Australian Critical Care xxx (xxxx) xxx

Contents lists available at ScienceDirect

Australian Critical Care

journal homepage: www.elsevier.com/locate/aucc

Research paper

Implementing paediatric appropriate use criteria for endotracheal suction to reduce complications in mechanically ventilated children with respiratory infections

Jessica A. Schults, RN, PhD [a, b, c, d, e, *, p], Karina R. Charles, RN, MN [b, c, d, p], Jane Harnischfeger, RN, MN [b, d], Robert S. Ware, BSc(Hons), PhD [e, f], Ruth H. Royle, RN, MEcon [e], Joshua M. Byrnes, BEcon, BComm, MEcon, M Health Econ, PhD [e, g], Debbie A. Long, RN, PhD [c, d, h], Amanda J. Ullman, RN, PhD [b, c, e, i], Sainath Raman, MBBS, MRCPCH, PhD, FCICM [c, d], Michaela Waak, MBBS, MD [c, d], Anna Lake, BN, RN [c], Marie Cooke, RN, PhD [j], Adam Irwin, MBChB, PhD [k, l], Lyvonne Tume, RN, PhD [m, n], Lisa Hall, BTech (BiomedSci) (Hons), PhD [a, o]

[a] Metro North Health, Herston Infectious Disease Institute, Queensland, Australia; [b] The University of Queensland, School of Nursing Midwifery and Social Work, Australia; [c] The University of Queensland, Children's Health Research Centre, Australia; [d] Queensland Children's Hospital, Paediatric Intensive Care Unit, Queensland, Australia; [e] Menzies Health Institute Queensland, Griffith University, Queensland, Australia; [f] School of Medicine and Dentistry, Griffith University, Queensland, Australia; [g] Centre for Applied Health Economics, School of Medicine and Dentistry, Griffith University, Australia; [h] School of Nursing, Centre for Healthcare Transformation, Queensland University of Technology, Queensland, Australia; [i] Children's Health Queensland Hospital and Health Service, Queensland, Australia; [j] School of Nursing & Midwifery, Griffith University, Australia; [k] The University of Queensland, Centre for Clinical Research, The University of Queensland, Queensland, Australia; [l] Infection Management and Prevention Service, Queensland Children's Hospital, Queensland, Australia; [m] Faculty of Health, Social Care & Medicine, Edge Hill University, Ormskirk, UK; [n] Paediatric Intensive Care Unit, Alder Hey Children's Hospital, Liverpool, UK; [o] School of Public Health, Faculty of Medicine, University of Queensland, St Lucia, Queensland, Australia

ARTICLE INFORMATION

Article history:
Received 19 March 2023
Received in revised form
11 September 2023
Accepted 15 September 2023

Keywords:
Implementation
Paediatric intensive care
Pediatrics
Endotracheal suction
Mechanical ventilation
Respiratory infection

ABSTRACT

Background: Endotracheal suction is used to maintain endotracheal tube patency. There is limited guidance to inform clinical practice for children with respiratory infections.
Objective: The objective of this study was to determine whether implementation of a paediatric endotracheal suction appropriate use guideline Paediatric AirWay Suction (PAWS) is associated with an increased use of appropriate and decreased use of inappropriate suction interventions.
Methods: A mixed-method, pre-implementation–post-implementation study was conducted between September 2021 and April 2022. Suction episodes in mechanically ventilated children with a respiratory infection were eligible. Using a structured approach, we implemented the PAWS guideline in a single paediatric intensive care unit. Evaluation included clinical (e.g., suction intervention appropriateness), implementation (e.g., acceptability), and cost outcomes (implementation costs). Associations between implementation of the PAWS guideline and appropriateness of endotracheal suction intervention use were investigated using generalised linear models.
Results: Data from 439 eligible suctions were included in the analysis. Following PAWS implementation, inappropriate endotracheal tube intervention use reduced from 99% to 58%, an absolute reduction (AR) of 41% (95% confidence interval [CI]: 25%, 56%). Reductions were most notable for open suction systems (AR: 48%; 95% CI: 30%, 65%), 0.9% sodium chloride use (AR: 23%; 95% CI: 8%, 38%) and presuction and postsuction manual bagging (38%; 95% CI: 16%, 60%, and 86%; 95% CI: 73%, 99%), respectively. Clinicians perceived PAWS as acceptable and suitable for use.
Conclusions: Implementation of endotracheal tube suction appropriate use guidelines in a mixed paediatric intensive care unit was associated with a large reduction in inappropriate suction intervention use in paediatric patients with respiratory infections.

* Corresponding author at: University of Queensland Centre for Clinical Research, Building 71/918 RBWH Herston, Brisbane City, QLD 4029, Australia.
E-mail address: j.schults@uq.edu.au (J.A. Schults).
[p] Equal contributions first author.

https://doi.org/10.1016/j.aucc.2023.09.008
1036-7314/

1. Introduction

Critically ill children frequently require a period of invasive mechanical ventilation to support cardiopulmonary function. These episodes are a time of significant vulnerability, with reliance on endotracheal tube (ETT) suction to maintain airway patency. Attendant risks during an episode of mechanical ventilation are considerable, with up to 50% of children experiencing a complication arising from the ETT suction procedure.[1,2] Current ETT suction practice is varied, with a lack of high-quality evidence and uncertainty regarding best practice.[3] This vacuum of knowledge has resulted in the *ad hoc* use of adjunct suction interventions such as 0.9% sodium chloride instillation or lung recruitment in the paediatric intensive care unit (PICU) cohort.[3–7] Such variation in care can be harmful.[8–10]

ETT suction practice in the PICU may be improved through the implementation of appropriate use criteria for suction. Appropriate use criteria incorporate best-available evidence and expert judgement to classify an intervention—in this case related to ETT suction, as 'appropriate' or 'inappropriate', based on clinical indication, disease, and patient phenotype.[11] Appropriate use criteria have been used successfully across medical, surgical, and critical care specialities[12,13] and are an important mechanism to support clinical decision-making, decrease practice variation, and improve patient safety. However, implementation of evidence-based practices in intensive care brings specific challenges, including intense time pressures and high patient acuity.[14–16] These challenges result in evidence-to-practice gaps that diminish the impact of interventions that may improve outcomes in this population.

We sought to implement and evaluate an ETT suction appropriate use criteria (Paediatric AirWay Suction [PAWS] protocol)[17–19] for children infected with respiratory infection. Our aim was to determine if PAWS implementation led to an increased use of appropriate intervention use and conversely a reduction in inappropriate intervention use. Secondary outcomes included safety events, duration of ventilation, PICU length of stay, respiratory support–free days, clinician acceptability and protocol uptake, and costs of the implementation activities.

