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REVIEW

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Decannulation following tracheostomy in children: A systematic review of decannulation protocols

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Abstract

Objective: To provide a systematic review of the existing pediatric decannulation protocols, including the role of polysomnography, and their clinical outcomes.

Methods: Five online databases were searched from database inception to May 29, 2020. Study inclusion was limited to publications that evaluated tracheostomy decannulation in children 18 years of age and younger. Data extracted included patient demographics and primary indication for tracheostomy. Methods used to assess readiness for decannulation were noted including the use of bronchoscopy, tracheostomy tube modifications, and gas exchange measurements. After decannulation, details regarding mode of ventilation, location, and length of observation period, and clinical outcomes were also collected. Descriptive statistical analyses were performed.

Results: A total of 24 studies including 1395 children were reviewed. Tracheostomy indications included upper airway obstruction at a well-defined anatomic site (35%), upper airway obstruction not at a well-defined site (12%) and need for long-term ventilation and pulmonary care (53%). Bronchoscopy was routinely used in 23 of 24 (96%) protocols. Tracheostomy tube modifications in the protocols included capping (n = 20, 83%), downsizing (n = 14, 58%), and fenestrations (n = 2, 8%). Measurements of gas exchange included polysomnography (n = 13/18, 72%), oximetry (n = 10/18, 56%), blood gases (n = 3,17%), and capnography (n = 3, 17%). After decannulation, children in 92% of protocols were transitioned to room air. Observation period of 48 h or less was used in 76% of children.

Conclusions: There exists large variability in pediatric decannulation protocols. Polysomnography plays an integral role in assessing most children for tracheostomy removal. Evidence-based guidelines to standardize pediatric tracheostomy care remain an urgent priority.

KEYWORDS

decannulation protocols, pediatric otolaryngology, pediatric respirology, tracheostomy decannulation

1 | INTRODUCTION

Due to advancements in medical care and home ventilation technology, the indications for tracheostomy tubes in children have evolved in recent decades.[1] Once primarily performed for acute infectious upper airway obstruction, common tracheostomy indications now include cardiopulmonary disease, chronic lung disease of prematurity, neurological impairment, craniofacial abnormalities, and prolonged intubation.[1–3] This shift in the indication for tracheostomy has altered our ability to predict when and how to safely decannulate children with a tracheostomy.

A tracheostomy tube for a child is not only associated with medical morbidity but also has important psychosocial effects on children and their families, including negative impacts on quality of life, sleep, relationships, social life, and employment.[4,5] As a result, decannulation of the tracheostomy tube is often a shared goal for patients, family caregivers, and their multidisciplinary care teams.

Decannulation is possible when a child's underlying condition necessitating the artificial airway resolves or considerably improves and/or a switch to noninvasive ventilation becomes feasible.[6] Complications of a tracheostomy tube that need to be addressed before decannulation include granulation tissue formation, subglottic stenosis, and wound infection.[7–11] Conversely, the risks of no longer having a tracheostomy include acute or chronic airway obstruction, chronic aspiration without pulmonary toilet, and difficult airway management.[6,12] Therefore, careful planning of a tracheostomy tube removal is required.

Despite the large morbidity and potential mortality associated with tracheostomy tube decannulation failure, the existing literature is limited with regard to best practice of pediatric decannulation.[6] Furthermore, variation in clinical practice exists as a culmination of several complex factors, including the patient's underlying disease and indication for tracheostomy, possible ventilation requirement, age at decannulation, and the health-care setting and available resources. Therefore, our aim was to systematically review the existing literature on pediatric tracheostomy decannulation protocols, including the methods used to assess decannulation readiness, role of polysomnography (PSG), and their associated clinical outcomes.

2 | METHODS

2.1 | General methodology

This article is written in agreement with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for systematic reviews and meta-analyses. See Supporting Information Appendix E1 in the online supplement for the PRISMA checklist. It is registered (ID: CRD42020155791) on the International Prospective Register of Systematic Reviews (PROSPERO).

2.2 | Data sources and searches

The online databases Ovid MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials (CCRCT), Cumulative Index to Nursing and Allied Health Literature (CINAHL), and Web of Science were searched to identify relevant literature. A manual search of all references in the included articles was then performed to identify other potential studies of interest. The search was performed from database inception to May 29, 2020. See Supporting Information Appendix E2 in the online supplement for the complete search strategy.

2.3 | Study selection

2.3.1 | Eligible studies

Selected studies examined decannulation following a tracheotomy procedure in children and adolescents 18 years of age and younger and were written in the English language.

2.3.2 | Exclusion criteria

Articles were excluded for the following reasons:

1. Did not involve pediatric subjects (older than 18 years of age).
2. Articles did not contain original research (e.g., review articles).
3. Purpose of study was not to investigate decannulation.
4. Did not describe a decannulation protocol.
5. Articles discussed pediatric tracheostomy tube insertion but not decannulation.

2.3.3 | Selection process

A reference library was maintained using the EndNote X9 software. Duplicate articles were first excluded. Three independent reviewers (R.V., C.M., R.A.) then screened the titles and abstracts to exclude publications that did not meet the inclusion criteria. Full texts of articles were obtained and assessed for final eligibility independently by three authors (R.V., C.M., R.A). Full articles were also read if a decision regarding inclusion/exclusion could not be made based on the available information included in the abstract.

