or 'children' or 'adolescent', and 'neurogenic bladder' or 'neuropathic bladder'. No language restrictions were applied. Studies describing neurogenic LUTD surgeries managed with a robotic approach were included. Titles and abstracts were initially screened to exclude unrelated studies. Studies were excluded for having adult patients, patients without neurogenic LUTD, unrelated surgical procedures like pyeloplasty or ureteric re-implantation alone, or a lack of robotic assistance. Reference lists of included studies were also reviewed for additional relevant publications. A manual search of related journals on Google Scholar was performed to identify any missed studies. All identified citations were uploaded to Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia) to facilitate the screening process. A detailed account of screening strategies is available in Appendix S1.

Data Extraction

Two reviewers (P.Y. and D.A.) independently screened the titles, abstracts, and full texts of the identified studies based on the eligibility criteria established a priori. Relevant information from the included studies was collected using a standardised data extraction form, including design, sample size, patient demographics, details of robotic surgical procedures, conversion rates, peri- or postoperative complications, length of stay, operative time, surgical revisions, and bladder function outcomes. Total complication rate was defined with the inclusion of any intra- or postoperative surgical event that was averse to the outcome of the procedure. Surgical revision was defined a priori as return to the operating room at any point during follow-up for procedure involving the urinary tract, bowel with augmentation/channel, or for any stomal procedures. Functional bladder outcomes included continence, persistence leakage, bladder capacity, and bladder compliance among others. Functional outcomes were assessed by type of procedure: catherisable channel construction with the aim of facilitating emptying without stomal leakage; cystoplasties with the aim of improving bladder capacity and/or compliance; and BNRs with the aim of facilitating bladder emptying. All outcomes from studies were measured throughout the respective established follow-up time. Disagreements during screening and data extraction were resolved through discussion and consensus between the reviewers.

Data Synthesis

Data extracted from the studies were summarised in tables and descriptive text, with studies categorised by the performed robot-assisted surgical procedures. Descriptive figures trending operative time, length of stay, and complication rate from studies over time were generated. With consideration to generalisability for operative time and length of stay, studies were only included in these descriptive figures if they did not include concomitant procedures except for ACE. For complication rate, studies were only included in this descriptive figure if they analysed five or more patients and at least 50% of the cohort did not undergo concomitant procedures except for ACE. We were more tolerant of concomitant procedures for complication rate due to both the excepted small number of studies available and to better reflect the real-world practical results of these procedures.

Quality and Risk of Bias Assessment

The quality of included studies was assessed using validated tools for each specific study design. For non-randomised cohort studies, the Risk of Bias in Non-randomised Studies of Interventions (ROBINS-I) tool was used [11]. For case reports and case series, the Joanna Briggs Institute (JBI) critical appraisal tools for case series or case reports were used to appraise validity, risk of bias, and clarity [12]. Two reviewers (I.A. and P.Y.) independently assessed the risk of bias for each included study, with disagreements resolved by consulting a third reviewer (D.A.).

Statistical Analysis

Due to the anticipated variability in study designs, neurogenic LUTD aetiology, and specific procedures, a comprehensive meta-analysis was not planned. Findings from comparative studies against open techniques for APV, which was expected to be the most prevalent procedure, were planned for meta-analysis in consideration of data availability. Statistical significance was set at $P < 0.05$. A random-effects model was employed to calculate all effect estimates along with their 95% CIs. For binary outcomes, risk ratios (RRs) were derived by comparing the count of reported outcomes to those at risk in each group. For continuous outcomes, standardised mean differences (SMDs) were computed. Cochran's Q-test (chi-squared) and the I^2 statistic was used to assess and quantify the statistical heterogeneity between the studies respectively [13]. The analysis was conducted using R, version 3.6.3 (R Foundation for Statistical Computing, Vienna, Austria). Descriptive statistics across all studies were reported when relevant. All study findings were synthesised narratively, with studies grouped and described based on relevant characteristics.

