TITLE

Mechanical ventilation, weaning practices, and decision-making in European pediatric intensive care units

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KEY WORDS**:** critically ill child; mechanical ventilation; intensive care; non-invasive ventilation; survey

Abstract

Objectives:

This survey had three key objectives. (1) To describe responsibility for key ventilation and weaning decisions in European pediatric intensive care units (PICUs) and explore variations across Europe. (2) To describe the use of protocols, spontaneous breathing trials (SBTs), non-invasive ventilation (NIV), high flow nasal cannula (HFNC) use, and automated weaning systems. (3) To describe nurse-to-patient staffing ratios and perceived nursing autonomy and influence over ventilation decision-making.

Design: Cross-sectional electronic survey.

Setting: European PICUs.

Participants: Senior ICU nurse and physician from participating PICUs.

Interventions: None

Measurements and main results: Response rate was 64% (65/102) representing 19 European countries. Determination of weaning failure was most commonly based on collaborative decision-making (81% PICUs, 95% confidence interval (CI) 70%–89%). Compared to this decision, selection of initial ventilator settings and weaning method were least likely to be collaborative (relative risk (RR) 0.30, 95% CI 0.20–0.47) and (RR 0.45, 95% CI 0.32–0.45). Most (>75%) PICUs enabled physicians in registrar (fellow) positions to have responsibility for key ventilation decisions. Availability of written guidelines/protocols for ventilation (31%), weaning (22%), and NIV (33%) was uncommon, whereas sedation protocols (66%) and sedation assessment tools (76%) were common. Availability of protocols was similar across European regions (all P values >0.05). HFNC (53%), NIV (52%) to avoid intubation, and SBTs (44%) were used in approximately half the PICUs >50% of the time. A nurse-to-patient ratio of 1:2 was most frequent for invasively (50%) and non-invasively (70%) ventilated patients. Perceived nursing autonomy (median (IQR) 4 (2, 6) and influence (median (IQR) 7 (5, 8)) for ventilation and weaning decisions varied across Europe (P values 0.007 and 0.01 respectively) and were highest in Northern European countries.

Conclusions: We found variability across European PICUs in interprofessional team involvement for ventilation decision-making, nurse staffing, and perceived nursing autonomy and influence over decisions. Patterns of adoption of tools/adjuncts for weaning and sedation were similar.

INTRODUCTION

Mechanical ventilation is a common therapy used in pediatric intensive care units (PICUs), which frequently necessitates the use of analgesic and sedative drugs (1). As a child's condition improves, weaning from sedatives and mechanical ventilation is attempted. Delays in recognizing when a child is ready to wean results in exposure to risks associated with prolonged sedation, iatrogenic withdrawal, ventilator associated lung injury, and ventilator associated infection. In contrast, overly aggressive weaning will expose the child to risks associated with respiratory muscle fatigue, compromised gas exchange, and extubation failure (1).

Bedside nurses are in an ideal position to recognize weaning readiness and to engage in the weaning process (2). However, there is little data describing nurses' or other healthcare professionals' role in decision-making related to ventilation, sedation, and weaning in PICUs. One survey previously examining nurses' roles and responsibilities regarding ventilation and weaning in PICUs in the United Kingdom (UK) (3), reported a high proportion of collaborative decision-making but infrequent independent titration of ventilator settings by nurses, and low adoption of paediatric weaning protocols. Exploration of current models of decision-making is important, as those models that prioritize doctor-nurse collaboration and nurse involvement in clinical-decision making have been linked to better safety and quality of care (4-8).

There are limited data describing ventilation and weaning practices in PICUs across Europe, and data available are out-dated. Knowledge of current practice is important to identify opportunities for adoption of current evidence, for benchmarking to establish the need for quality improvement and to describe usual care to inform future European research.
Given the dearth of evidence on current practices and decision-making related to ventilation, weaning and sedation we aimed to survey current practice. Our objectives were to describe:

(1) the professional group and seniority with responsibility for key mechanical ventilation, weaning, and sedation decisions; (2) the use of weaning adjuncts including protocols, spontaneous breathing trials (SBT), non-invasive ventilation (NIV), high flow nasal cannula (HFNC) use, and automated closed loop systems; (3) the registered nurse-to-patient staffing ratios for invasive and non-invasively ventilated patients; and (4) the perceived nurse autonomy and nurses' influence over decision-making for mechanical ventilation. We surveyed European PICUs and explored variation across northern, central, and southern European regions.