2. Methods

2.1. Study design

A pre-implementation–post-implementation study was conducted at the Queensland Children's Hospital (QCH), a specialist quaternary paediatric hospital in Brisbane, Australia, from September 2021 to May 2022. Study design was underpinned by the Capability, Opportunity, and Motivation Behaviour model and the Consolidated Framework for Implementation Research (CFIR),[20,21] which was used to explore stakeholder beliefs, values, and motivators. CFIR explores how domains such as outer and inner setting, processes, characteristics of the individuals, and intervention characteristics impact the effectiveness of intervention implementation. The study was approved by the institutional review board of the Children's Health Queensland (LNR/21/QCHQ/72967), Griffith University (2021/286), and the University of Queensland (2021/HE000963). The study is reported in line with the Standards for Reporting Implementation Studies (StaRI checklist).[22]

2.2. Study context and site

The QCH PICU is a tertiary referral 36-bed mixed unit offering cardiac and medical care including extracorporeal life support and air and land retrievals.

During the study period, any ETT suction event in a child (aged <16 years) receiving mechanical ventilation and diagnosed with a respiratory infection was eligible for inclusion. Respiratory infection was defined as a pathogen which may be transmitted via airborne or droplet routes; this could include highly infectious respiratory pathogens such as SARS-CoV-2.[23] We excluded ETT suctions in children undergoing treatment withdrawal or performed in emergent situations.

In this PICU, there are 196 registered nurses representing 160 full-time equivalent (FTE). Twenty percent of nurses hold a PICU postgraduate qualification. Of the 196 nurses, 93% are "ventilator credentialed", with 79% credentialed to care for a complex ventilated patient, and 64% are credentialed to care for a patient on high-frequency oscillatory ventilation. All nurses are "credentialed" to assist with ETT suction practices and manual ventilation.

2.3. Intervention description

The PAWS (Fig. 1) appropriateness use criteria for endotracheal suction interventions in paediatric patients with respiratory infections were developed in 2021,[17–19] with a multidisciplinary panel comprising experts in the fields of paediatrics, intensive care, and infectious disease from Australia and New Zealand using the RAND/UCLA methodology.[11] Suction interventions, derived from a systematic review[10] and considered usual care were included in an appropriateness ratings process (two independent rounds followed by in-person meeting). Interventions included presuction manual bagging of the patient, presuction oxygenation, instillation of 0.9% sodium chloride, open suction, closed/in-line suction, postsuction oxygenation, lung recruitment manoeuvre [increased positive end expiratory pressure (PEEP)] and post suction manual bagging of the patient. For children with a highly infectious respiratory disease and used for children with a respiratory infection, panellists recommended the following:

1. Closed-system suction as **appropriate**.
2. Interventions that required circuit disconnection as **inappropriate**. This included pre-suction and post-suction bagging and 0.9% sodium chloride administration (Fig. 1).

2.4. Implementation approaches

To support effective implementation of the PAWS protocol, we used a multistep approach underpinned by the Capability, Opportunity, and Motivation Behaviour model.[24] The framework considers three sources of behaviour: Capability (psychological and/or physical), Opportunity (social and/or physical), and Motivation (autonomic and/or reflexive)—COM-B. Behaviour source drivers (e.g., motivation) were perceived as a key factors in changing nurses' suction practices from traditional (*ad hoc*) to appropriate use criteria informed.[3,25] We developed a PAWS Logic Model[26] to guide our implementation strategy and monitoring process (Fig. 2). This included the following approaches:

i) *Education and local study champions*

Extensive in-unit education and training delivered on-site by the clinician research nurse, supported by JS, JH, and implementation scientist LH.[24] Education included key intervention functions such as evidence summaries, e-learning resources, and bedside education (Supplementary material 2). Activities reflected published evaluations of nurses' learning needs and perceived endotracheal suction knowledge–practice deficits.[3]

Please cite this article as: Schults JA et al., Implementing paediatric appropriate use criteria for endotracheal suction to reduce complications in mechanically ventilated children with respiratory infections, Australian Critical Care, https://doi.org/10.1016/j.aucc.2023.09.008

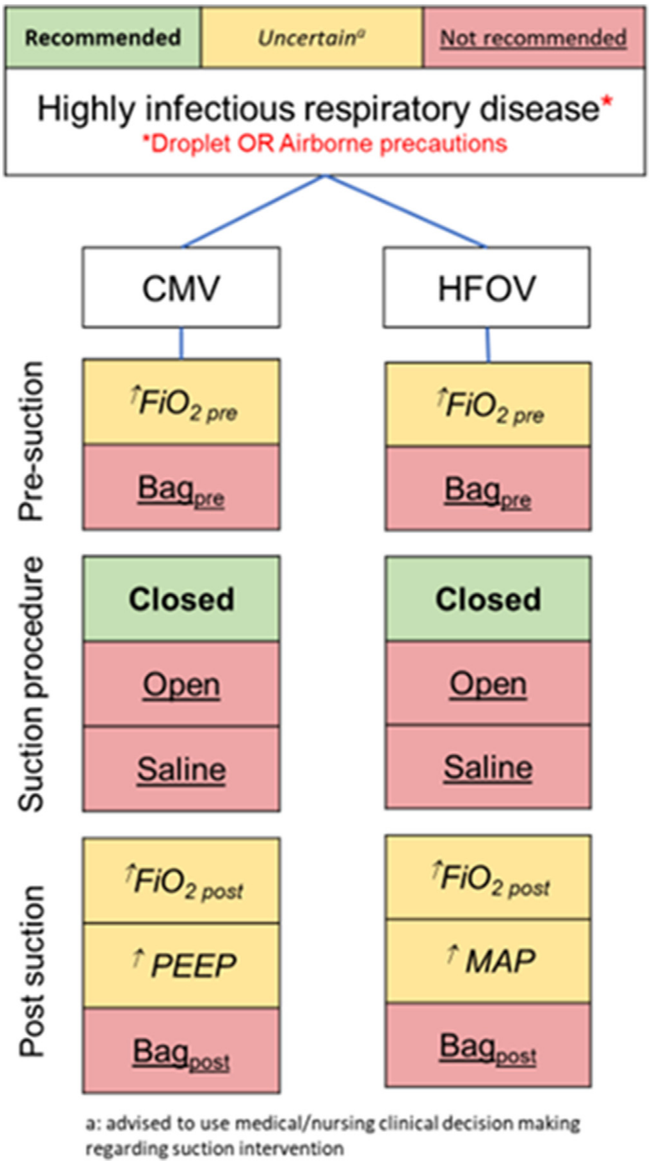

Fig. 1. Appropriate use criteria for endotracheal suction interventions in paediatric patients with respiratory infections—the Paediatric AirWay Suction protocol.

ii) *Intervention promotion and dissemination*

A detailed description of the intervention disseminated broadly to unit clinicians and organisational leaders using a multimodal approach such as posters, lanyards, emails, and educational resources at the bedside. The intervention had been developed with experts in the field and was evidence informed.

iii) *Interviews with PICU clinicians*

We conducted a series of interviews and informal short surveys with staff over the course of the study to monitor progress. This included,

- Pre-implementation bedside field notes/interviews (n = 25) were undertaken to ascertain staff preferences for implementing a new protocol in the unit. Interview recruitment comprised purposive sampling of PICU clinicians, complimented by selective sampling of PICU educators and leaders. Interviews were conducted until no additional themes were identified. Key themes arising from this data were mapped against the COM-B model to inform the development of a tailored, site-specific implementation plan to support PAWS roll out (Supplementary material 1).
- Daily 'check-ins' and the collection of field notes with staff caring for eligible patients.