Results

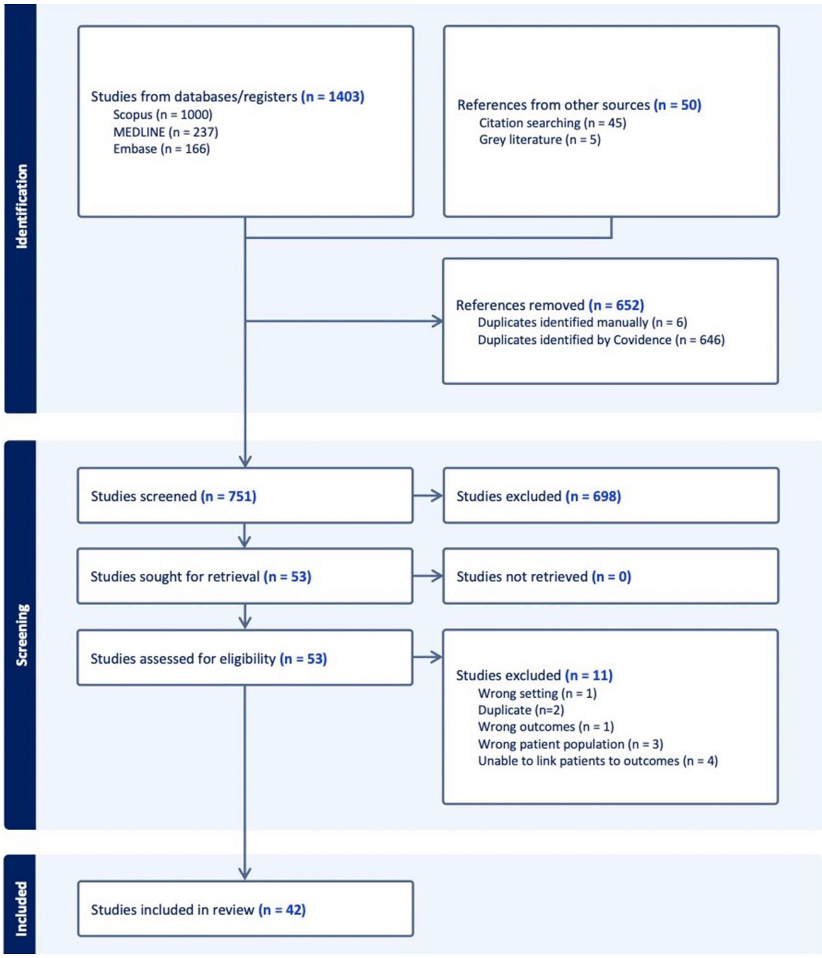
Study Selection

The literature search identified a total of 853 citations (a detailed search strategy is available in Appendix S1). After the removal of duplicates, 745 studies were subjected to a preliminary screening of titles and abstracts. This led to the exclusion of 693 citations that did not satisfy the pre-defined eligibility criteria. The remaining 52 studies underwent a full-text review, resulting in the exclusion of an additional nine studies due to reasons such as wrong setting/ patient population and lacking relevant outcomes. Ultimately, 42 studies were incorporated into this systematic review. The selection process is depicted in the PRISMA flow diagram (Fig. 1).

Study Designs and Overview

The studies included in the review comprised 20 case reports [3,4,14–31], 10 case series [32–41], six cohort studies [42–47], and six comparative cohort studies against open surgery [48–53], all published between 2004 and 2023. The surgical procedures covered were Mitrofanoff APV, Monti enterovesicostomy, appendicostomy or ACE, AC, and BNR. Table S1 provides a summary of the main findings and outcomes from all studies, detailing complications, conversions to open surgery, and reported bladder outcomes. A detailed account of perioperative parameters, including port

Fig. 1 The PRISMA workflow diagram detailing the process of this systematic review.



placement, operative times, and lengths of hospital stay, is presented in Table S2. Table S3 outlines specific definitions or lack thereof for functional bladder outcomes like continence improvement and leakage presented by each study. We have further separated these by type of procedure: catherisable channel construction, cystoplasties, and BNR. We performed a meta-analysis on five comparative studies with robotic vs open APV [33,48,49,52,53], focusing on operative and bladder outcomes.

Continuing, Fig. S1 shows graphical trends for operative time [3,4,14,16–19,21,26–28,31–33,35,36,41,42,44,46,50,51,53], length of stay [3,4,14,16,19,21,28,32,33,35,36,42,44,46,50,51,53], and complication rates [33–35,38,42,43,47–51,53] for studies over time. No clear trends were identifiable with the present data between procedures over time.