MATERIALS AND METHODS

Study Design and instrument

We conducted a cross-sectional online survey (Survey Monkey™) of European PICUs using a previously validated instrument (2). In addition to the original survey items relating to responsibility for ventilation and weaning decisions initial ventilator settings (titration of ventilator settings; assessing weaning readiness; determining weaning method; assessing weaning failure (need to reinstate ventilatory support or reintubate); and assessing extubation readiness), we added additional items on two common strategies used in pediatric respiratory failure: NIV and HNFC (9,10); and use of SBTs and sedation assessment (Questionnaire in the e-supplement). A European inter-professional panel of eight experts (content and survey methodology) assessed our modified survey instrument for clinical sensibility (clarity, redundancy, face validity) (11), resulting in minor modifications. The survey instrument was translated from English into French, German, Italian, and Spanish by bilingual local study investigators. We performed forward and backward translation; the backward English translation was assessed for accuracy by the lead investigator (LT) (Survey provided as supplementary material)

The survey was conducted alongside a prospective observational study of ventilation and weaning practices in European PICUs (VESPER). Both studies were endorsed by the

European Society of Pediatric and Neonatal Intensive Care (ESPNIC) and given permission to access their register of PICUs.

Sample

We used the ESPNIC register as a sample frame. The register included email addresses of medical and nursing heads of unit, PICU postal addresses and telephone numbers of PICUs within 18 European countries. In addition to the sample frame, we contacted PICUs not on the register, but known to the research team from previous European PICU collaborative studies (12,13). We excluded neonatal and adult intensive care units.

Participants

We invited a senior or specialist nurse (defined as a nurse in a position of responsibility, usually a nurse in charge of the PICU) and a senior physician (defined as a consultant or attending physician) from PICUs routinely providing mechanical ventilation for children aged 0 to16 years. We asked paired participants in PICUs to work collaboratively in providing responses to survey items. In ICUs with mixed adult/pediatric or neonatal/pediatric populations, participants were asked to consider *only* practices and decision-making for term babies and children up 16 years.

Survey Administration

We sent an email outlining the study to all PICUs identified in the sampling frame. PICUs expressing interest were provided further information. PICUs agreeing to take nominated a senior nurse and physician who were sent a link to the electronic survey platform Survey Monkey™. We provided three survey completion reminders, sent one week apart to maximize response rates. No participant identifiers were collected; however, we collected the hospital name and location target response reminders to non-responders. Participants were informed that completion of the questionnaire was voluntary and submission of responses constituted consent to participation. The study was reviewed and approved at the

Research Ethics Board of Groningen University in the Netherlands who waived the need for informed consent (METc 2015/187).

Statistical analyses

We exported survey response data from Survey Monkey™ into the Statistical Package for the Social Scientists (SPSS version 22) for analysis. We categorized countries according to northern, central, and southern regions of Europe as previously described in other European surveys (12,14). We examined continuous data for normality using the Kolmogorov-Smirnov (KS) test. We examined measures of central tendency (medians and interquartile ranges (IQR) due to non-normal data distribution) for continuous data and compared using Mann Whitney or Kruskall-Wallis tests. We calculated frequencies, proportions and their 95% confidence intervals for categorical data including the professional group and seniority holding responsibility for ventilation and weaning decisions. We calculated relative risks to determine the ventilation decisions most likely to be based on inter-professional collaboration. We used the Spearman's Rho test to examine correlations between ordinal scales used to rate nursing autonomy and influence for ventilation decision-making. We considered a *P* value of <0.05 as statistically significant; all tests were two-tailed.