2.3.4 | Data abstraction

Five authors (R.V., C.M., J.S., A.S., R.A.) independently extracted relevant data and assessed data quality. Any disagreements between the five reviewers were resolved through discussion with three other expert reviewers (J.C., N.W., E.P.). Demographic data collected from the studies included past medical diagnoses, primary indication(s) for

tracheostomy tube insertion, age at tracheostomy tube insertion, and age at decannulation. In addition, methods used to assess each child's readiness for decannulation were noted including bronchoscopy, tracheostomy tube modifications (downsizing, capping, or fenestrated tubes), and measurements of gas exchange (blood gas, oximetry, capnography, or PSG). After tracheostomy decannulation, details regarding mode of ventilation, location of observation, and length of observation period were recorded. Success and failure rates were also collected. Failed attempts were defined as children who could not be decannulated immediately or had to be recannulated within 6 months of the decannulation attempt. Lastly, all airway-related complications within 1 year of the decannulation were noted.

2.3.5 | Quality assessment of included studies

Qualitative assessment of all included studies was performed by three authors (R.V., C.M., J.S.) and disagreements were resolved by consensus with two expert authors (A.S., R.A.). The Newcastle-Ottawa scale (NOS) is a validated risk of bias assessment tool for observational studies. The NOS tool assesses the risk of bias in three domains; (1) selection of study groups; (2) comparability of groups; and (3) ascertainment of outcomes. Each domain contains a set of multiple-choice questions and the options with the lowest risk of bias in each domain were identified by a star. As the decannulation protocols described in all included studies were not compared against a control, a modification to the NOS scale was made to remove two items related to comparability (selection of the nonexposed cohort and comparability of cohorts). In our modified NOS tool, a maximum of six stars may be assigned to each study. Studies that scored at least five stars were defined as high quality, four stars as medium quality, and three or fewer stars as low quality. See Supporting Information Appendix E3 in the online supplement for the complete NOS scoring guide.

2.3.6 | Statistical analysis

Clinical and demographic characteristics of all children were summarized using descriptive statistics. The prevalence of each tracheostomy indication was calculated as a percentage of all children included from studies where the primary indication was clearly specified. Methods used to assess readiness and postdecannulation monitoring were reported as a percentage of all included studies. Success and failure rates were calculated as a percentage of all decannulation attempts. As comparisons were not made using raw data from individual studies, formal statistical testing was not conducted.

3 | RESULTS

3.1 | Study selection

A search of the literature using our search strategy produced 1292 articles (Figure 1). Full length articles of 40 studies were then retrieved to assess eligibility using our inclusion and exclusion criteria. Manual searches of the literature produced four additional articles.

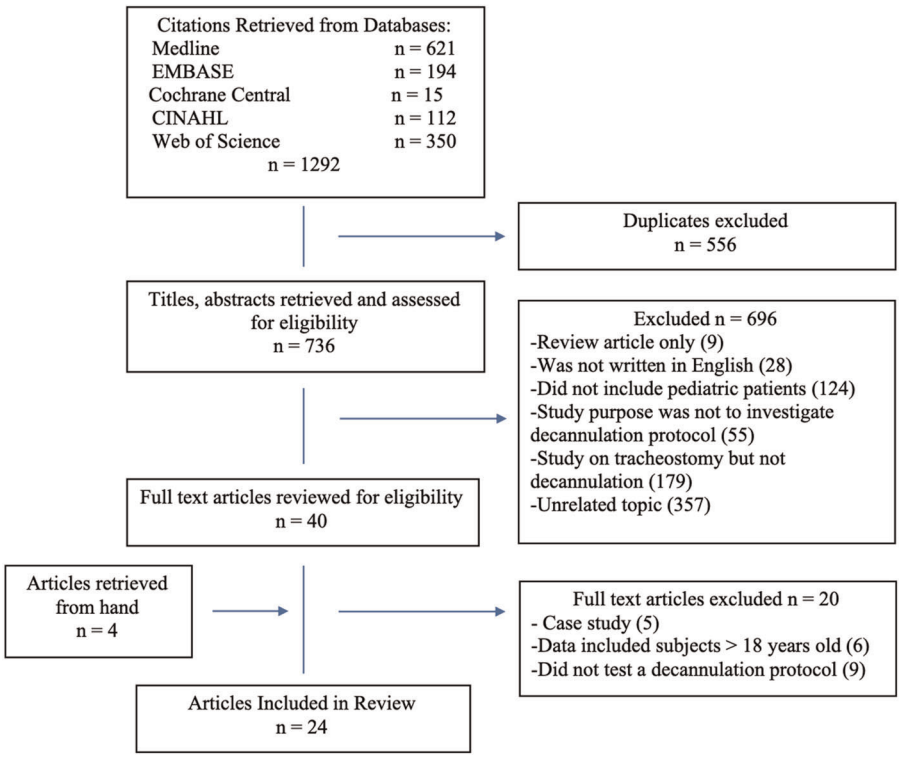

FIGURE 1 Flowchart outlining the articles retrieved using our search strategy and the reasons for including and excluding articles. CINAHL, Cumulative Index to Nursing and Allied Health Literature [Color figure can be viewed at wileyonlinelibrary.com]

Twenty articles were excluded as they did not meet inclusion criteria upon further inspection. The remaining 24 articles were included.

3.2 | Study demographic characteristics

From the 24 included studies, there was a total of 1395 children. The age at tracheotomy ranged from 0 to 18 years, with the duration of cannulation ranging from 0 to 12 years. All articles were published between 1978 and 2020. The number of pediatric participants in each of the studies ranged from 7 to 160. Demographic characteristics are summarized in Table 1.