2.5. *Evaluation*

2.5.1. *Clinical and cost outcomes*

The primary outcome was ETT suction intervention appropriateness, that is the percentage of audited ETT suctions that met PAWS recommendations (detailed previously in intervention description). Secondary outcomes included safety events (desaturation, hypotension, and bradycardia; outcomes assessed up to 10 min post-suction per published complication interval data),[1] duration of ventilation, PICU length of stay, respiratory support–free days, and costs of the implementation activities. Outcome measures and definitions are fully detailed in Supplementary material 3.

2.5.2. *Evaluation of PAWS implementation*

Implementation outcomes comprised protocol adoption, fidelity, and feasibility. In addition, we assessed clinician satisfaction with and perception of intervention acceptability and suitability.[27] Implementation evaluation was guided by the CFIR domains, which enabled an exploration of factors that influenced PAWS implementation and study outcomes. Mixed-methods data collection included semistructured interviews, field notes, and informal conversations with bedside clinicians.

Key stakeholder interviews (n = 10) took place with purposively sampled clinicians (bedside nurses) during the post-implementation period. Pre-implementation and post-implementation interviews were conducted with different nursing cohorts. PICU clinicians working in the unit were eligible to participate A semi-structured interview guide was used that also included three forced response questions to determine clinicians' acceptability of and satisfaction with the PAWS protocol as well as their perception of its suitability for intended purpose (measured on an 11-point Likert scale, where 0 = not at all satisfied and 10 = completely satisfied). Interviews were audio recorded and professionally transcribed to aid rigour. Informed written consent was gained from clinicians partaking in the interview.

2.5.3. *Sample size*

Based on historical data, we estimated 70% of patients received inappropriate ETT suction intervention use.[1] Assuming 80% power, a type 1 error of 0.05, and a decrease in inappropriate ETS intervention use by 20%, at least 93 suction audits were required in both the pre-implementation and post-implementation phases (186 total), allowing for a non-normally distributed outcome. We assumed suctions were independent of each other, with no sequential suctions collected on an individual patient on the same day.

2.5.4. *Randomisation*

ETT suctions were audited by clinical research staff using both in-person and electronic medical record forms for confirmation. The ETT suction audit schedule was randomly generated using Stata statistical software (StataCorp, College Station, TX, USA) by an independent statistician and was uploaded to the electronic data platform Research Electronic Data Capture™. Each weekday, one of the first five suctions was selected, and each participant had the selected suction audited. For example, if randomised to suction three, the third suction of the shift would be audited. Research and clinical staff were blinded to the allocation schedule.

Please cite this article as: Schults JA et al., Implementing paediatric appropriate use criteria for endotracheal suction to reduce complications in mechanically ventilated children with respiratory infections, Australian Critical Care, https://doi.org/10.1016/j.aucc.2023.09.008

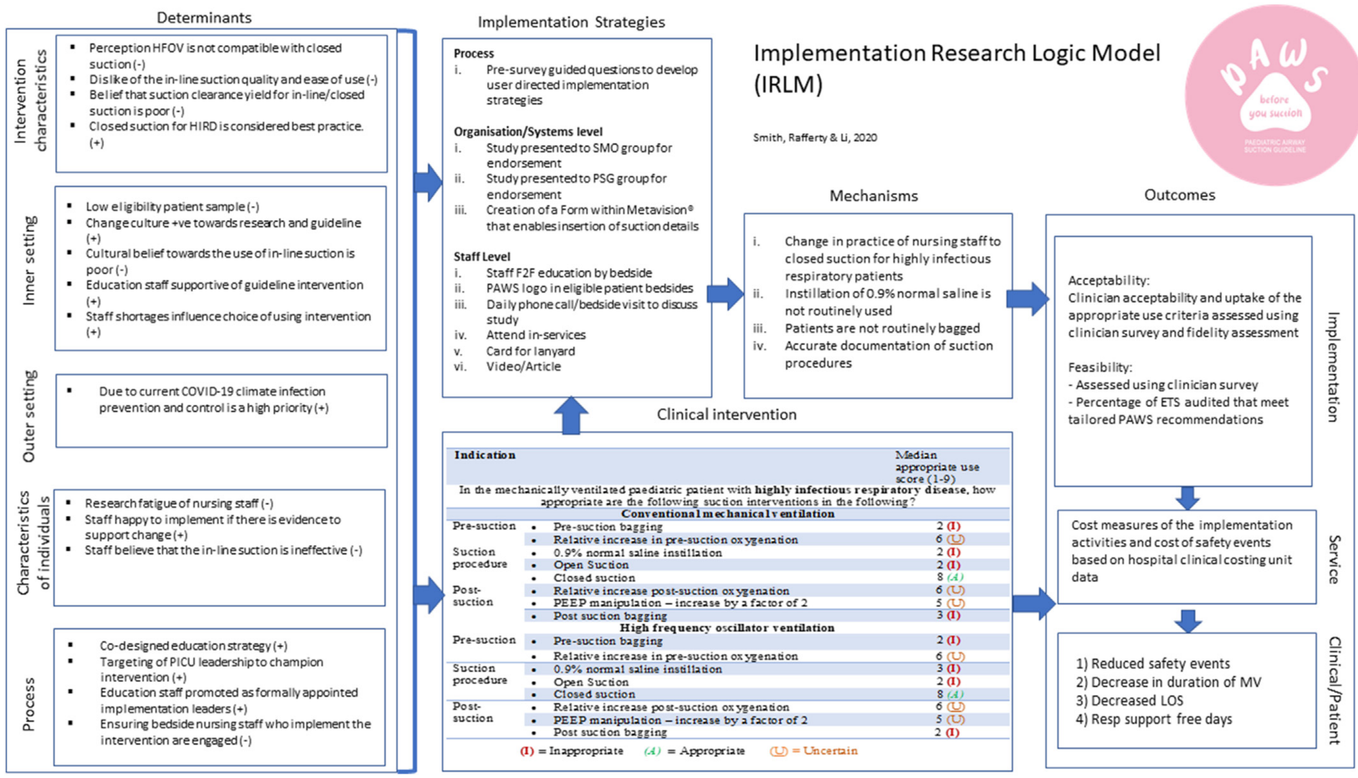

Fig. 2. Paediatric AirWay Suction logic model.

2.5.5. *Data collection*

Baseline data collection (pre-implementation) occurred over a 12-week period, where the PICU performed ETT suction per usual practice. After 3 months, the PICU transitioned to the 4-week training and implementation period during which, the PAWS protocol was rolled out. No patient data were collected during this time. Post-implementation data were collected for a 12-week period. A clinical research nurse collected clinical and outcome data for a maximum of 28 days post-extubation, using an audit *pro forma*. Costs were prospectively collected with respect to the implementation activities based on resource use (time, materials, etc.) and their respective unit costs (salary including on-costs, purchase price). Data were entered into the electronic data platform Research Electronic Data Capture™ Version 6.10.6. A codebook was used for the duration of the study, with data stored on password-protected computers and locked filing cabinets.

