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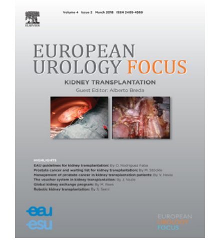

Review – Neuro-urology

Pediatric Neurogenic Bladder and Bowel Dysfunction: Will My Child Ever Be out of Diapers?

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Abstract

Context: Managing patient and parent expectations regarding urinary and fecal continence is important with congenital conditions that produce neurogenic bladder and bowel dysfunction. Physicians need to be aware of common treatment algorithms and expected outcomes to best counsel these families.
Objective: To systematically evaluate evidence regarding the utilization and success of various modalities in achieving continence, as well as related outcomes, in children with neurogenic bladder and bowel dysfunction.
Evidence acquisition: We performed a systematic review of the literature in PubMed/Medline in August 2019. A total of 114 publications were included in the analysis, including 49 for bladder management and 65 for bowel management.
Evidence synthesis: Children with neurogenic bladder conditions achieved urinary continence 50% of the time, including 44% of children treated with nonsurgical methods and 64% with surgical interventions. Patients with neurogenic bowel problems achieved fecal continence 75% of the time, including 78% of patients treated with nonsurgical methods and 73% with surgical treatment. Surgical complications and need for revisions were high in both categories.
Conclusions: Approximately half of children with neurogenic bladder dysfunction will achieve urinary continence and about three-quarters of children with neurogenic bowel dysfunction will become fecally continent. Surgical intervention can be successful in patients refractory to nonsurgical management, but the high complication and revision rates support their use as second-line therapy. This is consistent with guidelines issued by the International Children's Continence Society.
Patient summary: Approximately half of children with neurogenic bladder dysfunction will achieve urinary continence, and about three-quarters of children with neurogenic bowel dysfunction will become fecally continent. Most children can be managed without surgery. Patients who do not achieve continence with nonsurgical methods frequently have success with operative procedures, but complications and requirements for additional procedures must be expected.

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1. Introduction

Congenital spinal dysraphism accounts for the vast majority of cases of neurogenic bladder and bowel dysfunction in the pediatric population [1]. Rarer etiologies include urologic or anorectal malformations (eg, bladder exstrophy and imperforate anus), as well as acquired injuries from spinal cord/brain trauma or central nervous system tumors. Disruption

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of sensory and/or motor input to the bladder, urinary sphincter muscles, rectum, and anal sphincter results in urinary and gastrointestinal dysfunction.

Management of neurogenic bladder is critical to the prevention of life-threatening renal failure. The introduction of modern multimodal treatments including both nonsurgical and surgical techniques has resulted in increased life expectancy of patients with spina bifida (SB) [2]. With patients living longer, there is increasing focus on urinary continence. As better quality of life (QoL) research instruments have become available, it is apparent that patients enjoy better lives with successful management of urinary incontinence [3]. Although bowel dysfunction rarely leads to life-threatening complications, constipation and soiling have similar significant consequences on patient well-being. Therefore, it is incumbent on treating physicians to address both urinary and fecal continence, as well as associated issues, such as urinary tract infections (UTIs) and constipation, to maximize patients' QoL.

2. Evidence acquisition

2.1. Search strategy

A systematic PubMed/Medline search was conducted in August 2019 using Medical Subject Headings (MeSH) terms "neurogenic bladder" and "neurogenic bowel." Using Boolen techniques, we utilized the following additional MeSH terms: "neurogenic bladder AND sling, suburethral"; "neurogenic bladder AND artificial urinary sphincter"; "neurogenic bladder AND agents, anticholinergic"; "neurogenic bladder AND oxybutynin"; "neurogenic bowel AND fecal incontinence"; "neurogenic bowel AND enema"; "neurogenic bowel AND neuromodulator"; "neurogenic bowel AND electrical stimulation." To capture additional research beyond MeSH terminology, we also use the following keywords with our main MeSH terms: "neurogenic bladder AND intermittent catheterization"; neurogenic bladder AND augmentation"; "neurogenic bladder AND Mitrofanoff"; "neurogenic bladder AND bladder neck reconstruction"; "neurogenic bowel management"; "neurogenic bowel AND antegrade enema."

2.2. Study selection

All authors contributed to the design of the search strategy and inclusion criteria. All authors reviewed the final list of reviewable publications and ensured that they met the inclusion criteria. Study eligibility was defined using patient population, intervention, comparator, outcome, and study design.

There was no temporal restriction for bladder management. For the bowel management review, included publications dated after 1986, which marked the introduction of retrograde colonic enemas (RCEs), an important component in the modern therapy for neurogenic bowel [4]. Publications were included if they assessed neurogenic bladder or neurogenic bowel in humans. Study interventions included surgical and nonsurgical treatments. Regarding neurogenic bladder, nonsurgical management included clean intermittent catheterization (CIC), anticholinergic medications, and botulinum toxin; surgical management included bladder augmentation, continent catheterizable channels (CCCs), bladder outlet procedure, and artificial urinary sphincter (AUS). In evaluating patients with neurogenic bowel, nonsurgical management included RCEs, biofeedback, diet and behavioral therapy, neuromodulation, anal plugs, digital stimulation, and oral laxatives. Surgical management included Malone antegrade colonic enema (MACE or ACE), and Chait tube. Studies were limited to original articles available in the English language. Review articles, meta-analyses, case reports, meeting abstracts, editorials, and commentaries were excluded. Where multiple studies reported on the same patient population, only the most recent study was included. For the urinary management section, we limited the inclusion of reports with at least 50 patients and a majority of participants 0–18 yr old. For the review on neurogenic bowel management, studies had to include at least 20 patients and a majority of participants 0–18 yr old with neurogenic bowel as a diagnosis. There were no criteria regarding the inclusion or type of a control/comparator group. The primary outcome of interest was urinary or fecal continence. Secondary outcomes of interest included renal function, UTIs, QoL, or surgical complications/revisions.

2.3. Data abstraction

All authors independently reviewed full-text manuscripts that met the inclusion and study eligibility criteria. Abstracted data included total number of patients, underlying disorder, patient age, study design, treatment intervention, definition, and results of primary (continence) and secondary (renal function, UTIs, QoL, and surgical complications/revisions) outcomes. If definitions or results of outcomes were not included in the text, we noted these missing data.

2.4. Data synthesis

Overall urinary and fecal continence rates were calculated from studies that reported the exact numbers of patients who achieved a strictly defined continence result. The total number of patients studied and the total number of continent patients from each included study were averaged to obtain continence rates. This was performed for nonsurgical and surgical management of urinary and fecal incontinence, as well as surgical complication and revision rates for surgical management of neurogenic bowel. This was not performed for surgical management of neurogenic bladder owing to the great heterogeneity of surgical interventions.

3. Evidence synthesis

3.1. Management of neurogenic bladder

The flow diagram of the neurogenic bladder literature search and results is shown in Figure 1. A total of 49 studies

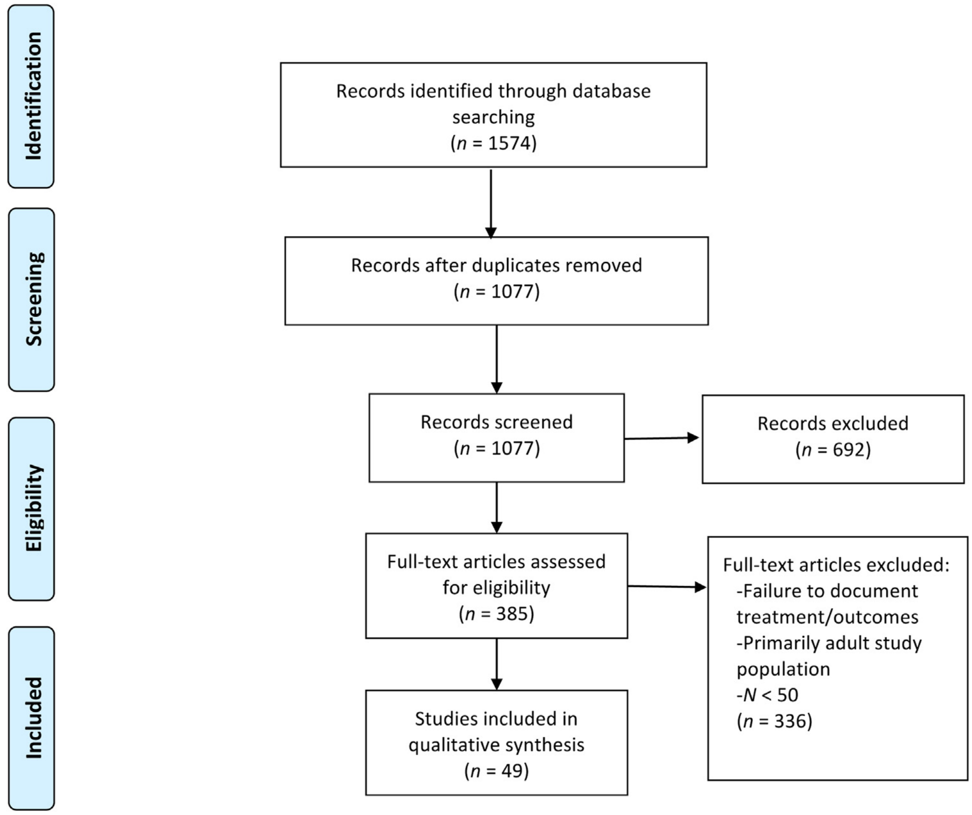

Fig. 1 – Flow diagram for neurogenic bladder review.

were included in the review: 24 studies for nonsurgical management (Table 1) [5–28] and 27 studies for surgical management (Table 2) [7,19,29–53]. The majority of patients enrolled in these studies had SB. Other diagnoses included neurogenic bladder disorders (eg, non-neurogenic neurogenic bladder, idiopathic detrusor overactivity, and detrusor sphincter dyssynergia), congenital urologic pathology (eg, bladder exstrophy/epispadias complex, cloacal exstrophy, and posterior urethral valves), and spinal cord pathology (sacral agenesis, spinal cord injury, and spinal cord malignancy). Only three studies were randomized controlled trials (RCTs) [18,21,24]. Two studies were open-label prospective studies assessing anticholinergic therapy [5,15]. There were no RCTs or prospective studies that addressed surgical neurogenic bladder management. Six studies were multi-institutional [12,13,15,19,21,23].

Data were obtained from retrospective chart review [6–9,11,14,16,17,20,22,23,25–30,32,33,35–39,41–44,47–53], prospective open-label studies, and patient-reported outcomes (satisfaction and QoL questionnaires) [6,19,21,22,32,53], including three multicenter surveys [12,13,19]. Four studies, all of which addressed surgical management, utilized national administrative databases [34,40,45,46].

The primary outcome in our review was urinary continence. The definition of continence widely varied and/or was completely undefined. Studies that defined continence as complete dryness, total absence of leakage, and/or no usage of protective pads were utilized to calculate an overall continence rate. Including both nonsurgical and surgical management, 445/895 (50%) children achieved complete urinary continence [5–9,11,20,25,26,32,41,49,50]. Studies were divided into nonsurgical and surgical management to further evaluate continence and other outcomes of interest.