3.3 | Indications for tracheostomy

Nineteen studies with 1141 children provided clear primary indications for tracheostomy tube insertion. Two of these studies provided more than one indication for tracheostomy.[18,25] For these particular studies, we used our clinical expertise to reach a consensus on the primary indication. The remaining four studies with 270 children did not clearly describe the primary reason for tracheostomy and were excluded from this analysis.[8,14,15,19] Tracheostomy indications were sorted into three categories based on a recent classification scheme for pediatric tracheostomy by Mitchell et al.[35] These categories included (1) upper airway obstruction at a well-defined anatomic site (401/1141, 35%); (2) upper airway obstruction not at a well-defined anatomic site or due to an underlying medical condition (136/1141, 12%); and (3) need for access to the lower airway for long-term ventilation and pulmonary care (588/1141, 53%). The second category refers to children with craniofacial anomalies and multiple sites of upper airway obstruction rather than one fixed anatomic site. The most common tracheostomy indications were chronic lung disease (*N* = 221/1141, 19%), followed by subglottic stenosis (*N* = 131/1141, 11%) and failure to wean from ventilation (*N* = 87/1141, 8%). A detailed summary of the tracheostomy indications is shown in Table 2.

3.4 | Decannulation protocols

Before decannulation, bronchoscopy was routinely used in in 23 of 24 (96%) protocols. Eleven studies specified the type of bronchoscopy used which included both flexible and rigid bronchoscopies in 7 (64%) protocols, rigid bronchoscopy only in 3 (27%) protocols, and flexible bronchoscopy only in 1 (9%) protocol. Tracheostomy tubes were capped in 20 (83%) studies, downsized in 14 studies (58%), and fenestrated in only 2 (8%) studies. Sixteen studies provided further details regarding capped tube trials. Of these, 6 (38%) studies[16,18,19,26,33] used a stepwise daytime to nocturnal progression over multiple days, 5 (31%) studies[6,21,27,31,32] used a 12 to 24-h capping trial, 3 (19%) studies[22,23,30] used only a single overnight capping trial, 1 (6%) study[13] used a 48-h capping trial, and 1 (6%) study[20] used capping for less than 12 h. Assessment of gas exchange was not reported in six studies. Of the 18 studies reporting gas exchange measurement(s), PSG was used in 13 (72%) studies, oximetry in 10 (56%) studies, blood gases in 3 (17%) studies, and capnography with end-tidal CO_2 in 3 (17%) studies. Details of all included decannulation protocols are summarized in Table 3.

Of the 1395 children from the included 24 studies, 1267 (91%) children underwent attempted decannulation. These children accounted for 1336 decannulation attempts, of which 1062 (79%) were successful and 274 (21%) failed, requiring recannulation. A pre-decannulation bronchoscopy was performed in all of these failed attempts; however, a PSG was performed in only 66 (24%) of the failed attempts. Among individual studies, success rates ranged from 23% to 100%.

After decannulation, details on the use of ventilation were reported in 13 studies. Of these, 12 (92%) studies transitioned children entirely to room air, 5 (38%) studies included the use of noninvasive ventilation, and only 2 (15%) studies included mention of intubation after decannulation. Children were mostly observed on the inpatient ward (*n* = 13, 54%) or intensive care unit (*n* = 8, 33%). In 2 (8%) studies, children were discharged home the day of decannulation. In one study (4%), children were admitted to a rehabilitation unit. Length of observation periods ranged between 0 and 32 days. In the 16 protocols that specified length of observation after decannulation, 646/852 children (76%) were observed in hospital for 48 h or less and 206 (24%) children were observed for greater than 48 h.

Rates of complications after decannulation ranged between 0% and 20%. Specific complications were reported in 10% (*n* = 59/586) of children from 12 studies. These included tracheocutaneous fistula (*n* = 35, 59%), respiratory tract infection (*n* = 10, 17%), suprastomal granulation tissue formation (*n* = 3, 5%), failure-to-thrive (*n* = 1, 2%), and unspecified need for recannulation (*n* = 10, 17%). One death was reported in a child with lower respiratory tract infection after decannulation. It is important to note that although tracheocutaneous fistula was the most commonly reported complication, several of the studies considered it to be a sequalae of long-term tracheostomy rather than a decannulation complication.

3.5 | Quality assessment

Twenty-two studies were retrospective cohort studies and two studies were prospective cohort studies.[13,31] The maximal obtained score using the modified NOS scale was six stars. This perfect score was achieved by 2 (8%) studies. Overall, 12 (50%) studies were deemed to be of high quality, 9 (38%) of medium quality, and 3 (12%) of low quality. NOS scores for all studies are included in Supporting Information Appendix E3. The criteria met by all included studies were "representativeness of exposed cohort" as they included pediatric patients aged 18 years and younger with conditions that are considered typical indications for tracheostomy. Conversely, the least met criterion was "demonstration that the outcome of interest was not present at the start of the study." These studies included children who may have undergone a previous attempt at

TABLE 1 Included studies and tracheostomy data of the selected population

Study (number)	Country of study	Type of study	Study objectives	Specific population	Number of children (M/F)	Age at tracheostomy, mean (range)	Age at decannulation, mean, years (range)	Duration of cannulation, mean, years (range)
Chauhan et al.[13]	India	Prospective cohort	Determine predictive factors of successful decannulation	NR	67 (45/22)	4.9	NR	NR
(*N* = 67)								
Canning et al.[14]	New Zealand	Retrospective cohort	Determine predictive factors of successful decannulation	NR	131 (76/55)	NR	4.8 (0.1–15)	2.3 (0 – 12)
(*N* = 131)								
Schweiger et al.[15]	Brazil	Retrospective cohort	Determine predictive factors of successful decannulation	NR	160 (93/67)	0.6 (IQR 0.3 – 2.5)	NR	1.2 (IQR 0.3 – 1.8)
(*N* = 160)								
Quinlan et al.[16]	USA	Retrospective cohort	Determine role of PSG in decannulation	Broncho-pulmonary dysplasia	125 (72/53)	NR	NR	NR
(*N* = 125)								
Pozzi et al.[17]	Italy	Retrospective cohort	Effectiveness of following a decannulation protocol	Acquired brain injury	84 (54/30)	NR	9.5	NR
(*N* = 84)								
Seligman et al.[6]	USA	Retrospective cohort	Determine success rate of a decannulation protocol	NR	23 (11/12)	0.3 (0.0–1.8)	2 (0.6–4)	NR
(*N* = 23)								
Bashir et al.[18]	USA	Retrospective cohort	Determine role of PSG in decannulation	NR	148 (88/60)	0.4 (0.2–0.7)	3.1 (2.2–4.9)	NR
(*N* = 148)								
Maslan et al.[19]	USA	Retrospective cohort	Describe pediatric decannulation	NR	46 (NR)	1.6	4.3	2.5
(*N* = 46)								
Sachdev et al.)[20]	India	Retrospective cohort	Evaluating role of flexible bronchoscopy in decannulation	NR	49 (35/14)	NR	3 (0.3–16)	0.7 (0.1 – 7.2)
(*N* = 49)								
Beaton et al.[21]	UK		Describe pediatric decannulation	NR	45 (25/20)	NR	2.5 (0.5–16.7)	2.8