Continent Channel Construction

Most of the included studies reported on the construction of continent catherisable channels with or without concomitant procedures [3,4,14–16,18,20,22–30,32,33,36–43,45–50,52,53]. Seven studies reported on APV alone [4,18,28,33,41,46,48,53], two reported on APV revisions [20,39], two reported on ACE construction [23,45], and one reported on a catherisable ureterostomy [25]. The remaining studies presented a variety of concomitant procedures alongside catherisable channel construction.

From inception until today, the use of four to five ports has been standard for these robotic procedures. For example, Gundeti et al. [3] up to Galansky et al. [52] describe an umbilical or supraumbilical camera port with or without open Hasson technique, two midclavicular working ports, and one or two assistant ports in the abdominal quadrants. Recently, three-port techniques have been described using a supraumbilical camera port, midclavicular working port, and opposing subcoastal assistant port [26,47]. The possibility of a single port approach has been explored in two newer studies, using prior gastrostomy tube site for entry [28,41]. The mean operative time for continent catherisable channel construction without concomitant procedures ranged from 120 to

555 min, while with concomitant procedures ranged from 300 to 600 min. Intraoperative complications were substantial, ranging from 16% to 50% in included cohorts. Complications included infections, urine leaks, bowel obstructions, and stomal stenosis among others detailed in Table S1. Conversion to open technique was rare among published studies, with cohorts reporting a range between 10% and 25%. Reasons for conversion included mostly small appendix or adhesions. Length of stay was variable ranging between 1 and 15 days.

Bladder outcomes for catherisable channel construction focused on stomal continence and patency. Continence was defined by 16 studies as lack of any reported urine leakage from stoma [3,4,14,18,30,32–35,42,46,47,49,52], by two studies as lack of reported urine leakage from stoma between 4-h catheterisation intervals [38,53], one study as lack of urine leakage from stoma following 250 mL bladder instillation [20], and one study as one or fewer episodes of reported urine leakage from stoma per week [40]. Persistent leakage was defined by one study as urine leakage from stoma despite conservative measures [48], by two studies as urine leakage from stoma despite conservative measures that required further continence procedures [43,50], by three studies as urine leakage from stoma despite interim anticholinergic therapy [27,33,36], and by one study as urine leakage from stoma despite maximised anticholinergics with onabotulinumtoxinA injections in addition to dextranomer/hyaluronic acid injections [39]. Faecal continence for ACE and cecostomy constructions was defined by one study as lack of gas or stool leakage from stoma in addition to no involuntary passage of stool at any time [14] and by one study as a lack of gas or stool leakage from stoma in addition to one or fewer episodes of involuntary passage of stool per week [40]. Five studies mentioned urinary/faecal continence but did not define them [16,23,25,29,37]. In the context of these differing definitions, we found that favourable continence rates were maintained in all studies, ranging from 70% to 100%. Although rates of surgical re-intervention were considerable, ranging from 10% to 43% in included cohorts. Issues like channel stenosis and urine leakage necessitated further procedures.

Our meta-analysis compared robotic and open approaches for APV with or without concomitant procedures for key intra- and postoperative outcomes, as described in Fig. S2. Four studies [33,48,52,53] reported on overall complication rate and pooled effect analyses did not find a significant difference (RR 1.03, 95% CI 0.66–1.67; P = 0.90). Similarly, four studies [33,48,52,53] reported on the need for surgical re-intervention and pooled effect analyses did not find a significant difference (RR 0.84, 95% CI 0.55–1.31; P = 0.45). Incontinence at follow-up was reported by four studies [48,49,52,53] and pooled effect analyses did not discern a significant difference (RR 0.89, 95% CI 0.36–2.19; P = 0.80). Pooled analyses for complications, surgical re-interventions, and incontinence did not have a high percentage of total variability due to between-study heterogeneity measured through the I^2 statistic. Continuing, three studies [49,52,53] examined operative time and pooled effect estimates found no significant difference between robotic and open groups (SMD 164 min, 95% CI −27 to 356 min; P = 0.09). Although estimates had a high percentage of total variability due to between-study heterogeneity (I^2 = 96%, P < 0.01) and earlier studies found greater differences between groups than later studies. Length of stay was examined by three studies [49,52,53] and pooled effect estimates showed that robotic groups had significantly shorter lengths of stay compared to open groups (SMD −5 days, 95% CI −8 to −2 days; P < 0.01). Although pooled estimates had a high percentage of total variability due to between-study heterogeneity (I^2 = 73%, P = 0.03).