RESULTS

Surveys were returned from 65 PICUs within 19 European countries; response rate 64% (65/102 PICUs)(Table 1). Of the 59 PICUs providing demographic characteristics the majority were in university affiliated hospitals (54, 92%), were intensivist-led (57, 97%), and were mixed medical-surgical (47, 80%) units, with 25 of the mixed PICUs also providing cardiac surgery (Table 2). The median PICU bed size was 12; median annual admissions were 550 with a median of 320 ventilated children admitted annually (Table 2). PICUs reported a registered nurse (RN)-to-patient ratio of 1:2 for invasively (29/58, 50%) and non-invasively (41/59, 70%) ventilated patients. Of 7 PICUs reporting a nurse-to-patient ratio lower than 1:2, 4 (57%) were from 10 participating units in France, the remainder were from

Belgium, Italy, and Turkey. A 1:1 nurse-to-patient ratio for invasively ventilated children was more common in the UK (16/19, 84%).

Profession with responsibility for key ventilation decisions and their seniority

Of 63 PICUs reporting decision-making responsibility, 7 (11%, 95% CI 5% to 21%) reported *all* 8 key decisions were made *only* by physicians; a further 7 (11%, 95% CI 5% to 21%) stated *all* 8 key decisions were based on inter-professional collaborative discussion. Countries where physician only decision-making across *all* 8 decisions occurred were from south and central Europe including France (4/10 PICUs), Croatia (1/1), Greece (1/1), and Poland (1/2). Countries where collaborative decision-making occurred across all 8 decisions were from northern Europe including the Netherlands (3/6 units), Slovenia (1/1), Sweden (1/1), Switzerland (1/2), and the UK (1/19). Considering responses from all PICUs, of the 8 key decisions, determination of weaning failure was most likely to be based on inter-professional collaborative decision-making (51/63, 81% of all responding PICUs, 95% CI 70% to 89%). In contrast, selection of initial ventilator settings (RR 0.30, 95% CI 0.20 to 0.47) and selection of the weaning method (RR 0.45, 95% CI 0.32 to 0.45) were least likely to be based on inter-professional decision-making (Tables 3,4).

More than 75% PICUs, physicians in registrar/fellow positions (i.e., above the level of junior residents or house officers) were permitted to have responsibility for all 8 key ventilation decisions. Extubation readiness (19/63, 30%), initiation of NIV (16/63, 25%), and selection of weaning method (15/63, 24%), were the 3 decisions most commonly reserved for senior (consultant/attending level) physicians only (Table 4). The most common decisions involving all levels of nurses irrespective of seniority were determination of weaning failure (26/45, 58%), weaning readiness (18/45, 45%), and discontinuation of NIV (18/41, 44%) (Table 5). Nurses rarely adjusted ventilator settings apart from titration of the fraction of inspired oxygen (FiO_2) (52/63, 83%, 95% CI 71% to 90%). Thirteen units (21%, 95% CI 13% to 32%)

reported nurses titrated the ventilator set respiratory rate; PEEP was least likely to be independently adjusted by nurses (Table 5).

Weaning and Sedation Strategies

Written guidelines or protocols were uncommon for mechanical ventilation (19/62 31%), weaning (14/63, 22%), and NIV (21/63, 33%), whereas sedation protocols (41/62, 66%) and sedation assessment tools (48/63, 76%) were more commonly used. The COMFORT and/or COMFORT B scale sedation assessment tool (15,16) was used by 43/48 (90%) PICUs; and 11/63 (17%) PICUs reported use of both weaning and sedation protocols. No trend was observed between use of ventilation, weaning, or sedation protocols and European region (all p values >0.05).

Approximately half the responding PICUs used HFNC (33/62, 53%) or NIV (33/63, 52%) in an attempt to avoid the need for intubation more than 50% of the time. SBTs to test extubation readiness were reported to be used in 28/63 (44%) PICUs more than 50% of the time. Routine use of elective extubation to NIV and automated closed loop modes was infrequent.