TABLE 1 (Continued)

Study (number)	Country of study	Type of study	Study objectives	Specific population	Number of children (M/F)	Age at tracheostomy, mean (range)	Age at decannulation, mean, years (range)	Duration of cannulation, mean, years (range)
		Retrospective cohort						
(*N* = 45)								
Lee et al.[22]	Australia	Retrospective cohort	Determine role of PSG in decannulation	NR	30 (20/10)	NR	7.6 (0.5–17)	2.5
(*N* = 30)								
Liptzin et al.[23]	USA	Retrospective cohort	Describe pediatric decannulation	NR	18 (17/1)	NR	2.6 (0.6–7.5)	NR
(*N* = 18)								
Wirtz et al.[24]	USA	Retrospective cohort	Determine success rate of a decannulation protocol	NR	35 (NR)	NR	0.4–17	1.5 (0.1 – 11)
(*N* = 35)								
Henningfield et al.[25]	USA	Retrospective cohort	Describe pediatric decannulation from home mechanical ventilation	NR	46 (25/21)	0.3	3.4	NR
(*N* = 46)								
Prickett et al.[26]	USA	Retrospective cohort	Determine incidence and timing patterns of elective decannulation failure	NR	50 (29/21)	0–16.6	5.5 (0.9–17.9)	NR
(*N* = 50)								
Funamara et al.[27]	USA	Retrospective cohort	Determine differences in decannulation rates based on indications for tracheostomy	NR	113 (NR)	5.2 (0–18)	0.1–18	0 – 5
(*N* = 113)								
Han et al.[28]	USA	Retrospective cohort	Determine predictive factors and length of time to decannulation	Pierre Robin Sequence	25 (13/12)	NR	NR	8
(*N* = 25)								
Kontzoglou et al.[29]	Greece	Retrospective cohort	Describe pediatric decannulation	NR	7 (NR)	0.4	2.3	2.2
(*N* = 7)								

(Continues)

TABLE 1 (Continued)

Study (number)	Country of study	Type of study	Study objectives	Specific population	Number of children (M/F)	Age at tracheostomy, mean (range)	Age at decannulation, mean, years (range)	Duration of cannulation, mean, years (range)
Gray et al.[30]	USA	Retrospective cohort	Determine predictive factors of decannulation	NR	30 (24/6)	3.2 (0–16)	5.7 (0.7–16.2)	1.8 (0 – 11.2)
(*N* = 30)								
Merritt et al.[31]	USA	Prospective cohort	Managing SSGT during decannulation	NR	10 (8/2)	NR	4.7 (1.2–16)	2.8
(*N* = 10)								
Waddell et al.[32]	UK	Retrospective cohort	Determine predictive factors and length of observation period after decannulation	NR	84 (39/45)	2.2 (0 – 14)	NR	3.5 (0-15.2)
(*N* = 84)								
Tunkel et al.[33]	USA	Retrospective cohort	Determine role of PSG in decannulation	NR	24 (NR)	NR	NR	2.3 (0.3 – 10)
(*N* = 24)								
Al-Saati et al.[8]	UK	Retrospective cohort	Role of surgical intervention in those deemed unsuitable for ward decannulation	NR	14 (11/3)	0.3 (0.1 – 0.8)	NR	3.2 (1.1 – 7.8)
(*N* = 14)								
Filston et al.[34]	USA	Retrospective cohort	Describe pediatric decannulation, specifically in infants	Infants	31 (NR)	0.0–0.9	0.2–3	NR
(*N* = 31)								

Abbreviations: IQR, interquartile range; NR, not reported; PSG, polysomnography; SSGT, suprastomal granulation tissue.

TABLE 2 Categorized indications for pediatric tracheostomy in the included studies

Classification	Patient conditions	Chauhan etal.[13]	Canning etal.[14]	Quinlan etal.[16]	Pozzi etal.[17]	Seligman et al.[6]	Bashir etal.[18]	Sachdev etal.[20]	Beaton etal.[21]	Lee etal.[22]	Liptzin et al.[23]	Wirtz etal.[24]	Henningfield etal.[25]	Funamara etal.[27]	Han etal.[28]	Kontzoglou etal.[29]	Gray etal.[30]	Merritt etal.[31]	Waddell etal.[32]	Tunkel et al.[33]	Filston et al.[34]	Total	Category Total
Upper airway obstruction at a well-defined anatomic site	Subglottic stenosis	2	25			6	36		7	4			2						37	4	8	131	401
Subglottic hemangioma																		10			10		
Tracheobronchomalacia					3	8		8	3			7									29		
Vocal cord paralysis						29		5	1			2						6			43		
Laryngeal obstruction						6	8	2				2					1	2			21		
Airway tumor						6															6		
Choanal atresia						3		1													4		
Facial trauma						3	8				1		11								23		
Airway compression						9			1			1									11		
Iatrogenic																				4	4		
Unspecified obstruction		50								5	14		22		2	22					115		
	Oral infection	4																				4	
Upper airway obstruction not at a well-defined anatomic site or due to an underlying medical condition	Micrognathia including PRS					2	7		10				1		25							45	136
								1													1		