2.5.6. *Analysis*

Data were summarised using descriptive statistics with continuous data reported as mean and standard deviation or as median and interquartile range (IQR) as appropriate. Categorical data are presented as frequency and percentage. Baseline characteristics across periods were compared using Fishers exact, Wilcoxon rank-sum, or independent samples t-tests. Associations between period (pre-implementation/post-implementation) and binary outcomes were investigated using generalised linear regression models with binomial distributions and identity link functions. Time period was included as the main effect. Robust standard errors clustered by child were included to account for possible nonindependence of observations from the same child. Effect estimates are reported as absolute difference (95% confidence interval [CI]); *p* value. The total cost of implementation per person was estimated first based on those treated within trial and then extrapolated to estimate the total cost per person over time. The extrapolated cost was based on 1664 admissions to the PICU per year,[28] 38% of which required ventilation and 22% of those acquiring a respiratory infection (resulting in 138 cases per annum), a useful life before protocol and practice change of 5 years, and forecasted requirements for continuing and ongoing maintenance. The net present value of all implementation and maintenance costs was estimated, with costs incurred in future years discounted at 5% per annum and divided by the total number of patients treated over the 5-year period (assuming no change in patients per annum over time). All analyses were performed in Stata v13.1 (StataCorp, College Station, Texas, USA). An α level of <0.05 was considered statistically significant.

A thematic-based approach was used to analyse qualitative data. This included a strategic focus on the CFIR domains and the key components of the intervention, particularly education and training that were provided to support PAWS implementation. We used Braun and Clarke's inductive thematic analysis.[29–32] Key themes (patterns) that identified how factors influenced PAWS delivery and receipt were explored within semistructured interviews. Further, how workflows supported, or did not support PAWS implementation, what was helpful or challenging when operationalising the protocol, and whether the protocol was useful in clinical practice. In a reflexivity exercise, the analysis was presented back to one-third of the interview participants to establish trustworthiness. Interviews were undertaken by two clinician researchers (KC, JS) not working in the PICU at the time of the study.

3. Results

3.1. *Sample characteristics*

Data from 439 eligible suctions, performed by 134 distinct nurses, from 30 unique patients were included in the analysis. From

September 2021 to April 2022, during the pre-implementation and post-implementation periods, 31 eligible patients were admitted to the PICU, and one patient did not have suction interventions performed during the period of intubation. Most (60%) patients were female, with a median (IQR) age of 24 (7–95) months, and 13 (43%) had at least one comorbidity. Patients were typically intubated with oral ETT (cuffed; n = 19; 63%) and received conventional mechanical ventilation. In the pre-implementation phase, respiratory infections were varied with rhinovirus being the most common respiratory pathogen (43%) compared to the post-implementation phase, which was most often SARS-CoV-2 (80%; Table 1).

3.2. Clinical and cost outcomes

Table 2 outlines ETT suction characteristics and outcomes.

3.2.1. ETT suction intervention appropriateness

In the pre-implementation period, the baseline frequency of inappropriate ETT suction intervention use (any use of an inappropriate intervention) was 99% (n = 247 suctions). Following PAWS protocol implementation, inappropriate ETT intervention use reduced to 58% (n = 111 suctions), an absolute decrease of 41% (95% CI: 25%, 56%; $p = <0.001$). Opensuction system use reduced from 99% to 51%, an absolute decrease of 48% (95% CI: 30%, 65%), and 0.9% sodium chloride use reduced by 23% (95% CI: 8%, −38%). Pre-suction and post-suction manual bagging use reduced by 38% (95% CI: 16%, 60%) and 86% (95% CI: 73%, 99%), respectively.

Closed–suction system use (appropriate intervention) improved from 1% to 49%, an absolute increase of 48% (95% CI: 30%, 66%; $p = <0.001$). Use of FiO_2 (rated 'uncertain' appropriateness) increased following protocol implementation by 8% (pre-suction) and 39% (post-suction) respectively.

3.2.2. Secondary outcomes

No significant difference was found between pre-implementation and post-implementation ETT suction events (desaturation, bradycardia, or hypotension). No clinically significant association was found between appropriate ETT intervention use and duration of ventilation, length of stay, and respiratory support–free days (Table 1).

3.3. Implementation evaluation

3.3.1. Acceptability, satisfaction, and suitability

Pragmatic bedside field notes/interviews were conducted with PICU bedside nurses (all female, registered nurses; range of nursing experience: 2 to 20+ years). Pre-implementation field notes/interviews revealed three key themes: (i) unit culture; (ii) education needs; and (iii) familiarity with the process. We mapped these themes to the COM-B sources of behaviour to develop multicomponent implementation strategies outlined in Supplementary material 1. Examples of the strategies include local change champions, daily phone calls, lanyard cards, and extensive education (both differing modalities and reach).

Overall post-implementation evaluation of the protocol and implementation strategies revealed clinicians (n = 10; 100% nurses) perceived PAWS as acceptable (median: 8, on a 11-point satisfaction Likert scale with range 0–10; IQR: 8, 9; 10 respondents) and suitable for use in the PICU (median: 8, IQR 7–10; 9 respondents). Clinicians were satisfied (median: 10, IQR: 8.25–10; 10 respondents) with the protocol, and reporting information was presented in a clear, easy-to-read, and linear fashion. The flowchart was preferred over pictures as it allowed for '*situational analysis*', '*you can do your job quicker, and you can do it safely*' (RN8). Colours did not detract but assisted '*rapid interpretation*' (RN2) in some cases.

Table 1
Sample characteristics.