3.1.1. Nonsurgical management of neurogenic bladder

Table 1 includes the 24 studies that addressed nonsurgical management of neurourologic disorders [5–28]. These papers included 16 studies CIC [6–8,10–13,15,17–21,24,27,28], six studies on anticholinergic medications [5,14,15,20,23,27], three studies on botulinum toxin [16,25,26], and one study on intravesical electrical stimulation [9]. While certain studies specifically focused on a single intervention, many patients were managed with multiple interventions highlighting the multimodality nature of treatment plans. CIC protocols were defined in only two studies [8,20]. Two studies evaluated the impact of catheter type (hydrophilic vs polyvinyl chloride and single use vs reusable) on CIC outcomes [21,24]. Patients utilized multiple anticholinergic medications, but solifenacin and oxybutynin were individually investigated in multicenter reviews or prospective open-label trials [5,14,15,23]. Evaluations of both onabotulinumtoxinA and abobotulinumtoxinA injected intravesically and intersphincterically were identified [16,25,26].

Table 1 – Nonsurgical management of neurogenic bladder—study characteristics and outcomes.

Reference	Patients	*N*	Age	Treatment	Study design	Outcome definitions	Continence outcome	UTI	Renal failure	QoL/satisfaction
Bolduc et al [5]	NB: 27 OAB: 45	72	Mean 8.9 yr (NB), 9.1 yr (OAB)	Solifenacin 1.25–10 mg Previous AC failure	Single center, prospective, open label ≥3 mo follow-up	Continence response Complete: totally dry Improvement: 90% decrease Partial: 50–89% Failure: <50%	Complete: 24/72 Improved: 42/72 Partial: 6/72 No difference between NB/OAB	NA	NA	AD: 22/72 90% compliant: 71/72
Cass et al [6]	NB:84 SB: 71 SCI: 5 SA: 4 SCD: 4	84	1–15 yr	CIC ≥ 5 yr ≥2 yr (if VUR/ hydronephrosis) AC: 59/84 PAB: 82/84	Single center, retrospective case review	Continence Total: no leakage UTI: >100k colonies	Total: 41/84 Damp: 4/84 Frequently damp: 8/84 Wet/dry: 7 Wet: 14	Febrile: 0 Asx: 7/84	BUN/Cr: normal, stable	"Pleased" Patients: 11/29 Parents: 25/60
Cass et al [7]	SB: 322 SCI: 47 CP: 11 SCD: 14	413	1–15 yr	CIC: 84 PAB: 82 AC: 63	Single center, retrospective case review	Not defined	Dry: 41/84 Slightly damp: 14/ 84 Damp/wet: 15/84 Wet: 14/84	NA	NA	NA
Castro-Gago et al [8]	SB	55	24 mo–14 yr	CIC q 3–4 h + AC	Single center, retrospective case review	Continence: Complete: 24 h dry Improved: 3 h dryness	Continent: 14/55 Improved: 39/55	Recurrent: 5/55, reduced from 27/55	NA	NA
Choi et al [9]	SB	88	Mean 33 mo	Intravesical electrical stimulation CIC: 48	Single center, retrospective case review	Continence Schurch score: 0–3, 0 = dry Improved: −1 point	Complete: 4/48 Improved: 23/48	NA	NA	NA
Costa Monteiro et al [10]	NB	332	14 d–19 yr	CIC: 119 AC: 187 PAB: 154	Single center, retrospective, longitudinal (6 yr) observational	NA	Incontinent Daytime: 8/200 Year 1: 84% Year 6: 75% Night: 11/198 Year 1: 81% Year 6: 67%	46/180 Year 1: 81% Year 6: 67%	NA	NA
Dik et al [11]	SB	144	Newborn enrollment	CIC PAbx AC	Single center, retrospective, longitudinal observational Mean FU 81	Continent: dry with CIC	Dry: 37/82 Pads: 3/82 Incontinent: 8/82	NA	NA	NA
Faleiros et al [12]	SB	188	Median 11 yr	CIC	Multicenter, cross sectional, survey 1 yr before and after CIC	UTI >100k colonies + fever/ WBC/pain/LUTS or bowel changes/ vomiting/ muscle spasticity	NA	Mean UTI/yr Before: 2.8 After: 1.1 $p < 0.001$	NA	NA
Faleiros et al [13]	SB	188	Median 11 yr	CIC Self vs assisted	Multicenter, Cross sectional, survey 1 yr before and after CIC	Continence Complete: no pads Partial: use of pads Incontinent: use of briefs	Assisted Partial/complete: 51% Incontinent: 49% Self Partial/complete: 74% Incontinent: 26%	NA	NA	NA

Table 1 (*Continued*)

Reference	Patients	*N*	Age	Treatment	Study design	Outcome definitions	Continence outcome	UTI	Renal failure	QoL/satisfaction
Ferrara et al [14]	SB	225	0.25–10 yr	Oxybutynin 0.1–0.2 mg/kg PO: 67 IV: 34	Single center, retrospective case review	NA	NA	NA	NA	Discontinued PO: 19/67 IV: 6/34
Franco et al [15]	DH	116	Mean 9.6 yr	Oxybutynin 10–15 mg qd + CIC	Multicenter, prospective, open label	Continence CIC without leakage	21.5% improvement over 24 wk $p < 0.00$	NA	NA	NA
Greer et al [16]	NB: 23 IDO: 15 DV: 6 DSD: 5 AR: 5 TH: 1 AD: 1	53	Median 8 yr	Botox IV: 134 cases IS: 23 cases Both: 5 cases CDC: 52 Previous AC failure	Single center, retrospective case review	Response: >90% symptom reduction on International Children's Continence Society scale	Response: 53/53 Median time 6 mo	NA	NA	NA
Huen et al [17]	NB: 52 SB: 20 BEE: 6 PUV: 5 TC: 4 SCD: 3 DD: 3 SCI: 2 SA: 2	52	Mean 14.5 yr	CIC + IV irrigant 30–50 ml G 480 mg: 4 NP 1–4 A: 48	Single center, retrospective case review 6 mo before and after follow-up	UTI >10k colonies + cloud/ foul-smelling urine/ fever/bladder spams/ pain/leakage or "physician decision"	NA	58% reduction ($p < 0.001$) Mean Before: 2 After: 1	NA	Discontinued: 6/ 52
Johnson et al [18]	NB	56	Mean Grp 1: 12.3 yr Grp 2: 9.9 yr	CIC + nitrofurantoin (25–50 mg) for 12 wk, placebo for 12 wk Biweekly urine samples	Double-blinded RCT, placebo controlled, crossover	UTI >100 mil colonies + pyuria 50 × 1 mil leukocytes/l + pain/ pyrexia/incontinence		Before: 19% After: 39% $p < 0.0003$		Compliance: 76.9%
Kari et al [19]	SB: 6 HD: 3 DD: 1	50	Mean 9.6 yr	CIC Urethra: 33 Mitrofanoff: 17	Multicenter survey based	NA	NA	Recurrent: 26/50 Urethral: 22/33 Mitrofanoff: 417 $p = 0.004$	NA	Patient "doesn't mind": 27/50 Urethral: 16/33 Mothers care for family is not impacted: 24/50 Urethral: 15/33
Kaufman et al [20]	SB	79	1 mo–14 yr	CIC q 3 h: 76 AC ± alpha-blocker or imipramine: 73	Single center, retrospective case review UT imaging (RBUS or IVP) q 6–12 mo	UT deterioration Hydronephrosis, ureteral dilation, or new/progressing VUR	Dry between CIC: 29/76	NA	Improved UTD: 52/ 76	NA
Kiddoo et al [21]	SB	66	Mean 10.6 yr	CIC Hydrophilic vs PVC catheter 24 wk period each	Multicenter, RCT, crossover	UTI pyuria + fever/pain/ incontinence/malaise/ cloudy, smelly urine		Mean person-wk UTI Hydro: 3.42 PVC: 2.20 $p < 0.001$		Satisfaction Hydro: 7.29% PVC: 87.5% Ease of handling H: 59.2% PVC: 95.8%

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Table 1 (***Continued***)

Reference	Patients	*N*	Age	Treatment	Study design	Outcome definitions	Continence outcome	UTI	Renal failure	QoL/satisfaction
Kurian et al [22]	SB	68	5–16 yr	Surveys: Barthels ADL Incontinence QoL (PIN-Q) General QoL (VAS)	Single center, Survey based	NA	NA	Incontinent: 20/29	NA	Poor QoL ADL and PIN-Q: 27.6% VAS: 34.5%
Lee et al [23]	SB	121	1–15 yr	Oxybutynin	Multicenter, retrospective case review	NA	Normalized: 74/121 Improved: 34/121 No change: 13/121			>70% Compliance: 101/121 No side effects: 104/121
Madero-Morales et al [24]	SB	83	Mean 12.7 yr	CIC Single use vs multiuse catheter AC: 50/83 PAB: 54/83	Single center, RCT Urine samples 0, 7, 14, 28, 42, 56 wk	UTI 100k colonies + cloudy urine/pain/malaise/fever		Single: 13/37 Multi: 14/38 p = 0.87		
Marte [25]	SB	68	5–17 yr	200 IU Botox All incontinent between CIC	Single center, retrospective case review	NA	Dry between CIC: 38/47 Improved but using pads: 9/47			
Peeraully et al [26]	NB: 28 NNB: 24	52	9.5–14.4 yr	Dysport 375 or 500 U CIC: 21/28	Single center, retrospective case review	Continence Moderate response—less frequent or reduced volume incontinence	Dry: 19/52 NB: 7/28 NNB: 12/24 Moderate response: 19/52 NB: 11/28 NNB: 8/24 No response: 12/52 NNB: 9/52 INB:3/52 SB less likely to be dry (p = 0.034) after initial injection but no difference with multiple injections			
Sager et al [27]	SB	60	Newborn enrollment	CIC and overnight indwelling Oxybutynin 0.25/mg/kg/d for DO or high pressure	Single center, retrospective case review	UTI 10k colonies + 38.5 +/pain/change in continence/cloudy smelly urine		Febrile before 1 yr: 21/60	DMSA scarring: 18/60 High-risk UDS: 14/60	

Table 1 (*Continued*)

Reference	Patients	N	Age	Treatment	Study design	Outcome definitions	Continence outcome	UTI	Renal failure	QoL/satisfaction
Timberlake et al [28]	SB: 123 CR: 7	130	Median 4.6 mo	CIC prior to toilet training: 52/130	Single center, retrospective case review	UTI 50k colonies +38.5 °C		6/130	Abnormal DMSA: 52/130	

AC = anticholinergic; AD = autonomic dysreflexia; AR = acute retention; Asx = asymptomatic; BEE = bladder exstrophy/epispadias; BUN = blood urea nitrogen; CIC = clean intermittent catheterization; CP = cerebral palsy; Cr = creatinine; DD = developmental delay; DH = detrusor hyperreflexia; DMSA = dimercaptosuccinic acid; DO = detrusor overactivity; DSD = detrusor sphincter dyssynergia; DV = dysfunctional voiding; FU = follow-up; G = Gentamicin; Grp = group; HD = Hirschsprung disease; IDO = idiopathic detrusor hypersensitivity; IV = intravesical; LUTS = lower urinary tract symptoms, NA = not available; NB = neurogenic bladder; NNB = non-neurogenic bladder; NP = neomycin/polymyxin; OAB = overactive bladder; PAB = prophylactic antibiotics; PO = per oral; PUV = posterior urethral valves; QoL = quality of life; RCT = randomized control trial; SA = sacral agenesis; SB = spina bifida; SCD = spinal cord disease; SCI = spinal cord injury; TC = tethered cord; TH = trigonal hypersensitivity; UDS = urodynamic studies; UT = urinary tract; UTD = upper tract deterioration; UTI = urinary tract infection; VAS = visual analog scale; VUR = vesicoureteral reflux; WBC = white blood cells.