(Continues)

TABLE 2 (Continued)

Classification	Patient conditions	Chauhan etal.[13]	Canning etal.[14]	Quinlan etal.[16]	Pozzi etal.[17]	Seligman et al.[6]	Bashir etal.[18]	Sachdev etal.[20]	Beaton etal.[21]	Lee etal.[22]	Liptzin et al.[23]	Wirtz etal.[24]	Henningfield etal.[25]	Funamara etal.[27]	Han etal.[28]	Kontzoglou etal.[29]	Gray etal.[30]	Merritt etal.[31]	Waddell etal.[32]	Tunkel et al.[33]	Filston et al.[34]	Total	Category Total
CHARGE syndrome																							
Pfeiffer syndrome								1													1		
Cystic hygroma								1										3			4		
Congenital heminasal aplasia					1																1		
Recurrent respiratory papillomatosis	1																	6			7		
Obstructive sleep apnea									2										7		9		
Unspecified craniofacial anomaly		25					4						12		3		2	8	7	7	68		
Need for access to the lower airway for long-term ventilation and pulmonary care	BPD/CLD			125			32		5	5	11	20	17					6				221	588
Failure to wean from ventilation		31					19	1				11				7			6	12	87		
Pulmonary hypoplasia												2									2		
Hypoplastic left heart									1												1		
Neuromuscular weakness						2	7	2	2						2		1				16		
						4						1									5		

TABLE 2 (Continued)

Classification	Patient conditions	Chauhan et al.[13]	Canning et al.[14]	Quinlan et al.[16]	Pozzi et al.[17]	Seligman et al.[6]	Bashir et al.[18]	Sachdev et al.[20]	Beaton et al.[21]	Lee et al.[22]	Liptzin et al.[23]	Wirtz et al.[24]	Henningfield et al.[25]	Funamara et al.[27]	Han et al.[28]	Kontzoglou et al.[29]	Gray et al.[30]	Merritt et al.[31]	Waddell et al.[32]	Tunkel et al.[33]	Filston et al.[34]	Total	Category Total
Central hypoventilation disorder (e.g., CCHS)																							
CNS infection				5					3									3			11		
CNS tumor				8		3			2												13		
Stroke				5																	5		
Hypoxic brain injury				11																	11		
Spinal injury									2												2		
Seizure disorder							2														2		
Traumatic brain injury				48				1										2			51		
Unspecified cardiopulmonary disease	60				9								24								93		
Unspecified neurological disease				7			1						44								52		
	Other/unknown					2				4	2						1		7			16	
Total			131	125	84	23	148	49	45	30	18	35	46	113	25	7	30	10	84	24	31	1058	1141

Note: Schweiger et al.[15], Maslan et al.[19], Prickett et al.[26], and Al-Saati et al.[8] were excluded from this analysis as the primary indication for tracheostomy was not clearly described.

Abbreviations: BPD, bronchopulmonary dysplasia; CLD, chronic lung disease; CCHS, congenital central hypoventilation syndrome; CNS, central nervous system; PRS, Pierre Robin sequence.

TABLE 3 Methodologies of the included decannulation protocols

	Assessment of readiness for decannulation				Postdecannulation				
Study author, year	Tube trial	Gas exchange measurement	Bronchoscopy, type if specified	Ventilation post-decannulation	Observation period, days (Range)	Admission	Success rate (%)[a]	Failure rate (%)[a]	Complications (%)
Chauhan et al.[13]	Downsized, capped	NR	Yes, rigid	NR	NR	Admitted, location not specified	61 (91%)	6 (9%)	NR
N = 67									
Canning et al.[14]	Downsized, capped	O/N oximetry, PSG, capnography	Yes, flexible and rigid	Room air, NIV, endotracheal intubation	2	ICU, inpatient ward	132 (84%)	26 (16%)	TCF (*N* = 2, 2%)
N = 131									
Schweiger et al.[15]	Downsized, capped	NR	Yes	NR	1–2	Inpatient ward	36 (23%)	124 (77%)	NR
N = 160									
Quinlan et al.[16]	Downsizing, capped	PSG	Yes	NR	1–2	Inpatient ward	101 (95%)	5 (5%)	NR
N = 125									
Pozzi et al.[17]	Downsized, capped	DN oximetry, PSG	No	NR	NR	Rehab unit	84 (100%)	0 (0%)	None
N = 84									
Seligman et al.[6]	Fenestrated, capped	DN oximetry	Yes, rigid	Room air	1–2	Admitted, location not specified	22 (85%)	4 (15%)	-TCF (*N* = 11, 48%)
N = 23									
-Respiratory distress (*N* = 2, 9%)									
-FTT (*N* = 1, 4%)-Respiratory									
tract infection (*N* = 1, 4%)									
Bashir et al.[18]	Downsized, capped	O/N oximetry, PSG, capnography	Yes	Room air, NIV	NR	ICU	146 (95%)	7 (5%)	NR
N = 148									
Maslan et al.[19]	Capped	DN oximetry, PSG		NR	0–1		45 (98%)	1 (2%)	

TABLE 3 (Continued)