Perceived nurse autonomy and influence on ventilator decision-making

We defined autonomy as the ability to make ventilation decisions and implement them without direct supervision of a medical colleague. This was measured on a 0 to 10 Likert scale with 10 representing complete autonomy. Median (IQR) perceived rating of nurse autonomy for ventilation decision-making was 4 (2, 6). The median (IQR) perceived nurse influence on ventilation decision-making was rated higher at 7 (5, 8). Perceived ratings of nursing autonomy and nurse influence on ventilator decision-making varied across European regions (p=0.007 and p=0.01 respectively) and were highest in northern compared to central and southern European countries. Perceived autonomy (p=0.01) and nurse influence (p=0.02) varied by nurse-to-patient ratio (highest in PICUs with a 1:1 nurse-to-patient ratio),

but were not influenced by presence of a weaning protocol (p=0.52 and p=0.41 respectively). Ratings of perceived nursing autonomy were positively correlated with those of perceived nursing influence over decision-making (p= 0.01) (Table 6).

DISCUSSION

We surveyed 65 PICUs across 19 European countries and found variation within and across countries in the professional group responsible for ventilation and weaning decision-making, as well as perceived nurse autonomy and influence and nurse-to-patient ratios. Despite nursing involvement in key decisions, few PICUs reported nurses independently titrated ventilator settings with the exception of FiO_2. We found similar rates of adoption of ventilation, weaning, and sedation protocols across northern, central and southern Europe. Use of HFNC and NIV to avoid the need for intubation was common and use of automated weaning systems was infrequent.

To our knowledge, this is the first study to explore decisional responsibility and roles related to mechanical ventilation and weaning in PICUs across Europe and differences in European pediatric ventilation practices. Despite some within and across country variation, we found most units reported a collaborative model of decision-making for key decisions related to ventilation and nurses had at least moderate influence over ventilation decision-making. Collaborative decision-making and nurse influence on ventilator decisions was more common in PICUs from the northern region of Europe. Though we did not measure this directly, we speculate reasons for this variation may include differences in nurse and physician staffing levels; the level of general nurse education[1,7] and provision of specialist ICU nursing education. Previous studies have demonstrated that staffing strategies targeting a higher level of nurse care, including staffing with more highly educated nurses and lower patient-to-nurse ratios, were associated with better patient outcomes (17,18). In most northern European countries nurses receive a baccalaureate level education and specialty post-graduate nursing education (19).

Perceived nurse autonomy and influence related to ventilation decision-making was positively correlated with nurse-to-patient ratios. Our group previously demonstrated this association in European adult ICUs (20). Nurse to patient ratios have been linked to PICU quality indicators. Lower nurse-to-patient ratios have been shown to increase infant mortality in the NICU (21), adverse events such as unplanned extubation (22), and healthcare acquired infections in the PICU (23).

Guidelines/protocols for ventilation, weaning and NIV are not commonly used. This may be because of the paucity of research evidence to guide practice in this area (24).
Likewise, automated closed loop weaning modes are not commonly used and their use is substantially lower than that reported in European adult ICUs (20). This is probably related to the limited availability of commercial automated weaning systems capable of ventilating children of all ages, as well as limited evidence of efficacy in the paediatric population (25). Although Neurally Activated Ventilator Assist (NAVA) can be used in all children, including very low birth weight infants (11, 26), Draeger Smart Care/PS™ currently can only be used in children over 30 Kg (27). Use of HFNC or NIV as a strategy to prevent intubation was also uncommonly reported. Although numerous studies report on the use of HFNC in children (28) evidence is equivocal with more studies needed to confirm its efficacy and safety.

Limitations

Our study has some limitations associated with self-report surveys including selection bias, self-report bias, confounding, lack of generalizability, and no means of data verification from participants. Despite our recruitment efforts, not all European countries were included and the number of units per country varied considerably with UK, France and Spain accounting for 60% of returned questionnaires. Despite asking about critical care specialist nursing education, many responses received related to initial PICU orientation programs as opposed

to formal specialty education therefore we were unable to test the hypothesis that specialty education influenced decisional responsibility.