Cystoplasties

Cystoplasty was described in the literature on its own or more often with concomitant procedures, especially APV. A total of five studies presented AC alone [17,19,31,44,51] and one reported on a reduction cystoplasty [44]. A single retrospective comparative study was available in the literature comparing AC alone with a robotic or open approach [51]. A single study showcased AC with a catherisable ureterostomy [25]. AC together with APV was reported by 12 studies [3,15,26,34,35,37,38,42,43,47,49,52].

Much like channel construction, port usage for cystoplasty similarly consisted of a four- to five-port technique with newer studies experimenting with a three-port technique [26,47]. Operative time had a wide range between studies, with AC alone ranging from 287 to 623 min, and AC with concomitant procedures ranging from 240 to 600 min. Intraoperative complications were variable, ranging from 0% to 47% for studies reporting on AC alone. The Cohen et al. [51] comparative study showed comparative overall complication rates with 53% for open and 47% for robotic groups. Specific complications included stomal stenosis, keloid formation, and bladder neck dehiscence are detailed in Table S1. No conversions to open technique were reported from studies on AC alone. Length of stay for studies with AC alone was variable, ranging between 6 and 11 days.

Bladder outcomes for cystoplasties focused on improving bladder capacity and/or compliance, as well as urethral or stomal continence as appropriate. Follow-up bladder capacity was assessed by two studies with catheter outputs [3,35], by three studies assessed with video urodynamic study (VUDS) [17,42,44], by three studies with catheter outputs or VUDS [47,49,51], and by two studies with cystography [19,31]. For studies without concomitant channel construction, continence was defined by two studies as a lack of urine leakage from urethra [44,47], by two studies as lack of urine leakage from urethra or stoma between 4-h catheterisation intervals [17,31], and by two studies assessed with cystography showing no urine leakage with filling [19,31]. Persistent leakage was defined by one study as involuntary urine leakage from urethra or stoma that did not improve with conservative measures [51]. Continence rates were favourable ranging from 73% to 100%. All studies reported increases in functional bladder capacity with Cohen et al. [51] showcasing a 150% increase in their robotic group compared to 73% in their open group.

Bladder Neck Reconstruction and Continence Surgeries

Robot-assisted BNR was described in the literature only alongside concomitant procedures [16,21,24,27,29,32,36–38,40,49,50,52]. However, seven studies featured BNR particularly as a part of their study objective [16,21,24,27,32,36,50]. A single retrospective comparative study focused on BNR with continent APV or enterovesicostomy [50].

Port placement has been consistent with a four- to five-port approach like cystoplasties and channel constructions. Storm et al. [32] up to Yang et al. [24] exemplified the use of an umbilical or supraumbilical camera port, two midclavicular working ports, and one or two assistant ports in the abdominal quadrants. Recently, Rodriguez et al. [27] experimented with a three-port approach with open Hasson technique and single opposing working and assistant ports. From studies that had a focus on BNR [16,21,24,27,32,36,50], the mean operative time including concomitant procedures ranged from 189 to 543 min. From these same studies, intraoperative complications were rare, with only the Grimsby et al. [50] comparative cohort reporting any complications at all, at a rate of 16%. Their open group had a similar complication rate of 12%. The reported complications included ileus, bowel obstruction, and UTI. Although the rest of these studies were case reports and small case series that may not be truly representative. Only two studies had conversions to open surgery, reporting a 25% and 15% rate of conversion respectively [36,50]. Reasons for conversion included small appendix or adhesions. Length of stay from studies that focused on BNR was favourable ranging between 1 and 7 days. Grimsby et al. [50] reported equal lengths of stay between their robotic and open groups at 4 days for both groups.

Bladder outcomes for BNR focused on resolving urinary leakage and improving emptying. For studies featuring BNR as a main procedure, persistent leakage was defined by two studies as urine leakage from urethra despite interim anticholinergic therapy [27,36] and by one study as urine leakage despite conservative measures that required further continence procedures [50]. Three studies mentioned urinary leakage but did not define it [16,21,24]. Overall, functional results for BNR-focused procedures showed inconsistencies. Case reports and case series highlighted continent, low-pressure bladders without trabeculation at follow-up. But the comparative cohort analysis from Grimsby et al. [50] reported that 42% of their robotic group required additional surgery to maintain continence and 16% underwent a subsequent AC at a follow-up of 28 months. Their open group had similar results, with 54% requiring additional continence surgery and 35% undergoing subsequent AC.