Study author, year	Assessment of readiness for decannulation				Postdecannulation				
	Tube trial	Gas exchange measurement	Bronchoscopy, type if specified	Ventilation post-decannulation	Observation period, days (Range)	Admission	Success rate (%)[a]	Failure rate (%)[a]	Complications (%)
			Yes, flexible and rigid			Inpatient ward, no admission			-Recannulation (*N* = 2, 4%)
N = 46									
-Respiratory tract infection (*N* = 1, 2%)-SSGT									
(*N* = 1, 2%)									
Sachdev et al.[20]	Capped	DT oximetry	Yes, flexible	Room air	2	ICU, inpatient ward	38 (88%)	5 (12%)	Unspecified recannulation (*N* = 5, 10%)
N = 49									
Beaton et al.[21]	Downsized, capped	O/N oximetry, PSG	Yes	Room air	2	Admitted, location not specified	33 (58%)	24 (42%)	-TCF (*N* = 19, 42%) Respiratory
N = 45									
tract infection (*N* = 1, 2%)									
Lee et al.[22]	Downsized, capped	PSG	Yes	Room air, NIV	NR	Inpatient ward	26 (87%)	4 (13%)	Respiratory tract infection (*N* = 1, 3%)
N = 30									
Liptzin et al.[23]	Downsized, capped	PSG, capnography, venous or capillary blood gas	Yes, flexible and rigid	NR	1–5	Inpatient ward	18 (86%)	3 (14%)	NR
N = 18									
Wirtz et al.[24]	None	NR	Yes, flexible and rigid	Room air	1–5	ICU	33 (94%)	2 (6%)	-TCF (*N* = 1, 3%)-Unspecified
N = 35									
recannulation (*N* = 1, 3%)-SSGT									

(Continues)

TABLE 3 (Continued)

Study author, year	Assessment of readiness for decannulation				Postdecannulation				
	Tube trial	Gas exchange measurement	Bronchoscopy, type if specified	Ventilation post-decannulation	Observation period, days (Range)	Admission	Success rate (%)[a]	Failure rate (%)[a]	Complications (%)
(*N* = 1, 3%)									
Henningfield et al.[25]	Capped	PSG	Yes, flexible and rigid	Room air, NIV	NR	Admitted, location not specified	46 (98%)	1 (2%)	-Sepsis (*N* = 1, 2%)-Respiratory
N = 46									
tract infection (*N* = 1, 2%)									
Prickett et al.[26]	Capped	PSG	Yes	Room air, NIV	2	ICU	41 (89%)	5 (11%)	None
N = 50									
Funamara et al.[27]	Capped	DT oximetry	Yes	NR	NR	Admitted, location not specified	32 (100%)	0 (0%)	NR
N = 113									
Han et al.[28]	Downsized	Arterial blood gas, PSG	Yes	NR	12–32	Admitted, location not specified	13 (52%)	12 (48%)	None
N = 25									
Kontzoglou et al.[29]	Downsized, capped	NR	Yes, rigid	NR	2	ICU	6 (86%)	1 (14%)	NR
N = 7									
Gray et al.[30]	Downsized, capped	DN oximetry	Yes, flexible and rigid	NR	3.8 (0–7)	Admitted, location not specified	28 (93%)	2 (7%)	NR
N = 30									
Merritt et al.[31]	Fenestrated, capped	DN oximetry, PSG	Yes, flexible and rigid	Room air	0	No admission	9 (90%)	1 (10%)	TCF (*N* = 2, 20%)
N = 10									
Waddell et al.[32]	Downsized, capped	NR	Yes	Room air	3	Inpatient ward	69 (68%)	32 (32%)	NR
N = 84									

TABLE 3 (Continued)

Study author, year	Assessment of readiness for decannulation				Postdecannulation				
	Tube trial	Gas exchange measurement	Bronchoscopy, type if specified	Ventilation post-decannulation	Observation period, days (Range)	Admission	Success rate (%)[a]	Failure rate (%)[a]	Complications (%)
Tunkel et al., 1996[33]	Downsized, capped	PSG	Yes	NR	NR	ICU	13 (93%)	1 (7%)	-SSGT (*N* = 1, 7%)
N = 24									
Al-Saati et al.[8]	None	NR	Yes	Nasotracheal intubation	7–12	ICU	9 (60%)	6 (40%)	Respiratory tract infection (*N* = 2, 14%)
N = 14									
Filston et al.[34]	None	Arterial blood gas	Yes	Room air	NR	Admitted, location not specified	21 (91%)	2 (9%)	Unspecified recannulation (*N* = 2, 6%)
N = 31									

Abbreviations: DN, daytime and nocturnal; DT, daytime; FTT, failure to thrive; ICU, intensive care unit; NIV, noninvasive ventilation; NR, not reported; O/N, overnight; PSG, polysomnography; SSGT, suprastomal granulation tissue; TCF, tracheocutaneous fistula.

[a]Success and failure rates reflect the number of decannulation attempts and may differ from the number of children in the study

decannulation (outcome of interest) using any protocol. Overall, the majority of included studies were of low risk of bias.

4 | DISCUSSION

To our knowledge, this is the largest review of pediatric decannulation protocols. Before decannulation, most children were evaluated by bronchoscopy and had tracheostomy tube modifications, such as downsizing and capping trials. During these trials, gas exchange was usually measured by oximetry and polysomnography (PSG). After successful decannulation, children were typically observed in room air for less than 48 h before discharge.

In 1999, the American Thoracic Society (ATS) released a statement on chronic tracheostomy care in children.[36] Only two criteria for pediatric decannulation were stated: (1) original need for tracheostomy no longer present and (2) patient does not depend on the tracheostomy tube to maintain a safe and adequate airway. In 2013, the American Academy of Otolaryngology-Head and Neck Surgery Foundation (AAO-HNSF) devised more specific criteria for pediatric decannulation[37]: (1) no ventilation requirement for 3 months; (2) no aspiration events or need for pulmonary toilet; (3) evidence of at least one mobile vocal cord; (4) bronchoscopic evidence of airway patency; and (5) successful trial of daytime capping for several weeks in children 2 years of age or older. However, the AAO-HNSF clinical consensus statement was devised by a limited number of pediatric otolaryngologists. Overall, there continues to be large variation in clinical practice.