In order to calculate the continence rates achieved, 14 studies provided meaningful continence outcomes [5–11,13,15,16,20,23,25,26]. The definition of continence was variable or poorly defined across the literature. Overall, 280/637 (44%) patients managed nonsurgically achieved complete continence, and 263/637 (41%) had improved continence. Incontinence or nonresponse was noted in 61/423 (14%). Outcomes varied among different causes of neurogenic bladder. For example, botulinum toxin had inferior outcomes in patients with SB compared with other causes of neurogenic bladder [26].

A total of 11 studies investigated nonsurgical measures to reduce the frequency of UTIs [6,8,10,12,17–19,21,24,27,28]. The definition of UTIs varied, but many studies included a minimal colony count (10 000–100 000 000) associated with at least one of the following symptoms: fever, abdominal/flank pain, emesis, increased incontinence, leukocytosis, cloudy or foul-smelling urine, and pyuria. A study early in the CIC era showed no symptomatic UTIs and only 8% incidence of asymptomatic bacteriuria in patients managed with CIC [6]. Initiation of CIC in a multicenter cross-sectional survey-based study revealed a statistically significant reduction in mean UTIs per year from 2.8 to 1.1, with 73% of patients having fewer UTIs on CIC [12]. Castro-Gago et al [8] showed more than five-fold decrease in the incidence of UTI after initiation of CIC and anticholinergic medication. Some studies showed benefit from the use of prophylactic antibiotics. A single-center RCT using oral nitrofurantoin in patients on CIC demonstrated a statistically significantly decreased incidence of UTIs from 39% to 19% [18]. Similarly, intravesical instillation of gentamicin or neomycin/polymyxin showed a 58% reduction in UTIs per year in patients on CIC [17]. A multicenter RCT comparing hydrophilic and polyvinyl chloride catheters found statistically significantly fewer UTIs in patients using polyvinyl chloride catheters [21]. A similarly designed single-center RCT found no difference in the rate of UTIs in patients utilizing single-use catheters versus those reusing and washing catheters [24].

Despite renal health being the most important outcome of neurogenic bladder, only four studies addressed renal outcomes [6,20,27,28]. No deterioration in blood urea nitrogen or creatinine was noted in 84 patients started on CIC [6]. Nonsurgical management with CIC and anticholinergics led to improvement in upper tract dilation in 68% of patients [20]. Two studies found renal scarring by dimercaptosuccinic acid (DMSA) scintigraphy in 30–40% of patients, which far exceeded the occurrence of documented febrile UTIs [27,28].

Nine studies investigated QoL related to the nonsurgical management of neurogenic bladder [5,6,14,17–19,21,23]. An early study of CIC and medical management found that 38% of children and 42% of parents were pleased [6]. Over 48% of patients "did not mind" management with CIC per urethra. Furthermore, 48% of mothers felt that CIC management did not impact their families [19]. Only one study utilized validated QoL instruments and found that 28–35% of patients on CIC had poor QoL [22]. The RCT of hydrophilic versus PVC catheters showed greater satisfaction with PVC

Table 2 – Surgical management of neurogenic bladder—study characteristics and outcomes.

Reference	Patients	*N*	Age	Treatment	Study design	Outcome definitions	Continence	Reoperation	Other outcomes
Barqawi et al [29]	NB: 60 BE: 17 PUV: 11 NNB: 7 PB: 5 CP: 2	109	2–37 yr	CCC (56) and/or MACE (both 42) Appendix: 50 Split appendix: 22 Ileum: 13 Ureter: 11 Stomach: 1 Sigmoid: 1	Single center, retrospective case review	NA	Continent: 95/98 SI: 4/98	SS: 13/98	NA
Cain et al [30]	NB: 69 BEE: 19 CE: 7 Other: 7	100	Mean 10.5 yr	CCC Appendix: 57 Ileum: 22 Continent vesicostomy: 21 Concomitant Sx Augment: 52 BNR/S: 48 MACE: 17	Single center, retrospective case review	NA	Continent: 98/100 SI: 2/100	Reop: 20/100 SS: 12/100 WD: 1/100 False passage: 2 Other: 3	NA
Cass et al [7]	SB: 323 SCI: 47 SCD: 14 CP: 11	413	<1–15 yr	Vesicostomy: 30 Ureterostomy: 7 Ileal diversion: 139 Colonic diversion: 17 AUS: 11	Single center, retrospective case review	NA	Leakage: 6/30	SS: 28 WD: 2 SBO: 2 AUS erosion: 2/11	UTD:16/88
Castellan et al [31]	NB	58	Median 11.4 yr	BNS with rectal fascia All CIC via stoma (49) or urethra (9)	Single center, retrospective case review	Complete continence Daytime 4–6 h, nighttime 6–8 h, and no stress incontinence	51/58	Reop: 7/58 WD: 2/58	NA
Deuker et al [32]	NB: 57 BE: 27 SCD: 14 Other: 9	107	2–17.9 yr	Mainz pouch Concomitant Sx: CCU: 95 Augment: 12	Single center, retrospective case review	Continence No pad	91/107	SS: 41/107 Reop for incontinence: 12/107	Very satisfied: 42/107 Satisfied: 46/107 Not satisfied: 1/107
Di Benedetto and Monfort [33]	SB:26 BE: 19 PUV: 1 CE: 1 SA: 1 Other: 2	50	3–23 yr	Augment Ileum or sigmoid: 30 Stomach: 20	Single center, retrospective case review	Continent 3 h dryness	Ileum: 22/30 Stomach: 17/20 Ileum SI: 0 Stomach SI: 2/20	Reop: 9/50 Ileum Ureteral stenosis: 1/30 AUS erosion/ malpositioned: 3/30 Stomach Ureteral stenosis: 2/20 BN stenosis: 1/20 SBO: 1/20	NA
Du et al [34]	NB/SB: 68 BE: 11 Other: 24	114	1–18 yr	Enterocystoplasty Concomitant Sx: Mitrofanoff: 69 BNS: 19 BNR: 18 UR: 19 MACE: 17	NSQIP cross sectional	NA	NA	Reop within 30 d: 11/ 114	NA

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Table 2 (***Continued***)

Reference	Patients	*N*	Age	Treatment	Study design	Outcome definitions	Continence	Reoperation	Other outcomes
Faure et al [35]	NB: 35 BE: 20	55	1.9–17.25 yr	Young-Dees BNR with and without BN bulking Concomitant Sx: Augment: 3 UR: 16 Mitrofanoff: 17 All CIC	Single center, retrospective consecutive	Social continence: dry 3 h, no daytime leakage, no pads	With bulking Initial: 4/20 After additional bulking: 2/16 Without bulking Initial: 6/35 After bulking: 13/29 Continent after additional BNS, BNC, augment: 7/14	NA	NA
Hendren and Hendren [36]	Not defined	129	Mean 12.7 yr	Augment Cecal: 65 Sigmoid: 46 Small bowel: 29 Stomach: 4 Colon: 1	Single center, retrospective consecutive	NA	NA	SBO: 2 Reop of antireflux mechanism: 16	NA
Husman and Cain [37]	SCI: 42 SB: 18 SA: 3	63	Not defined	Colocecal bladder augment with ileal CCC	Single center, retrospective consecutive	NA	Continent: 54/62 SI: 8/62 After additional BN bulking: 4/8 After additional BNR: 2/4 2/4	Reop: 30/62	Febrile UTI: 15/62 Unchanged UTD: 58/62 Increased UTD: 4/62
Kari et al [19]	SB: 6 HD: 3 DD: 1	50	Mean 9.6 yr	CIC Mitrofanoff: 17 vs urethra: 33	Multicenter, survey based	NA	NA	NA	Recurrent: 26/50 Urethral: 22/33 Mitrofanoff: 417 $p = 0.004$ Patient “does not mind”: 27/50 Mitrofanoff: 11/17 Mothers care for family is not impacted: 24/50 Mitrofanoff: 9/17
Kroll et al [38]	SB: 88 SCD: 11 BE: 7 PUV 6 IA: 6 CP: 3 Cancer: 5	115	2–17 yr	Mitrofanoff CIC: 62 and MACE: 72	Single center, retrospective consecutive	NA	Continent: 59/62 Mild leakage: 1/62	Reop: 3/62 SS: 3/62	NA
Leslie et al [39]	SB: 36% BE: 31% PUV: 6%	169	6 mo–22 yr	Mitrofanoff: 141 vs Monti-Yang: 28 Concomitant Sx: Augment: 35% BNR: 22% BNC:8%	Single center, retrospective consecutive	NA	SI: 10%	Reop: 67/169 SS: 17% No difference in reop Mitrofanoff vs Monti-Yang	NA

Table 2 (*Continued*)

Reference	Patients	*N*	Age	Treatment	Study design	Outcome definitions	Continence	Reoperation	Other outcomes
Maldonado et al [40]	Not defined	1873	Median 8 yr	Augment 30 d readmissions	Nationwide Readmission Database, cohort	NA	NA	Readmit: 19.6% Readmit Dx: GI complication: UTI: 14.1% WD: 1.8% SSI: 9.4%	NA
Medel et al [41]	Not defined	75	5–19 yr	Augment	Single center, retrospective consecutive	NA	Dry: 16/19 Reop for incontinence: 4/19	NA	Mild renal sufficiency: 2/26
Merriman et al [42]	SB: 78 BE: 11 VATER: 6 SA: 5 SCD: 2 PUV: 2 SCI: 2	108	3–20 yr	Augment Ileum: 59 Sigmoid: 33 Cecum: 4 Composite: 12	Single center, retrospective consecutive	NA	NA	Reop: 58/137 Urolithiasis: 34/137 Stomal revision: BNR/C/S: 26/137 Mean no. of reop procedures: 1.2 (SB 1.49, non-SB 0.83)	NA
Mitchell and Piser [43]	Not defined	129	Mean 13.4 yr	Augment Ileal: 33 Sigmoid: 39 Ileocecal: 51 Concomitant Sx: CCC: 7 BNR: 28 AUS: 15	Single center, retrospective consecutive	Continent Dry or <2 pads per day, dry during most nights Renal fx assessed via nuclear scan, IVP, mean serum Cr	82%		Readmit for UTI: 22% Stable/improved renal fx: 91%
Noordhoff et al [44]	SB: 55 VACTERL: 4 SCD: 1	60	Median 11.6 yr	BNS 43, BNR 17 Concomitant Sx: Augment: 80% CCC: 97% VUR: 5%	Single center, Retrospective consecutive	Continent 4 h without leakage	1 yr postop Overall: 23/60 BNS: 5/43 BNR: 8/17 *p* = 0.38 Long-term (median 10.4 yr) 46/60 Dry SI: 6 Reop for incontinence: 25/60 Dryness between 1 yr and long term did not differ for surgery	Urolithiasis: 23/60 Bladder perforation: 2/60	NA
Schlomer and Copp [45]	SB: 55/1% NB: 13.8% BEE: 12.6% CE: 4.5% Bladder obstruction: 2.9% Other: 11.2%	2813	Mean 9.1 yr	Augment Concomitant Sx: BNC/R/S: 16.8% CCC: 39.3%	Pediatric Health Information System, cohort	NA	NA	1–10 yr cumulative incidence URS: 0.4–2.4 PCNL: 1.1–8.8 Cystolithopaxy: 3.2–35.3 Reaugment: 1.8–13.4 Stoma surgery: 5.6–27.1 BNR: 2.9–12.6 BN injection: 4.5–17.2	NA