Assessment of Bias

For retrospective cohort studies, the ROBINS-I tool showed that one study had a low risk of bias [49], 10 studies had a moderate risk of bias [42–44,46–48,50–53], and one study had a serious risk of bias [45] (Table S4).

The JBI Checklist for Case Series revealed that two studies had a low risk of bias [34,35], five studies had a moderate risk of bias [32,33,36,38,39], and three studies had a serious risk of bias [37,40,41] (Table S5).

The JBI Checklist for Case Reports indicated that 13 studies had a low risk of bias [3,4,14,17,18,22,23,25,28–31], whereas seven case reports had a moderate risk of bias [15,19–21,24,26,27] (Table S6).

Discussion

We present the first systematic review on robot-assisted procedures for neurogenic LUTD. We highlight the increasing global utilisation of this approach in children for continent catherisable channel construction, cystoplasty, and BNR. Additionally, the ubiquity of complex contaminant procedures emphasises how surgeons are continuing to push the boundaries of what is possible in this age group. While operative times have been found to be longer, a benefit in length of stay has been identified as an important trade-off. Otherwise, postoperative complications and functional bladder outcomes continue to be promising and comparable to the open approach. Conversions to open surgery were rare and mostly indicated by adhesions or small appendices during channel constructions. Our meta-analysis from five studies on robotic vs open APV shows that length of stay was significantly reduced for robotic groups, while operative time, total complications, surgical re-intervention rates, and incontinence rates at follow-up were not significantly different.

Our work adds new insights to the findings of previous reviews on paediatric robot-assisted urological procedures. Early scoping reviews by Muneet et al. [54] and Chaussy et al. [55] emphasised the sparsity and technical difficulty of neurogenic LUTD procedures in this context. They had concerns that the limited space available within the paediatric abdomen made complex intracorporeal manoeuvres challenging. In contrast, recent reviews have been optimistic about the adoption and feasibility of robotic neurogenic LUTD surgeries [5]. Andolfi et al. [56] and Hou et al. [57] described a variety of indications for robotic assistance in this population with overall favourable outcomes. Newer literature does not emphasise technical challenges to be a limiting factor to the uptake of this technology. Our systematic review provides a detailed account of the increasing utility of robotics in a variety of neurogenic LUTD procedures. We show the flexibility of robotic platforms by using different port numbers and approaches to overcome technical considerations. Supporting the conclusions of more recent reviews, we affirm that robotic platforms for neurogenic LUTD reconstruction continue to be widely adopted with non-inferior or superior outcomes to open approaches.

Our analysis identified the strengths of a robot-assisted approach for neurogenic LUTD reconstruction. A growing body of evidence supports paediatric reconstructive procedures as well suited for a robotic platform. O'Kelly et al. [58] discuss how motion scaling, magnification, enhanced instrument dexterity, and tremor reduction naturally align with the more sensitive nature of paediatric surgery. From our review, Gundeti et al. [34,43] support this by highlighting these benefits during intracorporeal anastomoses for ileocystoplasty. While overall complications were found to be similar in comparative studies, a consistent improvement in length of stay over time is a strong indication that the benefits of robotic surgery are manifesting for these procedures.

The potential weaknesses of robot-assisted surgery for this population should also be carefully considered. We identified operative time to be consistently greater during robotic procedures. Our meta-analysis for APV did not find a significant difference in operative time even if it was higher in robotic groups, but this result was affected by between-study heterogeneity and small study effect. Although, we observed that recent cohorts [52,53] are seeing more similar operative times compared to older cohorts [49]. This may be an indication that surgeons are becoming more proficient over time and that increased operative time may become a less substantial consideration as we develop this technology. The learning curve for robotic procedures has also been left unaddressed in this specific context. Promising reports from various robotic paediatric urology training programmes show favourable learning curves [59], at least more favourable than laparoscopic procedures [60]. While high cost has traditionally been considered one of the main challenges for the adoption of this technology, modern studies have questioned this assumption. A 2012 analysis by Rowe et al. [61] found that reduced length of stay for robot-assisted urological procedures led to a significant 12% reduction in direct cost compared to open surgery. But together with newer studies [62], it is clarified that cost-effectiveness benefits only hold in high-volume centres. Low-volume and low-resource settings will likely still find it challenging to justify the acquisition and maintenance of a robotic platform for paediatric urologists.