Characteristics	Pre (n = 15)	Post (n = 15)	Post- vs Pre-implementation, *p*-value
Age, months[a]	10 (7–52)	71 (9–146)	0.10
Age, years			0.27
0–1 yrs	8 (53.3)	4 (26.7)	
1–8 yrs	5 (33.3)	6 (40.0)	
>8 yrs	2 (13.3)	5 (33.3)	
Gender, male	9 (60.0)	3 (20.0)	0.06
Weight, kg[a]	11.5 (4.5–65)	20 (3.6–84)	0.22
Diagnosis category			0.002
Respiratory	5 (33.3)	5 (33.3)	
Sepsis	4 (26.7)	0 (0.0)	
Oncology	0 (0.0)	1 (6.7)	
Trauma	0 (0.0)	1 (6.7)	
Neurology	2 (13.3)	3 (20.0)	
Neurological surgery	0 (0.0)	1 (6.7)	
General surgery	2 (13.3)	1 (6.7)	
Congenital heart disease	0 (0.0)	1 (6.7)	
Other	2 (13.3)	2 (13.3)	
Type of respiratory infection[b]			
Rhinovirus	9 (60.0)	4 (26.7)	0.14
Human Metapneumovirus	2 (13.3)	0 (0.0)	0.48
Parainfluenza	2 (13.3)	0 (0.0)	0.48
Adenovirus	1 (6.7)	0 (0.0)	0.50
SARS-CoV-2	0 (0.0)	12 (80.0)	<0.001
Haemophilus influenzae	0 (0.0)	1 (6.7)	1.00
Moraxella catarrahis	2 (13.3)	0 (0.0)	0.48
Streptococcus pneumoniae	4 (26.7)	0 (0.0)	0.10
Pseudomonas	1 (6.7)	0 (0.0)	1.00
MRSA	2 (13.3)	0 (0.0)	0.48
Comorbidity			1.00
Yes	6 (40.0)	7 (46.7)	
No	9 (60.0)	8 (53.3)	
Comorbidity type[b]			
Mental health	0 (0.0)	2 (13.3)	0.55
Neurology	2 (13.3)	4 (26.7)	0.78
Respiratory	1 (6.7)	0 (0.0)	0.71
Gastrointestinal	1 (6.7)	1 (6.7)	1.00
Metabolic	2 (13.3)	1 (6.7)	0.76
Malignancy	0 (0.0)	1 (6.7)	1.00
Technology dependency	0 (0.0)	1 (6.7)	1.00
Congenital or genetic defect	3 (20.0)	0 (0.0)	1.00
Transplantation	0 (0.0)	1 (6.7)	1.00
ETT size[a]	4.0 (3.5–4.5)	5.0 (3.5–6.5)	0.11
Nasal ETT	6 (40.0)	3 (20.0)	0.43
Cuffed ETT	15 (100.0)	15 (100.0)	1.00
Respiratory support free days PICU[a]	0.4 (0.06–1.0)	0.4 (0.05–2.7)	0.84
Ventilator associated pneumonia[c]	2 (13.3)	3 (20.0)	0.60
Length of PICU stay[a]	7 (2–12)	10 (5–12)	0.52
PIM 3	0.07 (0.16)	0.05 (0.07)	0.64
Ventilation hours[a]	75 (19–193)	99 (28–242)	0.60
Outcome			0.28
Discharged to ward	0 (0.0)	2 (13.3)	
Discharged to home	12 (80.0)	7 (46.7)	
Transferred	1 (6.7)	3 (20.0)	
Died in PICU	2 (13.3)	3 (20.0)	

[a] Median and interquartile range (interquartile range). Data are presented as n (%) unless otherwise indicated.
[b] Patients may have multiple infections and types of comorbidities.
[c] VAP = Ventilator associated pneumonia missing 10 pre-observation and 3 post-observation; hrs = hours; MRSA = methicillin-resistant *Staphylococcus aureus*; COVID-19 = Coronavirus 19; ETT = endotracheal tube; PICU = paediatric intensive care unit; PIM 3 = paediatric index of mortality 3.

3.3.2. PAWS adoption, feasibility, and fidelity

Field notes and interview data revealed that early adoption of PAWS was supported by key stakeholders such as the PICU nurse educator (e.g., in the first month after implementation use of closed

Table 2
Endotracheal suction characteristics and outcomes (439 suctions from 30 patients).

Outcomes	Pre-implementation	Post-implementation	Post-implementation vs pre-implementation[a]
	n (%) (N = 249)	n (%) (N = 190)	Absolute difference (95% CI); *p* value
Mode of ventilation[b]			
CMV	162 (65)	161 (85)	20 (2–37); 0.03
HFOV	86 (35)	20 (11)	−24 (−38 to −10); 0.001
Pre suction interventions			
Manual bagging[c]	224 (90)	98 (52)	−38 (−60 to −16); 0.001
Increase FiO_2[c]	22 (9)	28 (17)	8 (1–15); 0.022
Increase PEEP/MAP	1 (0)	2 (1)	0.01 (−0.01 to 0.03); 0.43
Suction system[c]			
Open	245 (99)	92 (51)	−48 (−65 to −30); <0.001
Closed	3 (1)	89 (49)	48 (30–66); <0.001
Normal saline	145 (58)	67 (35)	−23 (−38 to −8); 0.002
Reason for saline use			
Thick secretions	97 (39)	53 (28)	−11 (−28 to 6); 0.20
Mucous plugs	5 (2)	1 (1)	−0.1 (−0.03 to 0); 0.06
Nursing decision	29 (12)	11 (6)	−6 (−12 to 0); 0.05
Post suction interventions			
Manual bagging[c]	221 (89)	4 (2)	−86 (−99 to −73); <0.001
Increase FiO_2[c]	24 (10)	92 (49)	39 (20–58); <0.001
Increase PEEP/MAP[c]	13 (5)	4 (2)	−3 (−9 to 4); 0.40
Post suction events			
Desaturation	52 (21)	50 (26)	5 (−10 to 21); 0.49
Bradycardia	7 (3)	7 (4)	1 (−2 to 4); 0.56
Hypotension	13 (5)	5 (3)	−3 (−7 to 2); 0.30

The median (interquartile range) number of suctions per participant was 5 (2–11) Pre- and 8 (3–17) Post-. CMV = conventional mechaincal ventilation; HFOV = High frequency oscillation ventilation; MAP = Mean airway pressure; PEEP: positive end expiratory pressure.
[a] Regression models adjusted for repeated observations per participant.
[b] Unsure/unknown for 1 observation Pre- and 9 observations Post-.
[c] Presuction manual bagging missing 1 observation Post-; Pre suction increase FiO_2 and increase PEEP/MAP missing 27 observations Post-; Suction system missing 1 observation Pre- and 9 observations Post-; Post suction manual bagging and increase PEEP/MAP missing 27 observations Post-; Post suction increase FiO_2 missing 1 Post-.

suction systems increased from 14% to 97%). Local champions and extensive education were identified as a clear facilitator to PAWS implementation. In interviews, clinicians generally perceived the protocol as a '*good fit*' with a particular focus on use in children with COVID-19. Key barriers to optimal implementation were noted in interviews to be lack of time, staff support (both training in closed suction and a second set of hands), and clinician preference.

The greatest improvement in intervention appropriate use was seen in the use of closed suction systems, followed by a reduced use of 0.9% sodium chloride. Our qualitative records showed that in-person education, training, and communication drove this change in the observed technique. Reasons for protocol nonadherence (n = 111 episodes, 61 with clinician justifications, 50 with no justification provided) were categorised as (i) organisational requirement (n = 16; hospital policy to disconnect and perform open suction every 12 h); (ii) clinician decision (n = 16; e.g., nursing decision); or (iii) patient characteristics (n = 29; patient instability, thick secretions). Interview data revealed that adherence to the PAWS protocol depended on the clinician's perceived efficacy of recommended interventions with cultural preferences for open suction heavily influencing nonadherence. One participant noted *'people don't feel like it is as effective in some situation as doing a manual bag* (and open) *suction manoeuvre' RN1.*

The PAWS education strategy was perceived as an enabler to implementation, with clinicians highlighting the value of clinical skill training (e.g., in-line suction). Clinicians reinforced that ongoing education was needed to support the sustained implementation and maintenance of PAWS.