CONCLUSIONS

In this cross-sectional survey, we found variability across European PICUs in inter-professional team involvement in decision making, nurse staffing and perceived nursing autonomy and influence over decisions with greater nurse engagement in the Northern European countries compared to central and southern countries. Higher nurse-to-patient ratios were also associated with perceived autonomy and influence. However, patterns of adoption of guidelines and protocols to manage weaning were similar across European countries surveyed. These findings are important as they will assist with benchmarking and other quality improvement initiatives and will inform future research by describing current European practice.

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Table 1 Distribution of country responses

Country (n=19)	European region	No. responding units (n=65)
Austria	Central	1
Belgium	Central	1
Croatia	Central	1
Cyprus	Southern	1
Estonia	Central	1
France	Central	10
Greece	Southern	1
Ireland	Northern	1
Israel	Southern	1
Italy	Southern	3
Netherlands	Northern	6
Poland	Central	2
Slovenia	Central	1
Spain	Southern	10
Sweden	Northern	1
Switzerland	Central	2
Turkey	Southern	1
UK	Northern	19

Table 2 PICU Demographics

Characteristic (n =59)	n (%)
Hospital type	
University affiliated	54 (91.5)
Non-teaching	5 (8.5)
Unit type	
Closed ICU (intensivist-led)	57 (96.6)
Open ICU	2 (3.4)
Unit specialty	
Mixed medical and surgical PICU including cardiac surgery	25 (42.4)
Mixed medical and surgical PICU no cardiac surgery	22 (37.3)
Mixed NICU-PICU	8 (13.6)
Other[a]	4 (6.8)
PICU beds, median (minimum, maximum)	12 (4, 52)
PICU annual admits, median (minimum, maximum)	550 (100, 1700)
PICU beds capable of ventilation, median (minimum, maximum)	10 (2, 31)
PICU annual admits requiring ventilation, median (minimum, maximum)	320 (30, 1218)
RNs employed, median (minimum, maximum)	50 (11, 232
Nurse to patient ratio for invasively ventilated patients	
1:1	22 (37.9)
1:2	29 (50.0)
1:2.5	3 (5.2)
1:3	3 (5.2)
1:4	1 (1.7)
Nurse to patient ratio for non-invasively ventilated patients	
1:1	6 (10.2)
1:2	41 (69.5)
1:2.5	4 (6.8)
1:3	7 (11.9)
1:4	1 (1.7)
Consultants, median (minimum, maximum)	6 (1, 20)
Physicians in training, median (minimum, maximum)	5 (1, 29)

a Medical PICU (only), cardiovascular PICU only, surgical PICU only and a combined adult/paediatric ICU

Table 3 Eight Key Ventilation and Weaning Decisions reported by PICUs as collaborative

Decision	n/N	% (95% CI)	RR (95% CI)
Weaning failure	51/63	81 (70 - 89)	1
Wean/discontinue NIV	44/63	70 (58 - 80)	0.86 (0.71 - 1.06)
Weaning readiness	42/63	67 (44 - 77)	0.82 (0.67 - 1.02)
Titration of ventilator settings	41/65	63 (51 - 74)	0.78 (0.62 - 0.97)
Extubation readiness	40/63	64 (51 - 74)	0.78 (0.63 - 0.98)
Initiation of NIV	34/63	54 (42-66)	0.67 (0.52 - 0.86)
Weaning method	23/63	37 (26 - 49)	0.45 (0.32 - 0.64)
Initial ventilator settings	16/65	25 (16 - 36)	0.30 (0.20 - 0.47)

NIV: Non-invasive ventilation; CI: confidence interval; RR: risk ratio.