Table 2 (*Continued*)

Reference	Patients	*N*	Age	Treatment	Study design	Outcome definitions	Continence	Reoperation	Other outcomes
Schlomer et al [46]	SB: 39.3–46.9% BEE: 8.3–14.3% NB: 19.9–26.5% Other: 14.4–21.5%	1622	Mean 9.2 yr	Augment	Kids' Inpatient Database, cohort	Major surgical complication—SBO, blood transfusion, hemorrhage, technical complication, fistula	NA	Complication Overall: 30% Major surgical: 14%	NA
Scott et al [47]	SB: 89 SCI: 20 SA: 6	120	Mean 19.3 yr * 72% were <21 yr	AUS	Single center, retrospective consecutive	NA	NA	NA	Increased UTD: 4/120
Shekarriz et al [48]	NB: 100 BE: 12 CE: 6 PUV: 3, Other: 12	133	2–25 yr	Augment Ileum: 65 Sigmoid: 48 Urothelium: 20 Concomitant Sx: AUS: 26 Mitrofanoff: 30 BNC: 4 BNR: 20 BNS: 9 Kropp: 4	Single center, retrospective consecutive	Continent 4 h without leakage and no pads UTD Increasing Cr above age-adjusted values	127/133	Reop: 15/133 Bladder perforation: 17/133 SBO: 6/133 SBO Urolithiasis: 14/133	UTD: 4/133
Simeoni et al [49]	SB: 92 SA: 9 Medullary lipoma: 2	107	Mean 13.7 yr	AUS Concomitant Sx: Augment: 10 UR: 15 Urethral injection: 2 Diverticulectomy: 1	Single center, retrospective consecutive	NA	Total continence: 45/107	Reop: 63/107 Mechanical problems: 20/107	Hydronephrosis: 1/107
Snodgrass et al [50]	Not defined	83	Mean 9 yr	Bladder outlet Sx without augment BNS: 39 BNS with cinch: 44 Concomitant Sx: CCC: 83 All CIC q 3 h + oxybutynin	Single center, retrospective consecutive	Continent No pads	13/25	NA	UTD: 6/25
Stein et al [51]	SB: 112 Caudal regression: 12 IA: 6 Other: 23	149	Mean 12.1 yr	Urinary diversion, conduit diversion, CCC	Single center, retrospective consecutive	NA	Continent: 98% Mitrofanoff: 26/26 Monti-Yang: 3/24 Reop for incontinence: 5/57	Conduit diversion Reop: 21/57 SBO: 2/57 Bladder perforation: 1/12 SS: 9/57 CCU Reop: 47/58	Nephrectomy due to recurrent UTI: 4/57 UTD: 2.7%
Sultan et al [52]	PUV: 24 NB: 18 NNB: 14 BEE: 14 Other: 12	82	Mean 9.07 yr	Augment and CCU Ileum: 71 Sigmoid: 6 Colon: 4 Combination: 1 Mitrofanoff :70 Monti-Yang: 12	Single center, retrospective consecutive	NA	Continent: 79/82 Urethral leakage: 2/82 SI: 1/82	Urolithiasis: 3/82 SS: 2/82 SBO: 5/82 Minor complication: 13.3% Major complication: 10.8%	Recurrent febrile UTI: 2/82

Table 2 (Continued)

Reference	Patients	N	Age	Treatment	Study design	Outcome definitions	Continence	Reoperation	Other outcomes
Zhang et al [53]	SB: 15 TC: 14 SCD: 16 SCI: 4 Brain hemorrhage: 1	52	Mean 21.7 yr	Augment Concomitant Sx: UR: 15	Single center, retrospective consecutive	7 pt Satisfaction scale 5pt "Worry about the future" scale	AC for postop urge incontinence: 6/8	Reop: 2/52	Recurrent febrile UTI: 11/52 Increased Cr: 0/52 Mean satisfaction 1.27 (good) Mean QoL: 1.24 (a little bit worried)

AC = anticholinergic; AUS = artificial urinary sphincter; BEE = bladder exstrophy/epispadias; BN = bladder neck; BNC/R/S = bladder neck closure/reconstruction/sling; CCC = catheterizable continent channel; CCU = continent catheterizable urinary; CE = cloacal exstrophy; CIC = clean intermittent catheterization; CP = cerebral palsy; Cr = creatinine; DD = developmental delay; Dx = diagnosis; fx = function; GI = gastrointestinal; HD = Hirschsprung disease; IA = imperforate anus; MACE = Malone antegrade colonic enema; NB = neurogenic bladder; NNB = non-neurogenic neurogenic bladder; PB = prune belly; PCNL = percutaneous nephrostolithotomy; PUV = posterior urethral valves; QoL = quality of life; Reop = reoperation; SA = sacral agenesis; SB = spina bifida; SBO = small bowel obstruction; SCD = spinal cord disease; SCI = spinal cord injury; SI = stomal incontinence; SS = stomal stenosis; SSI = surgical site infection; Sx = surgery; TC = tethered cord; WD = wound dehiscence; UR = ureteral reimplant; URS = ureteroscopy; UTD = upper tract deterioration; UTI = urinary tract infection; VUR = vesicoureteral reflux.

catheters, which may be related to the greater ease of handling [21]. Anticholinergics are generally well tolerated. Solifenacin usage was associated with no side effects in 69% patients and 90% compliance [5]. Similarly, a large multicenter study noted that 83% of patients were 70–100% satisfied with oxybutynin therapy and 86% were without adverse effects [23]. Nitrofurantoin prophylaxis compliance was slightly lower in comparison but included the majority at 77% [18].

3.1.2. *Surgical management of neurogenic bladder*

The 27 studies addressing surgical management of neurogenic bladder are summarized in Table 2, which included 13 on bladder augmentation [32–34,36,37,40–43,45,48,52,53], nine studies on CCCs [19,29,30,37–39,48,51,52], four on bladder outlet procedures [31,35,44,50], two on urinary diversion [7,51], and two on AUS [47,49]. Although the large majority of studies defined a particular surgical intervention of interest, concomitant surgeries were frequently noted, such as augmentation with the creation of a CCC. Two studies specifically evaluated the outcomes of combined surgical treatment for neurogenic bladder and bowel with CCCs for bladder emptying and antegrade enema administration [29,38]. Bladder augmentation included the usage of stomach, sigmoid, ileum, cecum, intestinal composite, or urothelium; ileum followed by sigmoid colon was most commonly utilized. The most frequently created CCC was a Mitrofanoff CCC (appendicovesicostomy). Alternative gastrointestinal segments including the ileum (Monti-Yang), sigmoid, stomach, and ureter were also used for CCCs. Bladder outlet procedures included bladder neck reconstruction (BNR), bladder neck sling (BNS), and bladder neck bulking. Urinary diversion included vesicostomies, ureterostomies, and ileal and colonic diversions.

Eighteen studies reported on urinary continence [7,29–33,35,37–39,41,43,44,48–52]. Similar to studies on nonsurgical management, there was no universal definition of continence. Surgical studies that defined continence as complete dryness were utilized to calculate an overall rate of 64% (165/258) [41,42,49,50]. The majority of studies did not provide any defining constructs; however, six studies defined "social" or "acceptable" continence as 3–6 h of dryness in the daytime and/or usage of up to two pads per day [31,33,35,43,44,48]. Utilizing these studies, we calculated a 72% (330/456) overall rate of partial continence. Three studies made direct comparisons of surgical techniques. Di Benedetto and Monfort [33] found a higher incidence of continence with gastrocystoplasty (17/20, 85%) than enterocystoplasty (22/30, 73%). A slightly greater incidence of continence was achieved with the addition of bladder neck bulking injections with BNR (4/20, 20%) than with BNR alone (6/35, 17%) [35]. There was no statistically significant difference in continence between BNR and BNS either 1 yr postoperatively or in long-term follow-up, but overall continence of these procedures improved from 38% after 1 yr to 77% after a median follow-up of 10.4 yr. However, 41.7% of patients underwent additional procedures for incontinence [44]. Additionally, two out of

20 patients with gastrocystoplasty had stomal incontinence versus none in the enterocystoplasty group [33].

In comparison with nonsurgical management, fewer surgical studies reported UTIs as an outcome of interest. Six studies commented on recurrent UTIs, but it was not defined by any studies and no comparisons were made with preoperative UTI rates [19,37,43,51–53]. The rate of postoperative recurrent UTIs ranged from 2.4% following augmentation to 23% after Mitrofanoff CCC. Kari et al [19] found a statistically significant difference in the rates of recurrent UTIs between Mitrofanoff CCC (4/17, 23.5%) and CIC per urethra (22/33, 66.7%). Associated morbidity was noted in two studies. Mitchell and Piser [43] found that 22% of patients who underwent augmentation were hospitalized for a UTI. Furthermore, four out of 57 patients with urinary diversions and CCCs (7%) underwent a nephrectomy for recurrent UTIs [51].

In total, nine studies reported postoperative nephrologic outcomes [7,37,41,43,47–51,53]. Surgical management is associated with low rates of upper tract deterioration. The incidence of new or increased hydronephrosis ranged from 0.9% following AUS placement to 12% in other forms of bladder outlet surgery [49,50]. These favorable results have been shown to be sustained long term, as 0% of patients who underwent bladder augmentation had increased creatinine after a mean follow-up for 49 mo [53].

Reoperation rates and surgical complications were the most frequently reported outcomes found in 23 studies [7,29–42,44–46,48,49,51,52]. Overall, cumulative rates of reoperation and complications were not calculated due to the wide variety of surgical interventions investigated. Evaluation of the Nationwide Readmission Database identified 1873 patients who underwent bladder augmentation and found a 30-d readmission rate of 19.6% [40]. Similarly, in a cohort 1622 bladder augmentations in the Kids' Inpatient Database, there was 30% complication rate [46]. Reported postoperative problems included stomal stenosis, small bowel obstruction, bladder perforation, wound dehiscence, and bladder stones/nephrolithiasis. Merriman et al [42] specifically evaluated the risk of secondary surgeries after augmentation with CCCs and found that over half of patients, 53.7%, required at least one additional procedure. Patients experienced a mean of 1.2 secondary surgeries over a mean follow-up of 6.93 yr. They also found that children with SB had significantly higher rates of reoperations. In a single-center retrospective review, reoperative rates for CCCs were notably higher than conduit diversion (47/58, 81% vs 21/57, 36%) [51]. Conversely, in comparing differing CCC techniques, there was no significant difference in reoperative rates between Mitrofanoff and Monti-Yang, although the cohort sizes differed greatly (Mitrofanoff: N = 141, Monti-Yang: N = 28) [39].

QoL and patient satisfaction are widely under-reported in the surgical management of neurogenic bladder. Only three studies evaluated these outcomes [19,32,53]. Studies did not use validated questionnaires. Following Mainz pouch creation, the majority of children were very satisfied (42/107, 39.3%) or satisfied (46/107, 43.0%) with their outcome [32]. In a multicenter study, the majority of patients reported not minding catheterizing via a Mitrofanoff CCC (11/17, 64.7%) [19]. On a seven-point Likert scale for satisfaction (0 representing highest satisfaction), the mean score was 1.27 for patients who underwent bladder augmentation. These patients answered a five-point Likert scale regarding worry for the future, and a mean score of 1.24 implied that they worried very little about the future [53].