Macrocontextual and microcontextual factors influenced PAWS uptake, with COVID-19 effects (staff fatigue/illness and unit closures) posing significant challenges to PAWS implementation. Implementation of the PAWS protocol occurred during the peak of the pandemic in Brisbane, Australia, resulting in a change to workflow and capacity for research within the unit. As such post-implementation education required adaptation due to unit lockdowns that restricted research staff's access to the unit. For 3 of the 12 weeks, education shifted to online delivery, and communication was driven via calls to PICU team leaders and bedside nurses. Local investigators remained on the unit and supported implementation fidelity at the bedside. However, this was perceived as a barrier by some nurses with bedside education preferred, complemented by videos, posters, and lanyards.

3.3.3. Implementation costs and sustainability

Pre-implementation and post-implementation costs came to a total of $5326 reflecting, $832 in pre-implementation activity costs and $4537 for 58 h of post-implementation activities (Table 3). Equating to a cost of $357.88 per study participant. Overtime to sustain/maintain the PAWS intervention in the site PICU, considering ongoing education, and resource costs over a 5-year period the estimated expected cost per person treated is $17.31.

4. Discussion

We successfully implemented the PAWS protocol and observed improvements in the appropriate use of suction interventions for children with respiratory infections, despite contextual issues arising from COVID-19. With tailored implementation and support, we saw an increase of 48% in the use of appropriate suction interventions and a 41% reduction in the use of inappropriate suction interventions. Implementation activities included a strong focus on behaviour change mechanisms, such as education and training, and communication strategies to support ongoing monitoring of practice change. It is likely, with an increased sample size a significant change in important clinical endpoints such as duration of ventilation and respiratory support–free days may be seen with increased appropriate intervention use.[4] This may be largely due to the evidence base underpinning this protocol, which has already demonstrated individual practices to improve clinical outcomes for mechanically ventilated children.[9,33–36] Further at $17AUD per patient (over a 5-

Please cite this article as: Schults JA et al., Implementing paediatric appropriate use criteria for endotracheal suction to reduce complications in mechanically ventilated children with respiratory infections, Australian Critical Care, https://doi.org/10.1016/j.aucc.2023.09.008

Table 3
Paediatric AirWay Suction implementation activity costs.

Task	Pre-implementation (min)	Cost ($)
Pre- implementation activities		
Bedside interviews		
– Interview tool development, CRN	72	$76.17
– Conducting interviews, CRN	324	$342.79
– Assembling interviews, CRN	210	$222.18
Framework development, CRN	180	$190.44
Implementation activities		
Education planning		
– CRN	198	$209.48
– CNE	300	$390.05
– PI (in kind)	60	$63.48
Resource and development		
Time to develop, CRN	1227	$1298.16
Vimeo platform[a]	–	$288
Lanyards	–	$186
Posters	–	$147
Education delivery		
CRN	720	$761.76
CNE	600	$780.01
PI (in kind)	390	$412.62
Pre-implementation costs	786 min (13.1 h)	$831.58
Implementation costs	3495 min (58.25 h)	$4536.56

CNE: clinical nurse educator; CRN: clinical research nurse; PI: principal investigator.
[a] 12 month subscription. Queensland Health nursing stream wage rates (Oct 2021): CRN Grade 6 Band 1 $48.87 + 30% on costs = $63.48/hour; CNE Grade 7 Band 1 $60.01 + 30% on costs = $78.01/hour.

year period), this relatively small investment may lead to healthcare savings through reduced ventilator and PICU days; however, this requires more definitive cost effectiveness evaluation.

Endotracheal tube suction is a complex airway procedure. It is performed frequently (~9 times per day), yet implementation studies to improve practice and patient outcomes are few in the literature. To our knowledge, this is one of the first studies to evaluate the implementation of a standardised, age-adjusted suction protocol in children with a respiratory infection. We showed that fidelity does not have to be 100% to improve the appropriate use of suction interventions. The greatest improvement was seen in the increased use of closed suction and a reduced use of 0.9% sodium chloride. This is an important finding for clinical units and hospital administrators, confirming that small evidence-based changes can impact clinical practice and reduce harm, such as derecruitment and hypoxia.[4] With this change, we also saw a decrease in manual bagging (rated inappropriate intervention) and an increased use of ventilator fraction of inspired oxygen (rating uncertain intervention). The impact of these changes' increased appropriate use and reduced inappropriate use remains to be demonstrated in a larger patient cohort; however, it demonstrates clinicians acceptability to utilise evidence-based recommendations with suction care.

Our study has provided evidence on the challenges of implementing practice change in the complex and time-sensitive environment of paediatric intensive care. Patient heterogeneity, clinician staffing, unit ethos, and workflow, as well as time pressures inherent in caring for critically ill patients often prevent the optimal implementation of evidence-based initiatives.[16,37] In addition, practice change in critical care is heavily influenced by clinician biases, especially with scepticism among critical care providers who often prefer naturalistic decision-making to new evidence.[38–40] Over the study duration, clinicians reported a historic preference for the use of open suction and 0.9% sodium chloride instillation, describing a hesitancy to change. This challenge was anticipated based on our pilot work.[3,41] To address this, the PAWS implementation strategy was underpinned by the COM-B behaviour change theory[24] to explore interventions that improve clinicians' capability, opportunity, and motivation to deliver the PAWS recommendations. Pre-implementation consultation also revealed that bedside workflows are paramount considerations to nurses, and therefore, protocol recommendations needed to fit within unit workflows to be adopted consistently. Championing of the PAWS protocol by local key stakeholders in consultation with executive leadership was key to increasing intervention fidelity.

A considerable strength of this study was its pragmatic approach and use of a high-quality, contemporary clinical protocol. Implementation evaluation demonstrated education and local change champions are key facilitators in optimal implementation; COVID-19 impacts remained a key barrier. A key finding however was that clinicians perceived a clinical decision-making tool developed with key stakeholders and based on evidence as important to evaluate. We identified that whilst behaviour change takes time, you do not need 100% protocol adherence to achieve a positive impact on patient care. Behaviour change strategies that may support the greater use of appropriate interventions (e.g., closed suction) may include greater evidence for intervention justification, local policy, and unit support/leadership. Findings from this study have the potential to improve airway care, decrease adverse clinical outcomes, and inform the implementation of other evidence-based practices in PICU settings.

However, there are several limitations. Firstly, the small sample size limits our ability to speak to the effectiveness of the PAWS protocol on important patient outcomes such as ventilator-acquired infections and ventilator-free days. Second, the increase in patients diagnosed with COVID 19 in the post-implementation period may have impacted the uptake of closed suction or be influenced by the presence of the auditor (Hawthorne effect) However, we explore the effectiveness of implementation strategies using qualitative approaches that offer important insights to inform further exploration. Finally, the study was undertaken in a single academic tertiary referral centre in Australia, with a limited follow-up period. This decision limits the transferability of findings, in particular, the determination of how change is maintained over the longer term and the costs associated. However, we explore contextual factors and implementation decisions in the report as well as provide cost estimates to support the sustained uptake of PAWS using experience and assumptions from the initial phase.