Table 4 Seniority of Staff Making Decisions

Aspect of decision making	Seniority of physicians		
	Consultant[a] only	Registrar[b] and above	All physicians
Extubation readiness (n=63)	19 (30.2)	35 (55.6)	9 (14.3)
Initiation of NIV (n=63)	16 (25.4)	35 (55.6)	12 (19.0)
Weaning method (n=62)	15 (24.2)	32 (51.6)	15 (24.2)
Wean/discontinue NIV (n=63)	14 (22.2)	36 (57.1)	13 (20.6)
Initial ventilator settings (n=65)	13 (18.5)	33 (50.8)	20 (30.8)
Weaning failure (n=63)	13 (20.6)	36 (57.1)	14 (22.2)
Weaning readiness (n=63)	11 (17.5)	36 (57.1)	16 (25.4)
Titration of ventilator settings (n=65)	8 (12.3)	35 (53.8)	22 (33.8)
Aspect of decision making	Seniority of nurses		
	Senior nurses only	Specialist nurses only (ventilator practitioners or NPs)	All nurses
Weaning readiness (n=40)	15 (37.5)	7 (17.5)	18 (45.0)
Titration of ventilator settings (n=36)	14 (38.9)	16 (27.8)	12 (33.3)
Wean/discontinue NIV (n=41)	12 (29.3)	11 (26.8)	18 (43.9)
Extubation readiness (n=35)	11 (31.4)	8 (22.9)	16 (45.7)
Weaning method (n=29)	11 (37.9)	7 (24.1)	11 (37.9)
Initiation of NIV (n=31)	8 (25.8)	9 (29.0)	14 (45.2)
Weaning failure (n=45)	8 (17.8)	11 (24.4)	26 (57.8)
Initial ventilator settings (n=16)	6 (37.5)	4 (25.0)	6 (37.5)

a most senior attending physician responsible for patient decision making

b physician undertaking specialty training, also referred to as fellows in some countries

NIV: non-invasive ventilation; NP: nurse practitioner

Table 5 Titration of Ventilator Settings Performed by Nurses

Ventilator titration	n/N	% (95% CI)	RR (95% CI)
Increase FiO2	52/63	82.5 (71.4 - 90.0)	1
Decrease FiO2	51/63	81.0 (69.6 - 88.8)	0.98 (0.83-1.16)
Wean/discontinue HFNC	21/59	35.6 (24.6 - 48.3)	0.43 (0.30-0.62)
Titrate rate	13/63	20.6 (12.5 - 32.2)	0.25 (0.15-0.41)
Wean NIV	12/63	19.1 (11.3 - 30.4)	0.23 (0.14-0.39)
Initiate HFNC	10/59	17.0 (9.5 - 28.5)	0.21 (0.12-0.37)
Decrease pressure support	8/63	12.7 (6.6 - 23.1)	0.15 (0.08-0.30)
Titrate inspiratory pressure	7/63	11.1 (5.5 - 21.2)	0.13 (0.07-0.27
Increase pressure support	7/63	11.1 (5.5 - 21.2)	0.13 (0.07-0.27)
Titrate tidal volume	4/63	6.4 (2.5 - 15.2)	0.08 (0.03-0.20)
Initiate NIV	4/63	6.4 (2.5 - 15.2)	0.08 (0.03-0.20)
Select or change mode	3/63	4.8 (1.6 - 13.1)	0.06 (0.02-0.17)
Decrease PEEP	2/63	3.2 (0.9 - 10.9)	0.04 (0.01-0.15)
Increase PEEP	1/63	1.6 (0.2 - 8.5)	0.02 (0.00-0.13)

CI: confidence interval; RR: relative risk; FiO2: fraction of inspired oxygen; HFND: high flow nasal cannula; NIV: non-invasive ventilation; PEEP: positive end expiratory pressure.

n/N = number of units indicating that nurses titrated this setting over the total number of units that responded to this survey item

Table 6 Nurse Autonomy and Independence Related to Ventilator Decision-Making

Demographic	Nurse Autonomy	Nurse Influence
European region		
Northern	5 (3.5, 6.5)	7 (6, 8)
Central	3 (1, 5)	5 (3, 7)
Southern	3 (1.5, 4.5)	5.5 (4, 7)
Nurse-to-patient ratio		
1:1	5 (3.5, 6.5)	7 (6, 8)
1:2	4 (2.5, 5.5)	5 (3.5, 6.5)
>1:2	2 (1, 3)	4.5 (2.5, 6.5)
Use of a ventilation protocol		
Yes	5 (3, 7)	5 (3, 7)
No	4 (2.5, 5.5)	7 (5.5, 8.5)

All values are medians and interquartile ranges
Likert scale ranged from 0 (no autonomy/influence) to 10 (full autonomy/influence)