3.2. *Management of neurogenic bowel*

The flow diagram of the neurogenic bowel literature search and results is shown in Figure 2. A total of 65 studies were included in the review [4,9,54–116], including 33 using nonsurgical treatment modalities [4,9,54–84] and 32 reporting on surgical interventions for pediatric neurogenic bowel [85–93,95,55–116]. With the exception of two studies on neuromodulation, all the studies were retrospective or prospective patient cohort series predominantly with children having neurogenic bowel. Only two RCTs, one of which was double-blinded controlled and the other was patient blinded, were performed to investigate the effectiveness of electrical stimulation therapy.

Data were collected from retrospective chart reviews [56,58,64,72,73,79,82,85,87,90,91,93–95,98,106,109,115,116], interviews during clinic visits or by telephone [54,55,58–60,63–67,69,70,72,76,80,89,96,102,110,111,115], and patient-reported outcomes (questionnaires, bowel dysfunction scores, QoL questionnaires, or child behavior checklists) [55,58,62,65,69,71,74,76,77,83,96,110,112]. One report came from the Center for Disease Control and Prevention (CDC) Spina Bifida Registry looking at cross-sectional cohort data [81].

In order to calculate the continence rates achieved via treatment, only studies where fecal continence rates were reported are included. Further, the definition of fecal continence was variable or not defined across the literature, and so only papers using a definition of no stool loss or fewer than one accident per month were considered. Overall, 1417/1888 (75%) patients in both the nonsurgical and the surgical series achieved this strict level of fecal pseudocontinence [55–58,62–65,68–70,73,78,79,82,84,86,88–90,93,96–98,103,105,107,108,111,112,114,115]. The papers were grouped into nonsurgical modalities in Table 3 and surgical modalities in Table 4 to specifically investigate the unique parameters in treatment for each of these groups.

For calculating the fecal continence rates, the report from the CDC Spina Bifida Registry was not included, as it is a unique data set and the report did not link outcomes directly to the treatment modality [81]. In the 4664-participant dataset, they found that fecal continence improved with increasing age from 51% to 71% in their nonmyelomeningocele patients and from 22% to 49% in myelomeningocele patients.

3.2.1. *Nonsurgical management of neurogenic bowel*

Studies on nonsurgical interventions are summarized in Table 3. Of these 33 studies, one reported on toilet sitting, two on biofeedback, one on anal plug use, four on

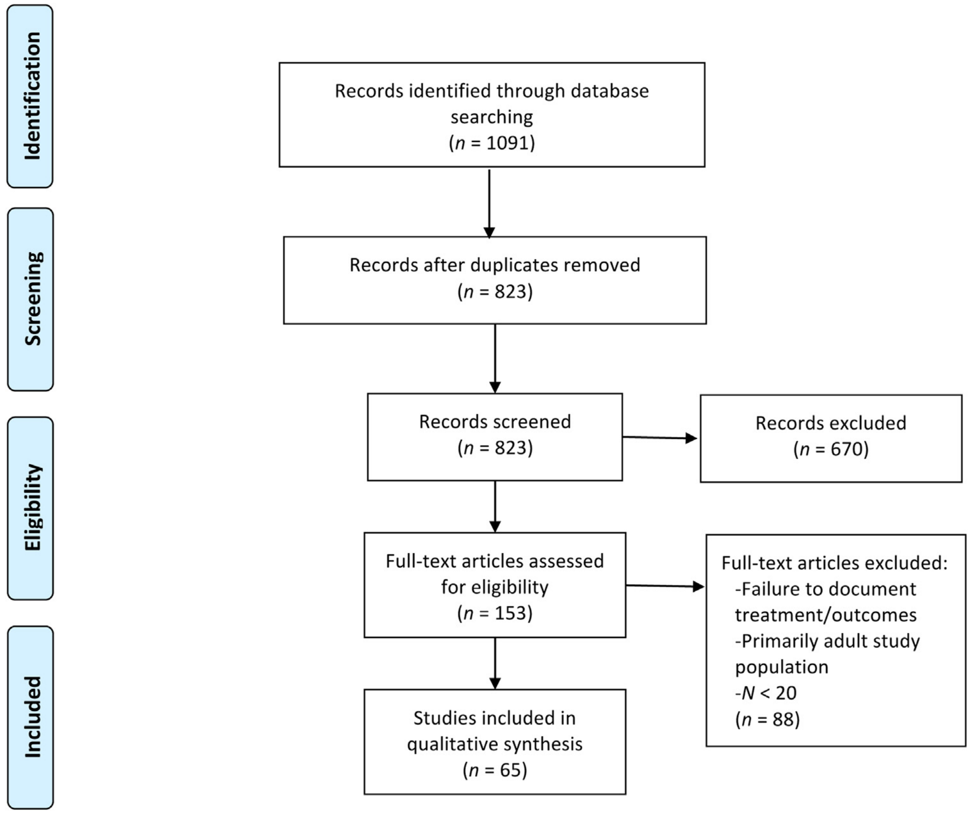

Fig. 2 – Flow diagram for neurogenic bowel review.

neuromodulation, and 15 on RCEs, and 11 used a combined therapeutic approach including diet, behavioral therapy, digital stimulation or evacuation, and oral laxatives. Using only studies that adhere to a definition of fecal continence (fewer than one accident per month or no stool loss), the overall number of patients achieving fecal continence was 667/855 (78%) [55–58,62–65,68–70,73,78,79,82,84].

Constipation was reported as a treatment parameter in seven studies, which found that 297/446 (67%) patients had resolution of their constipation after nonsurgical bowel therapy [9,65,69,77,78,80,83]. Corbett et al [72] did not report directly on constipation as a symptom but found that stooling frequency increased from once every 3 d to once every day after initiation of RCE. In the Choi et al's [117] study, 88% of the patients who were taking anticholinergics for bladder management complained of constipation, while only 64% of those not taking them were constipated.

Given the low cost and side-effect profile of dietary modifications, oral laxatives, and timed attempts at defecation, these maneuvers are typically first-line therapy for pediatric neurogenic bowel. For those who continue to have fecal incontinence or constipation, RCEs and suppositories are commonly the next step. In RCE studies, patients had already failed these first-line modalities, but this is not always explicitly mentioned. Using studies with a strict definition of fecal continence, the overall continence rate achieved in these 10 studies was 499/572 (87%) [55,65,68–70,73,78,79,82].

Neuromodulation or electrical stimulation as a bowel therapy was investigated in four studies, including a double-blind, placebo-controlled trial [59], a patient-blinded RCT [71], a prospective clinical trial [60], and a retrospective case review [63]. The studies by Marshall and Boston [59] and Kajbafzadeh et al [71] utilized a transcutaneous technique, while Palmer et al [60] employed a transrectal approach and Han et al [63] utilized the transurethral method. Palmer et al [60] and Han et al [63] reported that 71% and 50% of their patients achieved fecal continence with treatment. Constipation improved in 73% and resolved completely in 47% of the patients in the Han et al's [63] study. Marshall and Boston [59] reported 49% more spontaneous stooling with electrical stimulation, but this was not statistically different from controls. Using the transurethral method, Han et al [63] noted that 10 patients suffered from UTIs as a complication of treatment.

Several studies have investigated the impact that fecal incontinence and its resolution through therapy has on a patients' QoL [9,62,67,69,72,76–78,84] and satisfaction [55,58,60,70]. Tools for assessing QoL, particularly validated instruments, are becoming more available, but the lack of a standard method and variable application prevents comparison between studies. In studies where QoL was assessed, fecal incontinence was reported by patients and parents to be a significantly negative detractor from their QoL, and successful treatment produced a commensurate improvement in follow-up assessment [9,62,67,69,72,77,78,84]. Furthering

Table 3 – Nonsurgical management of neurogenic bowel—study characteristics and outcomes.

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Continence outcome	QoL/satisfaction
Whitehead et al [54]	SB FI: NA CO: NA	33	5–16 yr	19 SB behavior tx = 10 times toilet sitting qhs 14 biofeedback q 2 wk + behavior tx	Single center Prospective controlled Daily symptom log 1 mo before and during	Not defined	Biofeedback + behavior tx Accidents/wk decreased from 5.38 to 1.95 at 12 mo Continent: 5/14 Behavior tx only Accidents per week decreased from 5.77 to 2.3 at 12 mo Continent: 4/19 No difference between groups	NA
Shandling and Gilmour [4]	SB FI: 112 CO: NA	112	4–20 yr	RCE balloon with saline 20 ml/kg q 24–48 h	Single center Unspecified	Stool loss $<4\times$/mo	Continent: 100% 4 drop outs 5 returned to RCE after initial drop out	NA
Liptak and Revell [55]	SB: 30 SCI: 1 FI: 18/25 CO: 14/25	31	3–19 yr	Bowel cleanse, then RCE with balloon catheter q 24–48 h with saline 20 ml/kg	Single center Prospective Standardized questionnaire via phone or visit Satisfaction rated 1–4 (1 = extremely dissatisfied, 4 = extremely dissatisfied)	No stool loss	FI dropped from 18/25 at baseline; 7/25 at 18 mo; 1/16 at 30 mo 15 dropouts	Mean satisfaction improved from 1.1 at baseline to 2.8 at 18 mo to 3.3 at 30 mo
King et al [56]	SB FI: 35 CO: NA	40	18 mo–29 yr	Daily timed bowel attempts, reflex triggered BM	Single center Retrospective chart review Phone FU q 2 wk and during FU visits	Stool loss <1/mo	Continence Baseline: 5/40 at baseline 15 mo: 24/40 24/40 compliant with 19/24 continent 11/40 noncompliant with 0/11 continent	NA
Malone et al [57]	SB FI: 55 CO: NA	109	9–47.8 yr	Behavioral tx, manual evacuation, oral laxatives, suppositories	Multicenter Questionnaires Random cohort from $>$2000 pt database 109/144 responses	Not defined	Regular toilet: 94/104 Manual evacuation: 26/104 Laxative: 25/104 Suppositories: 13/103 FI: 55/104	NA
Scholler-Gyure et al [58]	SB FI: 14 CO: 4	53	7 mo–22 yr	RCE with cone tip catheter q 24 h with tap water	Single center Case review + questionnaire Frequent phone FU	No stool loss	27/41	Pain with RCE: 6/41 Unpleasant: 3/41 Complain time/effort: 51% Burden on family: 39% Parent satisfaction High: 63% Good: 37%

Table 3 (*Continued*)