We found that the most common indication for tracheostomy tube insertion in children was the need for access to the lower airway for long-term ventilation and pulmonary care (52%). This includes children with cardiopulmonary conditions, such as those with chronic lung disease, which was the largest primary indication for tracheostomy in our review. The least frequently reported indication was upper airway obstruction not at a well-defined site or due to underlying medical condition (12%). This category includes craniofacial syndromes. Our findings are similar to a previous 30-year review of pediatric tracheostomy by Gergin et al.[3] These authors also reported the most common indication to be cardiopulmonary disease (32%), while craniofacial anomalies comprised just 12% of all indications for tracheostomy tube insertion.

In our review, nearly all (96%) protocols included bronchoscopic examination of the child's airway before decannulation attempt. This relatively consistent practice among clinicians is due to two key advantages of bronchoscopy. First, it allows for confirmation of an adequate airway and reassessment of any underlying airway pathology that may have prompted the initial tracheostomy tube insertion.[38] Second, any visualized airway abnormalities allow clinicians to plan for corrective procedures in advance of the decannulation, such as granulation tissue excision.[39] The primary regions assessed by bronchoscopy include the velopharynx, oropharynx, palatine tonsils, tongue base, epiglottis, and the mobility of at least one vocal cord.[22] Flexible bronchoscopy allows for an airway examination to the smaller distal airways both through the larynx and the tracheostomy tube itself.[40] Rigid bronchoscopy is an important tool in assessing laryngeal and tracheal anatomy and for interventional procedures, such as excision of airway granulation tissue. These unique advantages of flexible and rigid bronchoscopy likely explain the use of both types together in most decannulation protocols. There does not appear to be a consensus regarding the optimal timing of decannulation following a favorable bronchoscopy; we found that in most protocols this time interval was within 3 months of the bronchoscopy. Notably, Pozzi et al.[17] opted against routine bronchoscopy, reserving the procedure only for children who exhibited respiratory distress to clarify its cause. These authors prioritized minimizing procedures and further stated that the role for routine bronchoscopy was unclear. No decannulation failures were reported by Pozzi et al.[17]; however, their protocol included a longer inpatient period lasting even months before decannulation which may provide some additional assurance of the child's underlying airway.

Although tracheostomy tube modifications were uniformly used in decannulation protocols, the type of modifications and the timing of trials varied considerably. The use of capped tracheostomy tubes was the most common modification followed by downsized tubes; fenestrated tubes were used the least. The purpose of tracheostomy tube modifications is to evaluate breathing through the natural upper airway.[20] Signs of failure include increased work of breathing, stridor, and coughing.[26] The AAO-HNSF statement does not recommend the routine use of downsizing and capping trials in young children less than 2 years of age since the tracheostomy tube occupies a relatively larger lumen in their small airways resulting in increased airway resistance.[37] Furthermore, downsizing tubes carries an increased risk of mucous plugging.[30,36] Downsizing may also not be possible in young children already using the smallest tracheostomy tube size commercially available. For these reasons, Seligman et al. instead recommended the use of fenestrated tubes in very small children to alleviate the large airway obstruction caused by the tube and render breathing easier for the child.[6] It should be noted that fenestrated pediatric tubes are not manufactured in the same manner as they are for adult sizes. In their study, Seligman et al. made off label modifications to the Food and Drug Administration (FDA) device by manually drilling fenestrations into the pediatric tracheostomy tube. However, clinicians must be aware that the use of fenestrated tubes is associated with an increased risk of granulation tissue.[30] With regard to the timing of downsizing and capping tubes, the ATS statement recommends a vague duration of days to weeks before decannulation.[36] Our review found that existing protocols may conduct tube trials for as short as 12–24 h. For example, Merritt et al.[31] suggested that a 24-h capping trial is sufficient time to assess readiness for decannulation as they did not have decannulation failures if a child was able to tolerate a cap for 24 h. This study's small sample size of 10 children should be considered in the interpretation of these findings. Other modifications to a tracheostomy can also be made such as the addition of a one-way speaking valve.[37] However, this modification was reported in only

select studies,[14,19,22,23,25] which limited its analysis in this review. Without data-driven guidelines, these important clinical decisions regarding tracheostomy tube modifications and timing are often left to the pediatric provider and influenced largely by anecdotal experience.

Our review found that PSG and oximetry were the most used gas exchange measures in children to assess readiness for decannulation. The key advantage of a PSG is its ability to evaluate dynamic upper respiratory function during sleep when pharyngeal muscle tone is decreased.[33] In the included protocols, PSG studies were performed with the tracheostomy tube in-situ after children were considered suitable for a decannulation attempt based on clinical and bronchoscopic assessment.[22] A PSG study occurred after tracheostomy tube modifications such as capping and/or downsizing were well tolerated by the child. Previous studies have attempted to identify favorable PSG parameters predictive of successful decannulation, such as Lee et al. who found that total apnea-hypopnea index (AHI) was significantly lower in children who had successful decannulation versus those who could not be decannulated (3.35/h vs. 18.5/h, $p < .05$).[22] Similar findings were reported by Quinlan et al.[16] However, other studies have not demonstrated clear associations between PSG findings and decannulation outcomes. For example, Tunkel et al.[33] reported a decannulation failure in a child with favourable PSG results. Notably, this child was later found to have suprastomal granulation tissue. Thus, a PSG may not replace the need for a comprehensive airway examination but can be used in combination to increase the chance of a successful decannulation.[41] In our review, 76% of failed decannulation attempts did not include a PSG. The significance of this finding is unclear due to the studies' raw data not being available to conduct a meta-analysis. Regardless, a PSG is resource-intensive, and its widespread use is limited by a lack of availability in many institutions and prolonged wait times. The utility of a PSG may also be limited based on the relative size of the tracheostomy tube compared with a child's airway lumen, with children under 2 years less likely to tolerate a capped PSG study. In these situations, oximetry may be considered although the success of pediatric decannulation using oximetry as a substitute for PSG requires additional study.[42,43]