5. Conclusion

Implementation science and behaviour change methodology informed the customisation and implementation of an evidence-based appropriate use criteria for endotracheal suction in a complex paediatric critical care environment. This study sheds light on effective approaches to implementation, and the positive impact appropriate use criteria can have in the context of infectious respiratory disease and endotracheal suction. Ultimately, the implementation of PAWS may prove to be useful in promoting the uptake and sustained use of evidence-based practices for endotracheal suction in paediatric intensive care; however, this requires further evaluation in large-scale studies.

Data availability statement

Qualitative data: The data that support the findings of this study are available on request from the corresponding author, [JS]. The data are not publicly available due to the sensitive nature of interview data [e.g., their containing information that could compromise the privacy of research participants].

Quantitative data: The data that support the findings of this study are available from the corresponding author, [JS], upon reasonable request and guided by Children's Health Queensland ethics committee.

Funding

This work was supported by the Children's Hospital Foundation: Health Services Research Grant [HSR022020, 2020].

CrediT authorship contribution statement

Dr Jessica Schults: Conceptualisation, Methodology, Investigation, resources, data curation, writing—original draft, visualisation, project administration.

Ms Karina Charles: Conceptualisation, Methodology, Investigation, resources, data curation, writing—original draft, visualisation, project administration.

Ms Jane Harnischfeger: Conceptualisation, Methodology, Investigation, resources, data curation, writing—review and editing.

Prof Robert S Ware: Conceptualisation, Methodology, Investigation, resources, data analysis, writing—review and editing.

Ms Ruth H Royle: Conceptualisation, Methodology, Investigation, resources, data analysis, writing—review and editing.

Prof Joshua Byrnes: Conceptualisation, Methodology, Investigation, resources, data analysis, writing—review and editing.

Associate Prof Debbie A Long: Conceptualisation, methodology, validation, writing—review and editing.

Prof Amanda J Ullman: Conceptualisation, methodology, validation, writing—review and editing.

Dr Sainath Raman: Conceptualisation, methodology, validation, writing—review and editing.

Dr Michaela Waak: Conceptualisation, methodology, validation, writing—review and editing.

Ms Anna Lake: Consumer, conceptualisation, methodology, validation, writing—review and editing.

Prof Marie Cooke: Conceptualisation, methodology, validation, writing—review and editing.

Dr Adam Irwin: Conceptualisation, methodology, validation, writing – review and editing.

Associate Prof Lyvonne Tume: Conceptualisation, methodology, validation, writing—review and editing.

Associate Prof Lisa Hall: Conceptualisation, Methodology, Investigation, resources, data analysis, writing—review and editing.

Conflict of interest

The authors have no conflicts of interest to disclose.

Acknowledgement

The authors have no additional acknowledgements to disclose.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aucc.2023.09.008.

References

[1] Schults J, Long D, Mitchell M, Cooke M, Gibbons K, Pearson K, et al. Adverse events and practice variability associated with paediatric endotracheal suction: an observational study. Aust Crit Care 2019. https://doi.org/10.1016/j.aucc.2019.08.002.

[2] Willson DF. Why bother? The new paradigm of pediatric "ventilator-associated condition". Crit Care Med 2019;47(7):1009–10. https://doi.org/10.1097/ccm.0000000000003788.

[3] Schults JA, Cooke M, Long D, Mitchell ML. "When no-one's looking," the application of lung recruitment and normal saline instillation with paediatric endotracheal suction: an exploratory study of nursing practice. Aust Crit Care 2019;32(1):13–9. https://doi.org/10.1016/j.aucc.2018.03.002.

[4] Schults JA, Cooke M, Long D, Schibler A, Ware RS, Charles K, et al. Normal saline and lung recruitment with paediatric endotracheal suction (NARES): a pilot, factorial, randomised controlled trial. Aust Crit Care 2021;34(6):530–8. https://doi.org/10.1016/j.aucc.2021.01.006.

[5] Tume LN, Copnell B. Endotracheal suctioning of the critically ill child. J Pediatr Intensive Care 2015;4(2):56–63. https://doi.org/10.1055/s-0035-1556747 [published Online First: 2015/06/01].

[6] Tume LN, Baines P, Guerrero R, Johnson R, Ritson P, Scott E, et al. Patterns of instability associated with endotracheal suctioning in infants with single-ventricle physiology. Am J Crit Care 2017;26(5):388–94. https://doi.org/10.4037/ajcc2017844 [published Online First: 2017/09/03].

[7] Tume LN, Baines PB, Guerrero R, Hurley MA, Johnson R, Kalantre A, et al. Pilot study comparing closed versus open tracheal suctioning in postoperative neonates and infants with complex congenital heart disease. Pediatr Crit Care Med 2017;18(7):647–54. https://doi.org/10.1097/pcc.0000000000001192 [published Online First: 2017/05/11].

[8] Morrow B, Argent A. A comprehensive review of pediatric endotracheal suctioning: effects, indications, and clinical practice. Pediatr Crit Care Med 2008;9(5):465–77. https://doi.org/10.1097/PCC.0b013e31818499cc.

[9] Owen EB, Woods CR, O'Flynn JA, Boone MC, Calhoun AW, Montgomery VL. A bedside decision tree for use of saline with endotracheal tube suctioning in children. Crit Care Nurse 2016;36(1):e1–10. https://doi.org/10.4037/ccn2016358.

[10] Schults JA, Mitchell ML, Cooke M, Long DA, Ferguson A, Morrow B. Endotracheal suction interventions in mechanically ventilated children: an integrative review to inform evidence-based practice. Aust Crit Care 2020:S1036–7314. https://doi.org/10.1016/j.aucc.2020.05.003.

[11] Fitch K, Bernstein SJ, Aguilar MD, Burnand B, LaCalle JR. The RAND/UCLA appropriateness method user's manual. Santa Monica, CA: Rand Corp; 2001.

[12] Suh RD, Genshaft SJ, Kirsch J, Kanne JP, Chung JH, Donnelly EF, et al. ACR appropriateness criteria(R) intensive care unit patients. J Thorac Imaging 2015;30(6):W63–5. https://doi.org/10.1097/rti.0000000000000174.

[13] Salik JR, Sen S, Picard MH, Weiner RB, Dudzinski DM. The application of appropriate use criteria for transthoracic echocardiography in a cardiac intensive care unit. Echocardiography (Mount Kisco, NY) 2019;36(4):631–8. https://doi.org/10.1111/echo.14314 [published Online First: 2019/04/11].

[14] Rogan J, Zielke M, Drumright K, Boehm LM. Institutional challenges and solutions to evidence-based, patient-centered practice: implementing ICU diaries. Crit Care Nurse 2020;40(5):47–56. https://doi.org/10.4037/ccn2020111 [published Online First: 2020/10/02].

[15] Steffen KM, Holdsworth LM, Ford MA, Lee GM, Asch SM, Proctor EK. Implementation of clinical practice changes in the PICU: a qualitative study using and refining the iPARIHS framework. Implement Sci 2021;16(1):15. https://doi.org/10.1186/s13012-021-01080-9.