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Continence outcome	QoL/satisfaction
Marshall and Boston [59]	SB FI: NA CO: NA	50	4–18 yr	Daily 1 h at home transcutaneous ES	Single center Randomized double-blind placebo-controlled trial Frequent phone FU to improve compliance 1 wk diary	Not defined	Insignificant finding of 49% more spontaneous stools with ES Placebo effect No complications	NA
Palmer et al [60]	SB FI: NA CO: NA	55	2–14 yr	Home transrectal ES, 30 min qd, 5 d/wk	Single center Prospective clinical trial	Improvement: less BM, better rectal sensation, ability to hold consciously	Complete success with improvement in all parameters: 20/55 Partial success with improvement in any parameter: 30/55 Continence: 71%	No complications Parental subjective opinion decreased success rate
Ponticelli et al [61]	SB FI: 52 CO: 57	73	7–25 yr	10 biofeedback sessions 12 conventional (laxatives, stimulants, enema) 30 no treatment	Single center Prospective controlled trial Questionnaire of bowel habits	Not defined	Biofeedback + behavioral tx: Continence: 4/10 Improved: 2/10 Behavioral tx only: Improved: 7/10	NA
Krogh et al [62]	SB FI: 55 CO: NA	125	2–18 yr	Digital evacuation, suppositories, RCE, laxatives	Multicenter 184-item questionnaire and validated CBCL 125/208 responded	Stool loss <1/mo	Manual evacuation: 25/125 Suppositories: 13/125 RCE: 35/125 Laxatives: 35/125 FI: 55/100 (>4 yr)	47/61 identified FI as a problem FI had major negative impact on QoL: 10/42, 2–5 yr old; 21/46, 6–10 yr old; 17/37, 11–18 yr old
Han et al [63]	SB FI: NA CO: NA	24	4–13 yr	Daily home transurethral ES, 5 d/wk for 4 wk	Single center Retrospective case review FU cycle: 2 wk q 3–6 mo	No stool loss	FI episodes decreased significantly from 7.3/wk at baseline to 4.8/wk Complete continence: 12/24 UTI in 10 patients using transurethral ES	NA
Verhoef et al [64]	SB FI: NA CO: NA	350	16–25 yr	Laxatives, RCE, manual evacuation	Multicenter Data from interviews, neurophysiological testing, retrospective medical history 179/350 responded	Stool loss <1/mo	Regular toileting: 5/80 Manual evacuation: 13/80 RCE: 24/80 ACE: 16/80 FI: 22/80	FI reported as problem: 47/61
Mattsson and Gladh [65]	SB FI: 40 CO: 40	40	10 mo–11 yr	RCE cone tip catheter with median 300 ml tap water q 24 h	Single center Parent questionnaire (8 items) Manometry in 28 SB pts at baseline and after 1–3 yr	No stool loss	Continent: 35/40 No CO: 40/40 5 dropouts	Independent care: 1/40 Satisfied: 35/40 Improved well-being: 36/40 Time consuming: 40/40

Table 3 (*Continued*)

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Continence outcome	QoL/satisfaction
Vande Velde et al [66]	SB FI: NA CO: NA	80	5–18 yr	Stepwise: timed BM, manual evacuation, RCE, ACE	Single center Descriptive cohort study	Stool loss <1/wk	Regular toileting: 5/80 regular toileting Manual evacuation: 13/80, 38% with FI RCE: 24/80, 13% with FI ACE: 16/80, 0% with FI FI: 22/80	NA
Shoshan et al [67]	SB FI: 20 CO: NA	20	4–29 yr	Anal plug use start at week 1	Single center Self-controlled clinical trial Daily record FU at weeks 0, 1, 2, and 5 Effect on FI scale 0–4 (0 = not bothersome, 4 = very bothersome)	Not defined	Accidents/wk decreased: 4 to 0 by week 5 5 dropouts	FI impeding daily life: 50% FI slightly interfering: 40% at 5 wk
Eire et al [68]	SB FI: NA CO: NA	33	5–22 yr	Disimpaction, then RCE with balloon catheter (median 500 ml saline q 24 h, then q48 at continence)	Single center Selected motivated patients Retrospective case review	No stool loss	Continent: 32/33	Independent care: 2/33
Ausili et al [69]	SB FI: 16 CO: 60	60	8–17 yr	RCE with balloon catheter	Single center Prospective clinical trial Validated questionnaire (NBDL range 0–47, 47 = severe bowel dysfunction) and QoL Visit before and 3 mo after RCE	Stool loss <1/mo	Relief of FI: 12/16 Relief of CO: 36/60 NBD decreased from 17.5 to 8.5 after tx	Parents report improved QoL and satisfaction rate NBD score improved from 17.5 to 8.5
Pereira et al [70]	SB: 28 Other: 7 FI: NA CO: NA	40	6–25 yr	RCE with balloon catheter, avg 616 ml tap water q 3 d	Single center Prospective clinical trial Standard questionnaire on bowel function and QoL (score 0–10, 0 = great reduction, 10 = great improvement)	No stool loss Pseudocontinence: no stool loss on treatment	Pseudocontinence increased from 10/35 to 28/35 Significant decrease in time spent versus conventional management	Partial or total independent care: 16/35 Mean satisfaction score of 7.3
Kajbafzadeh et al [71]	SB FI: NA CO: NA	30	3–12 yr	Home cutaneous ES for 20 min 3×/wk	Single center Randomized control trial 15 tx, 15 sham Bowel diary NBD: range 0–47 (47 = severe bowel dysfunction) Manometry prior to and after tx	Stool loss <1/wk	Constipation decreased in 11/15 and remained in 8/15 after 6 mo Increase of stool frequency from 2.5 to 4.7 stools/wk after tx Significant improvement in manometric parameters	No complications

Table 3 (*Continued*)

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Continence outcome	QoL/satisfaction
Choi et al [117]	SB FI: NA CO: NA	53	3–13.8 yr	Stepwise: (1) PEG 3350 at 0.5 g/kg qd, (2) if failure, RCE cone or balloon catheter with tap water q 48–72 h	Single center Prospective clinical trial Survey questionnaire on bowel sx, QoL, and general (40 items)	Stool loss <1/wk	Success PEG alone: 6/53 Success RCE alone: 43/47 FI decreased from 6.9 to 0.5 accidents/wk Bowel care time decreased from 27 to 15.9 min	Significant reduction in impact on travel and socialization, also caregiver support and emotional impact
Corbett et al [72]	SB: 15 ARM: 5 HD: 4 FI: 24 CO: NA	24	4–16 yr	Transanal irrigation (Peristeen) variable regimen (mean q 2 d frequency with median volume of 300 ml)	Single center Combination retrospective review with pre/post-treatment validated QoL questionnaire	Not defined	3 immediate dropouts After use of Peristeen: Stool frequency decreased from 3 to 1/d Accidents decreased from 14 to 1/wk % of BM in toilet vs self-increased 20–100% Time spent decreased from 75 to 30 min 19/24 continue TAI	QoL score increased from 40.5 to 51.5
Pacilli et al [73]	SB: 11 ARM: 6 HD: 1 FI: 11 CO: 12	23	2–15 yr	Transanal irrigation (Peristeen), variable frequency, 10–20 ml/kg QOD: 16/23 QD: 4/23 Q3D: 3/23 PO laxatives: 9/23	Single center Retrospective chart review	Clean: no stool loss Improved: occasional leakage, better than baseline	Clean: 16/23 Improved: 3/23 improved	Independent care: 30% Did not tolerate: 4/23 Mild discomfort: 3/23
Choi et al [74]	SB: 173 FI: 62 CO: 73	173	2–18 yr	Manual extraction, suppositories, enema, laxatives, ACE, TAI	Single center Questionnaire on bowel function and QoL sent to parents of pts in clinical database	Stool loss <1/wk	FI: 62/173 Constipation:73/173 Constipation in pts on AC: 88% Not on AC: 64%	Pts with constipation had lower QoL related to travel and socialization vs children without Pts with FI had lower QoL related to travel and socialization, caregiver's emotions, family relationships, and finances
Kelly et al [75]	SB FI: 24 CO: 24	24	3–21 yr	TAI (Peristeen) initiated qhs with 20 ml/kg tepid tap water	Single center Prospective clinical trial NBoDS questionnaire completed before and 2 wk, 2 mo, 6 mo after initiating tx	Stool loss <1/mo	TAI at 6 mo: 24/24 Mean NBoDS score at baseline: 20.21; at 2 wk, 12.75; at 2 mo, 13.21; at 6 mo, 9.67	NA

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Table 3 (*Continued*)

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Continence outcome	QoL/satisfaction
King et al [76]	SB FI: 20 CO: NA	20	14.5 mo–5.3 yr	TAI (Peristeen) with variable regimen	Multicenter Questionnaires to pts on clinical database: Fecal Incontinence QoL, St Marks Fecal Incontinence Score, Cleveland Clinic Constipation Score, Neurogenic Bowel Dysfunction Score Interviews	Not defined	TAI at 4 yr: 9/20	Discontinuation: 10 d: 3/20 4–12 mo: 6/20 46–48 mo: 2/20 Owing to balloon difficulties: 4/20 Too difficult: 4/20 Pain: 3/20 No difference between using vs discontinued group for: FI, CO, or QoL
Midrio et al [77]	SB: 37 ARM: 41 FI: 39% SB, 60%ARM CO: 39% SB, 50% ARM	83	6–17 yr	TAI (Peristeen) started at 10/20/ml/kg qd × 1 wk then up to 1 l 3×/wk	Multicenter Prospective clinical trial Bristol Scale, bowel function questionnaire, and QoL (age 6–11 CHQ-pf50, age 12–17 SF36) at initiation and 3 mo after initiation	Not defined	ARM FI dropped: 50–18.6% SB FI: 39–9.8% ARM CO: 69–23.6%	Significant improvement in QoL for both ARM and SB
Ausili et al [78]	SB: 38 ARM: 36 FI: 33 CO: 60	74	6–17 yr	TAI (Peristeen) started at 10/20/ml/kg qd × 1 wk then up to 1 l 3×/wk	Multicenter Prospective clinical trial Bristol Scale, bowel function questionnaire, and QoL (age 6–11 CHQ-pf50, age 12–17 SF36) at initiation, 3 mo after initiation, and at least 24 mo after initiation	Stool loss <1/mo	SB pts with FI decreased 15/38 at start, 4/37 at 3 mo, 6/36 at 2+ yr ARM pts with FI decreased 18/36 at start, 6/35 at 3 mo, 8/31 at 2+ yr SB patients with constipation decreased 35/38 at start, 15/37 at 3 mo, 18/36 at 2+ yr ARM with constipation decreased 25/36 at start, 9/35 at 3 mo, 12/31 at 2+ yr	Older and younger patients with SB and ARM had increased QoL at 3 mo and 2+ yr after initiating TAI
Costigan et al [79]	SB: 96 IA: 96 HD: 28 IC: 15 Other: 19 FI: NA CO: NA	192	2–17 yr	87 Peristeen TAI, 70 Willis TAI, 8 Braun TAI, 3 Tube, 24 ACE Washouts daily 28, QOD 106, 3×/wk 52, weekly 6	Single center Retrospective chart review	Socially clean: absence of soiling day and night	Socially clean: 180/192 HD: 23/28 IA:28/34 SB: 95/96 IC: 15/15 Other: 19/19 Medication in washout: 112/122	NA

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Table 3 (*Continued*)

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Continence outcome	QoL/satisfaction
Radojicic et al [80]	SB FI: NA CO: 70	70	4.6–15 yr	Group 1: AC + CIC + bowel tx (daily enema, laxatives, diet) Group 2: AC + CIC	Single center Prospective, nonrandomized controlled clinical trial	Not defined	Group 1 CO baseline: 35/35 CO 1 yr: 4/35 Mean UTI baseline: 3.2/yr Mean UTI 1 yr: 0.3 yr Group 2 CO baseline: 35/35 CO 1 yr: 35/35 Mean UTI baseline: 3.1/yr Mean UTI 1 yr: 1.1 yr	NA
Alabi et al [81]	SB FI: 1453/3801 CO: NA	4664	0–25 yr	Not defined	Cross-sectional data from National Spina Bifida Registry (USA)	No stool loss	FI:1453/3801 Fecal continence non-SB: 51–71% Fecal continence SB: 22–49% Pts <10 yr had lower rate of fecal continence	NA
Alhazmi et al [82]	SB FI: 109 CO: NA	280	60–216 mo	TAI (Peristeen) started 2–3×/wk, then variable	Single-center retrospective chart review	No stool loss with minimal or no constipation	With median follow-up of 48 mo Fecal continence: 101/109 Diaper free: 26/10 Diapers for urinary incontinence: 48/101 Diapers for fear of soiling despite continence: 27/101	NA
Eid et al [83]	SB FI: 9 CO: 21	30	4–18 yr	Psychological support, diet, RCE, ACE	Single center Prospective case series Measured bowel dysfunction (Wexner), rectal diameter, UTI frequency, urodynamics over 6–18 mo	Not defined	CO improved: 21/30 to 8/30 FI improved:9/30 to 2/30 Rectal diameter decreased: 34.83 to 27.9 mm Wexner score decreased: 12.67 to 10.17 Decreased urinary frequency, irritative sx and nocturnal enuresis Improvement in urodynamic parameters after treatment UTI in 21/30 at start to 5/30 at follow-up	NA

AC = anticholinergic; ACE = antegrade colonic enema; ARM = anorectal malformation; BM = bowel movement; CIC = clean intermittent catheterization; CO = constipation; ES = electrical stimulation; FI = fecal incontinence; FU = follow-up; HD = Hirschsprung disease; IA = imperforate anus; IC = idiopathic constipation; NA = not available; NBD = neurogenic bowel dysfunction; PEG = polyethyleneglycol; pt(s) = patient(s); QoL = quality of life; RCE = retrograde colonic enema; SB = spina bifida; SCI = spinal cord injury; sx = surgery; TAI = transanal irrigation; tx = therapy; UTI = urinary tract infection.