There are limitations to our findings that are important to discuss. Most included studies were case reports that included concomitant procedures, which introduces a risk of selection bias. The wide range of follow-up periods further complicates the assessment of the long-term viability and success of these robotic procedures. This variability makes it difficult to apply the results of this review to specific clinical cases. This is further constrained by notably short follow-up periods (<2 months) for several included case reports that may limit true assessment of long-term outcomes [3,17,19,20,25,27,36]. Furthermore, the cohort studies mainly reflected the experiences of individual institutions, which may not accurately represent the practices of the wider surgical community, thereby limiting the broader applicability of our findings. Our meta-analysis on robotic vs open APV is also limited in its scope and generalisability. Only five studies are included, with pooled analyses for operative time and length of stay limited to three studies that suffered from concerns of between-study heterogeneity. Future studies should focus on directly comparing robot-assisted surgeries to traditional laparoscopic procedures for paediatric neurogenic LUTD, as this comparison is critical but absent in the literature. Low-volume or low-resource settings may be better suited to traditional laparoscopy, but its comparative outcomes are yet unknown. Future studies should also make consistent use of the Clavien–Dindo classification for surgical complications, which is sparingly featured in current literature and would prevent further variability in reporting standards for operative or postoperative events. Additionally, long-term outcomes and cost-effectiveness analyses in diverse clinical settings should be prioritised to better understand the broader applicability and sustainability of robotic techniques. Investigating the learning curve and training requirements for surgeons new to robotic platforms will also be crucial to optimise their integration into paediatric urology. Measuring comparative quality of life using validated instruments and scores is a vital element of surgical planning for patients with neurogenic LUTD that is currently absent from the literature. Future studies should incorporate quality-of-life measurement in addition to surgical outcomes to complete a holistic assessment of these procedures. Lastly, multicentre studies with standardised protocols can help mitigate biases and provide more generalisable results.

Conclusion

This systematic review provides an overview of the increasing adoption of robot-assisted surgeries for paediatric neurogenic LUTD, reflecting a growing interest in their application. The results suggest that robot-assisted techniques may offer benefits such as reduced length of stay compared to open approaches, while showing comparable rates of complications and functional outcomes in certain contexts. However, the evidence remains limited by heterogeneity in study designs, small sample sizes, and predominantly single-centre experiences which constrain generalisability. Longer operative times and a lack of standardisation in complication reporting further point to the need for caution in drawing definitive conclusions. Future research should focus on multicentre studies with standardised protocols to evaluate the long-term efficacy, safety, and cost-effectiveness of robot-assisted procedures compared to both open and traditional laparoscopic approaches. Consistent use of validated classifications for complications and outcome metrics is essential to enhance comparability across studies. Moreover, incorporating quality-of-life assessments will provide a more comprehensive understanding of the impact of these techniques on patients' outcomes.

Disclosure of Interests

The authors do not report any financial or non-financial competing interests pertaining to this work.

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Abbreviations: AC, augmentation cystoplasty; ACE, antegrade continence enema; APV, appendicovesicostomy; BNR, bladder neck reconstruction; JBI, Joanna Briggs Institute; LUTD, lower urinary tract dysfunction; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; ROBINS-I, Risk of Bias in Non-randomised Studies of Interventions; RR, risk ratio; SMD, standardised mean difference.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Fig. S1. Trending operative time (A), length of stay (B), and total complication rate (C) for robotic neurogenic bladder procedures by studies from 2004 to 2024. Included surgeries encompass APV, AC, simultaneous APV and AC, and bladder neck dissection (BNR).

Fig. S2. Comparison of robotic vs open approach for Mitrofanoff APV with or without concomitant procedures using forest plot pooled effect estimates for selected outcomes: overall complications (A), surgical re-intervention rate (B), urinary incontinence (C), operative time (D), and length of stay (E).

Table S1. Included study characteristics, described complications, and bladder outcomes.

Table S2. Perioperative parameters for robotic procedures of included studies.

Table S3. Included study functional outcomes definitions.

Table S4. Bias risk assessment using the ROBINS-I tool for included cohort studies.

Table S5. Bias risk assessment using the JBI Checklist for Case Series tool for included case series.

Table S6. Bias risk assessment using the JBI Checklist for Case Reports tool for included case reports.

Appendix S1. The MEDLINE search strategy is provided below, from inception until July 12th, 2024.