The length of observation periods after decannulation also varied among the included protocols. No specific recommendations are made by the ATS; however, they note that most children are typically monitored for 24–48 h.[36] In our review, 76% of children were observed for 48 h or less. However, only three protocols monitored children for the 24–48-h period suggested by the ATS.[6,15,16] Some authors suggest that shorter observation periods are safe and promote resource conservation. For example, Prickett and Sobol[26] found that all decannulation failures in their study occurred within the first 12 h. Observation typically occurred on the inpatient ward or ICU setting. Only Pozzi et al.[17] used a rehabilitation unit for observation as their population uniquely included children with acquired brain injury. It is also important to consider that the postdecannulation monitoring abilities are likely related to the location of observation. For example, some institutions may not be able to conduct continuous pulse oximetry outside of the ICU setting.

We found that most children with successful decannulation were transitioned immediately to room air. Noninvasive ventilation (NIV) was utilized in approximately one-third of all protocols. NIV has been previously associated with an increased risk of tracheocutaneous fistula formation.[44] Our review found that three of the five studies that reported this complication did not use NIV.[21,24,31] Only Canning et al.[14] clearly reported tracheocutaneous fistula while using NIV. Thus, the use of ventilation modes other than NIV does not eliminate the risk of a tracheocutaneous fistula. Intubation was included in only two protocols. In Al-Saati et al.,[8] children whose tracheostomies were known to be complicated by large suprastomal granulomas or tracheal wall collapse underwent planned nasotracheal intubation to splint the airway. Similarly, in Canning et al.,[14] children with previous failed decannulation attempts underwent brief planned endotracheal intubation to secure the airway. Hence, most children do not require ventilation support after tracheostomy removal and can be safely transitioned to room air.

This review has notable limitations. First, nearly all included studies were retrospective review articles that rely on the accuracy of clinical records. For example, primary indications for tracheostomy or complications after decannulation were not provided in all studies. Second, most studies had findings reported from a single pediatric center; this may affect generalizability across all pediatric patients and health-care settings because of variability in resources and personnel. Third, we acknowledge the heterogeneity in the profiles of children in the included studies. This may suggest that each study's decannulation protocol was related to their specific population and may further affect the applicability of our review's findings to all children undergoing decannulation. Fourth, the population included in our review of children ready for decannulation does not reflect the overall pediatric population who receive a tracheostomy. For instance, some children with a tracheostomy may continue to deteriorate as a result of their underlying condition and may never reach consideration for decannulation. Fifth, our review restricted complications to 6 months postdecannulation which may not capture more long-term negative outcomes. Lastly, without raw data from individual studies for a meta-analysis, we were unable to perform more quantitative comparisons.

In conclusion, the absence of clear evidence-based guidelines in pediatric tracheostomy decannulation has led to large variability in clinical practice. In this review, we summarized the existing protocols for tracheostomy decannulation in children. Most protocols include bronchoscopy with gas exchange measurement by either PSG or oximetry. After decannulation, children were typically admitted to hospital for a short period to observe for early complications. None of the studies included in this review compared decannulation outcomes based on primary indication for tracheostomy or the use of bronchoscopy versus gas exchange measurements (PSG or oximetry). Future studies are encouraged to investigate such factors that may predict decannulation success. As the role of PSG is currently not clear, this will allow clinicians to better understand which children may benefit from PSG based on their underlying condition. Additionally, clinicians can determine the optimal means of airway

evaluation to increase likelihood of successful decannulation. We also acknowledge that the existing literature largely contains studies from high-income countries. Hence, there is a need for studies on decannulation protocols from other parts of the world where the population of children with tracheostomies may differ. Lastly, we did not observe a clear relationship between indications for a child's tracheostomy and the decannulation protocol most required. Future studies should also evaluate decannulation protocols more specifically for a group of tracheostomy indications using a classification scheme such as that of Mitchell et al.[35] Overall, although the likelihood of decannulation failure is relatively low, the outcomes are potentially catastrophic. This highlights the need for standardized evidence-based pediatric tracheostomy care guidelines to improve overall decannulation outcomes.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

AUTHOR CONTRIBUTIONS

Rahul Verma: Data curation (lead); formal analysis (lead); methodology (lead); writing– original draft (lead); writing–review and editing (equal). **Cora Mocanu**; data curation (lead); formal analysis (lead); methodology (lead); writing–original draft (lead); writing–review and editing (equal). **Jenny Shi**: Data curation (lead); formal analysis (lead); methodology (lead); writing–original draft (lead); writing–review and editing (equal). **Michael Miller**: Formal analysis (lead); writing–review and editing (equal). **Jackie Chiang**: Formal analysis (supporting); methodology (supporting); writing–review and editing (equal). **Nikolaus Wolter**: Formal analysis (supporting); methodology (supporting); writing–review and editing (equal). **Evan Propst**: Formal analysis (supporting); methodology (supporting); writing–review and editing (equal). **Aaron St-Laurent**: Conceptualization (lead); supervision (lead); writing–original draft (lead); writing–review and editing (equal). **Reshma Amin**: Conceptualization (lead); project administration (lead); supervision (lead); writing–original draft (lead); writing–review and editing (equal).

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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SUPPORTING INFORMATION

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