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Table 4 – Surgical management of neurogenic bowel—study characteristics and outcomes.

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Outcomes	QoL/satisfaction
Hensle et al [85]	SB FI: NA CO: NA	27	10–31 yr	ACE daily, 642 ml tap water	Single center Retrospective chart review	No stool loss	Continent: 19/25 Complications: 10/27 Reop: 3/27	NA
Shankar et al [86]	SB: 27 FI: NA CO: NA	40	6–21 yr	ACE QOD	Single center Retrospective case review QOLI score: 0–5 (5 ideal) CTT and manometry in 34 pts	Stool loss <1/mo	Continent: 17/27 Complications: 23/40 Reop: 11/40 Dropout: 4	Mean QOLI: 3.5 with improvement in all
Webb et al [87]	SB: 43 FI: NA CO: NA	57	5–30 yr	ACE q 72 h with phosphosoda or soap/ H_2O	Single center Retrospective case review	Not defined	"Good/excellent" results: 40/43 Complications: 8/57 Reop: 3/57	Patient satisfaction good to excellent
Curry et al [88]	SB: 108 ARM: 22 HD: 23 IC: 30 FI: NA CO: NA	273	7.5– 29.9 yr	ACE or cecostomy button	Multicenter Retrospective case review	Full continence: no leakage except minor during irrigation	Full continence: 68/108 SS: 30%	NA
Aksnes et al [89]	SB FI: 16 CO: 4	20	6.3–17 yr	ACE qd 900 ml tap water	Single center Prospective clinical trial Questionnaires (CBCL, YSR, SPPA) prior to and 6 mo after surgery FU visit and phone call	No stool loss	Continent: 16/20 Independent care: 16/20 Reop: 6/20	SPPA: improved self-esteem and close friends No difference on CBCL and YSR
Dey et al [90]	SB: 31 FI: NA CO: NA	62	3.8–21.4 yr	ACE 550 ml saline	Single center Retrospective case review Satisfaction questionnaire	Stool loss <1/mo	Continent: 27/32 Complications: 35/62 Reop: 22/62 Continued using ACE: 51/62 Dropouts: 11	Satisfaction correlated to continence Satisfaction median score 9/10
Casale et al [91]	SB FI: NA CO: NA	275	Mean 11 yr	ACE with or without concurrent urologic surgery	Single center Retrospective chart review	Not defined	Continent: 94% Complications: 27% No difference in continence rate or complications in ACE alone vs combination	NA
Lemelle et al [92]	SB FI: NA CO: NA	423	10–47 yr	Right ACE: 40 Left ACE: 7 1.2 l tap water or saline	Multicenter Chart review + interview Conventional bowel tx 382 compared with ACE 41	5-point Likert Scale (1 = always, 5 = never)	Continence rate superior in ACE group Shorter irrigation times for left ACE, but worse continence rates for right ACE	NA
Bani-Hani et al [93]	SB: 199 FI: NA CO: NA	236	2–36 yr	ACE qd with 642 ml ± medicated irrigant If immediate FI, increase volume and time sitting, if late FI, add 17 g PEG to irrigant	Single center Retrospective chart review	No stool loss	Continent: 96/236 Continent with PEG: 221/236	NA
Bani-Hani et al [94]	SB: 199 FI: NA CO: NA	236	2–36 yr	ACE qd, 642 ml tap water	Single center Retrospective chart review	No stool loss	Continent: 221/236 Complications: 98/236 Reop: 51/236	NA
Wong et al [95]	SB: 41 FI: NA CO: NA	64	6–15 yr	Chait cecostomy tube, glycerin or saline q 48–72 h	Single center Retrospective chart review + interview, phone, structured questionnaire (score 0–24, with 0 = perfect continence, 24 = complete incontinence)	Not defined	FI score in SB patients improved from 18 to 7 28/64 complications	NA

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Table 4 (*Continued*)

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Outcomes	QoL/satisfaction
Yardley et al [96]	SB: 27 FI: NA CO: NA	61	15.5–35.1 yr	ACE variable regimen	Single center Mail/phone questionnaire	Stool loss <1/mo	Continent: 11/16 SB Complications: 5/36 Reop: 2/36 Dropouts: 25	With ACE, satisfaction score 4/5
Matsuno et al [97]	SB FI: NA CO: NA	25	4.1–23.1 yr	13 RCE 12 ACE q 24–-48 h, tap water	Single center Chart review comparing ACE with RCE	No stool loss	Pseudocontinent ACE: 8/12 RCE: 10/13 Independent care ACE: 8/12 RCE: 3/13	NA
Bar-Yosef et al [98]	SB FI: NA CO: NA		6–22 yr	ACE and artificial sphincter	Single center Retrospective chart review	Not defined	Continent: 19/21 Complications: 3/21 Reop: 2/21	NA
Ok and Kurzrock [99]	SB families FI: NA CO: NA	23	Not defined	ACE variable regimen	Single center FICQoL 51-item questionnaire before and 6 mo after operation	Not defined	23 families preop 18 families postop Accidents decreased postop from 3.9 to 0.5/wk Decreased diaper usage	Improvement in caretaker anxiety, depression, and bother
Siddiqui et al [100]	SB: 40 FI: 21 (10/40 SB) CO: 38	105	Median 11.1 yr	ACE with saline; if inadequate, PEG added	Single center Retrospective chart review	Stool loss <1/wk	Continent SB: 30/40 Complications: 74/117 Reop: 39/117	NA
Vande Velde et al [101]	SB FI: NA CO: NA	40	5–38 yr	22 RCE 15 ACE	Singe center Retrospective cohort Questionnaire at office FU	No stool loss	Continent Children: 19/26 Adults: 9/15 Independent care Children: 5/25 Adults: 8/15 Dropouts: 5 FU more likely in continent pts	2/6 children report FI as problem 4/6 adults report FI as a problem
Chang et al [102]	SB: 21 ARM: 15 Hinman: 1 FI: NA CO: NA	49	Right ACE Mean 10.4 yr Left ACE Mean 7.0 yr	25 left-sided ACE 26 right-sided ACE (2 prior left-sided ACE) Variable regimens	Single center Retrospective chart review with telephone FU Satisfaction score: 1 = poor, 5 = excellent	Not defined	Continent Left: 17/25 Right: 25/26 SI Left: 7/25 Right: 0/26 Complications Left: 8/25 Right: 7/26 Reop Left: 6/25 Right: 2/26 Discontinued Left: 11/25 Right : 0/26	Patient satisfaction higher with right Right vs Left

Table 4 (*Continued*)

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Outcomes	QoL/satisfaction
Chu et al [103]	FI: NA CO: NA	23	Mean 8.8 yr	ACE variable timing 4 tap water 19 water + glycerin	Single center Retrospective chart review	Only "rare" accidents or occurring during GI illness	Continent: 18/19 SI: 3/16 13/16 required less than qd frequency Irrigant volume decreased vs other published studies	NA
Ellison et al [104]	FI: NA CO: NA	90	Mean 13.6 yr	48 right-sided ACE 6 transverse colon ACE 55 left-sided ACE	Single center Retrospective chart review	Not defined	Continent Left: 54/55 Right: 46/48 Transverse: 4/6 Complications: Left: 28/55 Right: 24/48 Transverse: 2/6 Flush time shorter for left: 37.3 vs 61.2 min	NA
Hoy et al [105]	FI: NA CO: NA	46	Not defined	26 ACE 23 Chait cecostomy	Single center Retrospective chart review with minimum 1 yr FU	Ability to wear underwear without accidents	Continent ACE: 22/26 Chait: 21/23 Complications ACE: 15/26 Chait: 17/23 Reop ACE: 8/26 Chait: 0/23 Conversions ACE to Chait: 3/26 Chait to ACE: 2/23 Mean LOS ACE: 5.2 d Chait: 4.0 d	NA
Masadeh et al [106]	SB: 41 ARM: 16 FI: NA CO: NA	68	Mean 11 yr	19 ACE 49 Cecostomy tube	Single center Retrospective chart review	Not defined	Continent Overall: 68% ACE: 74% Chait: 66% SI ACE: 10/19 Chait: 10/49 Complications ACE: 17/19 Chait: 39/49	NA
Imai et al [107]	SB FI: NA CO: NA	21	7.9–29.5 yr	ACE variable regimen	Single center Retrospective chart review Mailed questionnaire to evaluate outcomes, complications, QoL, satisfaction score (1–10, with higher = more satisfied)	No stool loss except some leakage with flush	Continent: 11/21 Complications: 8/21 Reop: 1/21	18/21 reported satisfaction with ACE

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Table 4 (*Continued*)