[16] Kahn JM. Bringing implementation science to the intensive care unit. Curr Opin Crit Care 2017;23(5):398–9. https://doi.org/10.1097/mcc.0000000000000446.

[17] Schults J, Charles K, Long D, Brown G, Copnell B, Dargaville P, et al. The Paediatric AirWay Suction (PAWS) appropriateness guide for endotracheal suction interventions. Aust Crit Care 2021. https://doi.org/10.1016/j.aucc.2021.10.005.

[18] Schults J, Charles K, Long D, Erikson S, Brown G, Waak M, et al. Appropriate use criteria for endotracheal suction interventions in mechanically ventilated children: the RAND/UCLA development process. Aust Crit Care 2021;35(6):661–7.

[19] Charles KR, Hall L, Ullman AJ, Schults JA. Methodology minute: utilizing the RAND/UCLA appropriateness method to develop guidelines for infection prevention. Am J Infect Control 2022;50(3):345–8. https://doi.org/10.1016/j.ajic.2021.12.012.

[20] Safaeinili N, Brown-Johnson C, Shaw JG, Mahoney M, Winget M. CFIR simplified: pragmatic application of and adaptations to the Consolidated Framework for Implementation Research (CFIR) for evaluation of a patient-centered care transformation within a learning health system. Learn Health Syst 2020;4(1):e10201. https://doi.org/10.1002/lrh2.10201.

[21] Melder A, Robinson T, McLoughlin I, Iedema R, Teede H. Integrating the complexity of healthcare improvement with implementation science: a longitudinal qualitative case study. BMC Health Serv Res 2022;22(1):234. https://doi.org/10.1186/s12913-022-07505-5.

[22] Pinnock H, Barwick M, Carpenter CR, Eldridge S, Grandes G, Griffiths CJ, et al. Standards for Reporting Implementation Studies (StaRI) statement. BMJ 2017;356:i6795. https://doi.org/10.1136/bmj.i6795.

[23] Brouqui P, Puro V, Fusco FM, Bannister B, Schilling S, Follin P, et al. Infection control in the management of highly pathogenic infectious diseases: consensus of the European Network of Infectious Disease. Lancet Infect Dis 2009;9(5):301–11. https://doi.org/10.1016/S1473-3099(09)70070-2.

[24] Michie S, van Stralen MM, West R. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. Implement Sci 2011;6:42.

[25] Schults J, Cooke M, Long D, Mitchell M. Normal saline and lung recruitment with pediatric endotracheal suction: a review and critical appraisal of practice recommendations. Dimens Crit Care Nurs 2020;39(6):321–8. https://doi.org/10.1097/DCC.0000000000000442.

[26] Smith JD, Li DH, Rafferty MR. The Implementation Research Logic Model: a method for planning, executing, reporting, and synthesizing implementation projects. Implement Sci 2020;15(1):84. https://doi.org/10.1186/s13012-020-01041-8.

[27] Proctor E, Silmere H, Raghavan R, Hovmand P, Aarons G, Bunger A, et al. Outcomes for implementation research: conceptual distinctions, measurement challenges, and research agenda. Adm Policy Ment Health 2011;38(2):65–76. https://doi.org/10.1007/s10488-010-0319-7 [published Online First: 2010/10/20].
[28] ANZICS Centre for Outcome and Resource Evaluation. Report of the Australian and New Zealand Paediatric Intensive Care Registry 2018. Victoria, AUS: ANZICS CORE; 2018. p. 28.
[29] Braun V, Clarke V. Toward good practice in thematic analysis: avoiding common problems and be(com)ing a knowing researcher. Int J Transgend Health 2023;24(1):1–6. https://doi.org/10.1080/26895269.2022.2129597.
[30] Braun V, Clarke V. Is thematic analysis used well in health psychology? A critical review of published research, with recommendations for quality practice and reporting. Health Psychol Rev 2023:1–24. https://doi.org/10.1080/17437199.2022.2161594 [published Online First: 2023/01/20].
[31] Braun V, Clarke V. Using thematic analysis in psychology. Qual Res Psychol 2006;3(2):77–101. https://doi.org/10.1191/1478088706qp063oa.
[32] Thorne S, Kirkham SR, O'Flynn-Magee K. The analytic challenge in interpretive description. Int J Qual Methods 2004;3(1):1–11. https://doi.org/10.1177/160940690400300101.
[33] Evans J, Syddall S, Butt W, Kinney S. Comparison of open and closed suction on safety, efficacy and nursing time in a paediatric intensive care unit. Aust Crit Care 2014;27(2):70–4. https://doi.org/10.1016/j.aucc.2014.01.003.
[34] Fisk AC. The effects of endotracheal suctioning in the pediatric population: an Integrative Review. Dimens Crit Care Nurs 2018;37(1):44–56. https://doi.org/10.1097/dcc.0000000000000275 [published Online First: 2017/12/02].
[35] Maggiore SM, Lellouche F, Pignataro C, Girou E, Maitre B, Richard JC, et al. Decreasing the adverse effects of endotracheal suctioning during mechanical ventilation by changing practice. Respir Care 2013;58(10):1588–97. https://doi.org/10.4187/respcare.02265.
[36] McKinley DF, Kinney SB, Copnell B, Shann F. Long-term effects of saline instilled during endotracheal suction in pediatric intensive care: a randomized trial. Am J Crit Care 2018;27(6):486–94. https://doi.org/10.4037/ajcc2018615.
[37] Lane-Fall MB, Christakos A, Russell GC, Hose B-Z, Dauer ED, Greilich PE, et al. Handoffs and transitions in critical care—understanding scalability: study protocol for a multicenter stepped wedge type 2 hybrid effectiveness-implementation trial. Implement Sci 2021;16(1):63. https://doi.org/10.1186/s13012-021-01131-1.
[38] Croskerry P. The cognitive imperative: thinking about how we think. Acad Emerg Med 2000;7(11):1223–31. https://doi.org/10.1111/j.1553-2712.2000.tb00467.x.
[39] Costa DK, White MR, Ginier E, Manojlovich M, Govindan S, Iwashyna TJ, et al. Identifying barriers to delivering the awakening and breathing coordination, delirium, and early exercise/mobility bundle to minimize adverse outcomes for mechanically ventilated patients: a systematic review. Chest 2017;152(2):304–11. https://doi.org/10.1016/j.chest.2017.03.054.
[40] Sinuff T, Muscedere J, Adhikari NK, Stelfox HT, Dodek P, Heyland DK, et al. Knowledge translation interventions for critically ill patients: a systematic review. Crit Care Med 2013;41(11):2627–40. https://doi.org/10.1097/CCM.0b013e3182982b03.
[41] Tume L. Endotracheal suction in high risk patients. Eur J Pediatr 2016;175(11):1404–5. https://doi.org/10.1007/s00431-016-2785-8.

Please cite this article as: Schults JA et al., Implementing paediatric appropriate use criteria for endotracheal suction to reduce complications in mechanically ventilated children with respiratory infections, Australian Critical Care, https://doi.org/10.1016/j.aucc.2023.09.008