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Outcomes	QoL/satisfaction
Wide et al [108]	SB FI: NA CO: NA	106	7–16 yr	Normal toilet 20 Rectal microenema 4 TAI 50 ACE 32	Multicenter Mailed questionnaires (functional and PedsQL 4.0 for QoL) to pts on clinical database Norway + Sweden	Not defined but specific accident rates reported	11/20 normal toileting pts, 0/4 microenema, 14/50 TAI and 10/32 ACE pts achieved zero accidents 8/20 normal toileting pts, 4/4 microenema, 18/50 TAI and 18/32 ACE pts achieved <1 accident/mo 14/50 TAI and 10/32 ACE pts achieved <1 accident/wk	Children and parents report more complete bowel evacuation with ACE Parents satisfaction higher with ACE than TAI No significant differences in independence between TAI and ACE
Chong et al [109]	ARM: 64 SB: 40 HD: 10 IC: 40 Other: 5 FI: NA CO: NA	133	0–18 yr	ACE or Chait tube	Single center Retrospective chart extraction	Not defined	Social continence: 115/133 Reop: 45/133 At median 7 yr FU, 99/133 still using ACE, 18/133 discontinued due to incontinence, 16/133 discontinued due to achieving continence without use	NA
Anselmo et al [110]	SB: 25 ARM: 2 FI: 27 CO: 27	27	3–27 yr	Left-sided ACE variable regimen	Single center Retrospective case series Telephone interview to assess usage and satisfaction	Not defined	Continent: 24/27 Reop: 7/27 SI: 0 74% still use ACE at 75-mo FU	74% satisfied with left-sided ACE and would recommend to others
Bevill et al [111]	SB: 69 IA: 14 SA: 3 FI: NA CO: NA All male	86	3–42 yr	Group 1: Chait cecostomy tube Group 2: no cecostomy tube, only conventional neurogenic bowel management	Single center Retrospective chart review and clinic questionnaires to assess function and satisfaction (Likert responses dichotomized into positive or negative/ neutral responses	Complete/near complete: stool loss <3/yr (54/109) Partial: stool loss 1–3/ mo	Chait tube group: 23/53 had 0–3 accidents/yr, 19/53 had 1–3/mo, 6/53 had >3/mo Non-Chait tube group: 13/33 had 0–3 accidents/yr, 4/33 had 1–3/mo, 10/33 had >3/mo 47% of Chait tube pts report >1 mo to achieve perfect irrigation Complications: 1/53 SSI, 33/53 granulation tissue requiring AgNO3 tx, 8/53 accidental tube removal, 6/53 leakage with revision Reop: 7/53	Overall satisfaction rate with cecostomy tube 88%, with 92% reporting that they would have it placed again
Ibrahim et al [112]	SB FI: 23 CO: NA	23	3.5–17.8 yr	ACE variable regimen	Single center Retrospective chart review PedQOL administered prior to and 5, 10, and 15 mo after surgery Modified VAS to assess satisfaction in parents + pts	Full continence: no leakage except during irrigation Partial continence: clean with significant rectal or stoma leakage with subjective improvement	Full continence: 13/23 Partial continence: 8/23 Incontinent: 2/23 incontinent Complications: 16/23 Reop: 4/23	Mean PedQOL score prior to surgery 47.86, 5 mo postop 88.34, 10 mo postop 88.9, 10 mo postop 89.01 Parents' satisfaction score (VAS 1–10) was 3.06 before and 8.0 after surgery Patient satisfaction score was 1.75 prior to and 7.75 after surgery

Table 4 (*Continued*)

Reference	Patients	*N*	Age range	Treatment	Study design	Continence definition	Outcomes	QoL/satisfaction
Koyfman et al [113]	SB: 4 ARM: 3 HD: 3 Colonic neuropathy: 10 Slow transit CO: 12 FI: 9 CO: 29	38	3.1–32.1 yr	Laparoscopic/ endoscopically placed cecostomy tube	Single center Retrospective cohort	Success = daily stool evacuation with "minimal" to no stool loss over 7 d	"Successful" continence: 36/38 Complications: 47/38 Reop: 0	NA
Large et al [114]	SB FI with ACE: 108/115 CO with ACE: 7/115	172	10.1–18.6 yr	ACE 115 No ACE 57 (all on conventional tx)	Single center Retrospective chart review	No stool loss over prior 4 wk	Continent With ACE: 64/115 Without ACE: 29/57 Ambulatory patients: 64/104 Nonambulatory patients: 29/68	NA
Ayub et al [115]	SB + HD + CO: 24 Slow transit CO: 18 FI: 32 CO: NA	42	3–20 yr	19 ACE 23 Chait tube	Single center Retrospective chart review Phone interview to assess function/ outcomes and satisfaction (1–10 Likert scale)	Stool loss <1/mo	Continent Pre-ACE: 10/42 Post-ACE: 37/42 Complications: Short term (<2 wk): 10/42 Long term (>2 wk): 40/42 Reop: 5/42 15/42 discontinued ACE (8 of which no longer required it for continence)	Avg Likert scores for satisfaction 8.3/10, ease of use 9.4/10, and discomfort 3.6/ 10
Halleran et al [116]	ARM: 80 SB: 37 HD: 25 FI: NA CO: NA	204	2.4–35.6 yr	ACE 150 Chait cecostomy 54	Single center Retrospective chart review	Not defined	Complications ACE: 38/150 Chait: 56/54 Reop: ACE: 25/150 Chait: 34/54	NA

ACE = antegrade colonic enema; ARM = anorectal malformation; CO = constipation; CTT = colon transit time; FI = fecal incontinence; FU = follow-up; GI = gastrointestinal; HD = Hirschsprung disease; IA = imperforate anus; IC = idiopathic constipation; LOS = length of stay; NA = not available; PEG = polyethyleneglycol; pts = patients; QoL = quality of life; QOLI = Quality of Life Inventory; RCE = retrograde colonic enema; Reop = reoperation; SA = sacral agenesis; SB = spina bifida; SI = stomal incontinence; SS = stomal stenosis; SSI = surgical site infection; TAI = transanal irrigation; tx = therapy; VAS = visual analog scale.

that point, King et al [76] found that patients using transanal irrigation compared with those who discontinued the regimen had similar rates of fecal incontinence, constipation, and QoL, implying that bowel continence was a stronger factor in QoL than treatment modality. Liptak and Revell [55], Scholler-Gyure et al [58], and Pereira et al [70] found that patient satisfaction with therapy was good and improved with follow-up. However, Palmer et al [60] noted that the subjective parental opinion dampened their evaluation of success for electrical stimulation, and they attributed this to unrealistic expectations associated with a novel therapy.

3.2.2. *Surgical management of neurogenic bowel*

Surgical intervention for neurogenic bowel primarily involves the creation of a conduit to allow the patient (or caregiver) to administer an antegrade enema, whereby the irrigant is introduced upstream in the gastrointestinal tract to be flushed out of the bowel downstream. Classically, the MACE/ACE is achieved by opening the distal tip of the appendix and bringing this out as a stoma on the lower right quadrant of the abdomen or the umbilicus. Alternatively, a specialized plastic conduit (eg, a Chait tube) can be introduced percutaneously into the cecum and left in place, although this does require exchange periodically. Recently, surgeons have utilized colonic flaps on the left side of the large intestine, and less frequently the transverse colon, to create the ACE conduit. Theoretically, this should allow for shorter washout times, and it can be an especially useful approach for patients who have undergone a prior appendectomy.

The 32 studies captured for review are summarized in Table 4. Of these, 17 utilized the strict definition of fecal continence and these were used to determine that the overall achievement of fecal continence was 750/1033 (73%) [85,86,88–90,93,96–98,103,105,107,108,111,112,114,115].Most of these studies considered an ACE using tan appendix or cecal flap, and found an overall rate of continence of 562/738 (76%) [85,86,88–90,93,96–98,103,105,107,108,112,114]. A smaller subset investigated a left-sided ACE procedure, but none of these studies adhered to strict definition of fecal incontinence [92,102,104,110]. Finally, two studies measured outcomes from ACE administered by a cecostomy tube, typically a Chait tube, and were able to achieve an overall strict continence rate of 44/76 (58%) [105,111].

Surgical complications were frequent with all methods for administering ACE, with overall complications of 711/1378 (52%) [85–88,90,92,93,97,98,100,102–107,111–113,115,116], and surgical revisions were required in 288/1275 (23%) [85–87,89,90,93,96,98,100,102,105,107,109,112,113,115,116]. Classical, right-sided ACE conduits were found to have a complication rate of 416/1033 (40%) and a surgical revision rate of 179/900 (20%) [85–87,90,93,96–98,100,102–107,112,116]. Complications and revisions required for the left-sided ACE were 46/80 (45%) and 9/53 (17%), respectively [102,104,110]. From the studies on cecostomy tubes, the complications were 207/217 (95%), and 42/168 (25%) required surgical revisions [105,106,111,113,116]. The most common complications for ACE conduits were stomal stenosis, stomal leakage, and surgical site infections. For Chait cecostomy tubes, the most common problems were related to leakage around the tube, tube dislodgement, and surgical site infections.

Fourteen of the surgical series measured patient satisfaction or assessed QoL scores, but as with the nonsurgical papers, the variability of the instruments prohibits direct comparison [86,87,89,90,96,99,101,102,107,108,110–112,115]. Similar to results from the nonsurgical series, patients and parents in four studies reported satisfaction and QoL that were directly correlated with achieving fecal continence [90,101,108,112]. Wide and colleagues [108] compared satisfaction rates between patients undergoing transanal irrigation versus ACE, and found that the latter reported better bowel evacuation and higher satisfaction. However, both patient groups achieved the same level of independence in managing their bowel regimens. In a study looking at satisfaction rates in patients undergoing left- and right-sided ACE procedures, Chang et al [102] found that patients had greater satisfaction with stoma placement on the right side of the body.

3.3. **Discussion**

Including all treatment modalities for managing neurogenic bladder, the overall rate of urinary continence was 50%, with 44% of patients achieving complete continence with nonsurgical methods and 64% of patients achieving continence after surgical interventions. With regard to bowel management, 78% of patients attained fecal continence via nonsurgical means, while 73% of patients became continent after surgical treatment that predominantly utilized ACEs. Considering that patients who fail nonsurgical management proceed to surgical modalities, these results suggest that the majority of patients with neurogenic bladder and bowel can ultimately achieve urinary and fecal continence using modern treatment regimens.

While surgical continence procedures are highly effective, there is significant risk of surgical complications and revision surgery may be needed. Complication rates between the different procedures for attaining urinary and fecal continence vary but are typically at or above 50%, with many patients undergoing multiple operations. This, along with the upfront cost of major surgery, has led to the development of a stepwise approach that first employs nonsurgical methods and utilizes surgical interventions for those patients who fail to achieve continence. The International Children's Continence Society promotes this progression in their published guidelines for treating neurologic bladder and bowel dysfunction in children [118].

The vast majority of academic literature on the management of pediatric neurogenic bowel and bladder comes from large academic centers with multidisciplinary clinics devoted to this patient population. Each of these centers has developed their own management protocols with their own assessment tools and offered their own definitions of "successful" therapy, which makes comparisons difficult. In the USA, the CDC has enrolled nearly 10 000 patients from over 25 centers in the National Spina Bifida Patient Registry using well-defined outcome definitions. In the UMPIRE protocol, the CDC has combined this with a standard, albeit flexible, treatment protocol to better define the optimal management of neurogenic bladder in the future [119]. This will allow for better comparison of treatments and outcome results. Ultimately, this will aid in the development of risk stratification aids that could provide valuable prognostic data in the treatment of neurogenic bladder and bowel.

4. Conclusions

Approximately half of children born with neurogenic bladder and bowel dysfunction can achieve continence with nonsurgical therapy. The majority of children who cannot attain continence with these measures are able to do so successfully after surgical intervention, but this comes with a high cost of postoperative complications and need for additional procedures. Therefore, agencies such as the International Children's Continence Society promote a stepwise approach. The entire literature supporting this approach consists of low-quality evidence predominantly from retrospective chart reviews. We are optimistic that better-quality information will be available in the future with the creation of large-scale registries, such as the CDC-sponsored Spina Bifida Registry in the USA, which use strictly defined protocols and strict outcome definitions.

Author contributions: J. Todd Purves had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Purves.
Acquisition of data: Johnston, Purves.
Analysis and interpretation of data: Johnston, Wiener, Purves.
Drafting of the manuscript: Johnston, Wiener, Purves.
Critical revision of the manuscript for important intellectual content: Johnston, Wiener, Purves.
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