Current Use of Invasive and Noninvasive Monitors in Academic Pediatric Intensive Care Units

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Abstract

To describe the current use of noninvasive monitoring compared with traditional invasive monitoring in Pediatric Critical Care Medicine (PCCM) accredited fellowship programs in the United States. A web-based survey with the primary aim of describing the utilization of noninvasive monitoring compared with invasive monitoring was distributed to PCCM program directors (PDs) at the 64 accredited fellowship training programs. Questions focused on demographics and the utilization of invasive and noninvasive monitoring for specific patient populations and disease states. Forty-two (66%) PDs responded to the survey. Capnography and near-infrared spectroscopy (NIRS) were the most commonly reported noninvasive monitoring technology. Arterial and central venous catheters were widely used. Other invasive monitoring devices were used sparingly. Despite widespread use of both invasive and noninvasive monitoring in academic pediatric critical care units across the United States, there is significant variability in the use of noninvasive monitoring compared with invasive monitoring. Further investigation is needed to define the standard of care for the use of noninvasive monitors as practitioners attempt to optimize care while minimizing risks and complications.

Keywords

- invasive monitoring
- noninvasive monitoring
- patient safety
- pediatric critical care
- fellowship

Introduction

Cardiorespiratory monitoring is essential in the care of critically ill patients and may involve the use of invasive modalities, such as arterial, central venous, intracardiac and/or Swan-Ganz (SG) catheters.^{1–3} These invasive lines pose potential risks for infection, intravascular thrombosis, and vessel perforation.⁴ To minimize these risks, there is growing interest in the use of noninvasive monitoring.⁵

Recent technological advances have introduced sophisticated and reliable noninvasive monitoring techniques to the fields of critical care medicine.⁵ However, it is likely that equipoise exists regarding the impact of noninvasive monitoring on patient outcomes when compared with more invasive approaches.^{6,7} Guidelines for care in pediatric intensive care units (PICUs) published by the Society of Critical Care Medicine and the Section on Critical Care Medicine of the American Academy of Pediatrics recommend continuous

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end-tidal carbon dioxide (EtCO₂) monitoring and pulse oximetry as minimum requirements, coupled with availability of other invasive monitoring, such as invasive arterial, central venous, and pulmonary artery catheters.^{8,9}

In spite of monitoring technology being used by many pediatric intensivists, the extent of applications, education, and training in Pediatric Critical Care Medicine (PCCM) fellowship programs has not been described. Therefore, we conducted a web-based survey with the primary aim of describing the utilization of noninvasive monitoring compared with invasive monitoring in academic PICUs in the United States. The secondary aim was to measure perceptions of PCCM program directors (PDs) on how frequently these technologies are integrated into fellows' education and development.

Methods

Survey questions were drafted and developed by the authors after reviewing relevant published literature on capnography, near-infrared spectroscopy (NIRS), Pulse Index Continuous Cardiac Output (PiCCO), and bispectral index (BIS) literature.^{5,6,10–12} A draft survey was tested with four PCCM practitioners who discussed their responses and identified unclear, confusing, or redundant items. A near-final version was pilot tested with additional six PCCM practitioners. The final survey of Current Use of Invasive and Noninvasive Monitors in Academic PICUs included 103 questions, logic-embedded, web-based survey administered via RedCap,¹³ which could be completed in approximately 6 to 10 minutes. Survey questions are shown in ►Appendix A (supplemental digital content). Active programs and email addresses of PDs were obtained by cross-referencing the American Medical Association Residency Fellowship Electronic Interactive Database.¹⁴ After receiving institutional review board exemption, this survey was distributed by email to PCCM PDs at the 64 Accreditation Council for Graduate Medical Education-accredited fellowship training programs between February and April 2015. Those who did not respond received three reminders within 2 months. The response rate was calculated by dividing the number of participants who answered the questionnaires by the 64 total invited PDs.

The questionnaire was divided into three sections: 83 questions focused on the utilization of invasive and noninvasive monitoring for specific patient populations and disease states, 15 questions focused on fellow education regarding different monitoring technologies and 5 on demographics items. Subjective questions regarding the utilization of invasive and noninvasive monitoring were answered with a 5-point Likert scale (always, often, sometimes, rarely, or never). While subjective questions focused on fellows' education and experience with different monitoring technologies were answered with a 5-point Likert scale (strongly agree, agree, neutral, disagree, or strongly disagree).

Statistical Analysis

For the purposes of this study, an institution with 30 pediatric critical beds or less was classified as "small," while an institution with more than 30 pediatric critical care beds was

classified as 'large.' Similarly, pediatric critical care fellowship programs were stratified by number of fellows, with programs of six fellows or less classified as 'small' and programs with more than six fellows classified as 'large.'

Median and interquartile range (IQR) were used to present descriptive statistics of continuous variables, while percentages were used to present categorical variables. When respondents provided a range response to numerical questions, the midpoint of that range was used for data analysis (e.g., if the respondent stated that fellows place "80–100" arterial catheters over the course of their fellowship, "90" was used for analysis). Continuous variables were compared using Wilcoxon's rank sum test, while categorical variables were compared with chi-square analysis. *P* values of <0.05 were considered significant.

Results

Forty-two (66%) of the 63 invited PDs responded to the survey. ►Table 1 delineates the characteristics of the responding institutions. ►Table 2 summarizes responses regarding the use of invasive and noninvasive monitoring for specific patient populations and disease states.

Invasive Monitoring

Per respondents, arterial catheters and central venous catheters are widely used in the management of critically ill children. Other invasive monitoring devices are used sparingly, including SG catheters and PiCCO catheters (►Table 2). Use of SG catheters was most commonly reported in postoperative cardiac patients, where 18% of respondents reported "sometimes" using SG catheters. The restricted use of SG catheter utilization is also reflected in the reported numbers of catheters placed by fellows (►Table 3), with fellows placing significantly more arterial catheters and central venous catheters than SG catheters (*p* < 0.001 for each).

All responding fellowship PDs agreed that pediatric critical care fellows should master placement of arterial and central venous catheters, while only 17% agreed that fellows should master the placement of SG catheters (*p* < 0.001 for SG catheter compared with either arterial or central venous catheters). Similarly, all fellowship directors felt that their fellows should master arterial and central venous waveform

Table 1 Program characteristics reported by responding institutions

Variable	<i>N</i> = 42
Number of ICU beds (median, IQR)	35 (23, 48)
Institutions classified as "large"	23 (55%)
Separate cardiac ICU	28 (67%)
Number of PCCM faculty (median, IQR)	11 (9, 15)
Number of fellows (median, IQR)	8 (5, 10)
Fellowship programs classified as "large"	26 (61%)

Abbreviations: ICU, intensive care unit; IQR, interquartile range; PCCM, pediatric critical care medicine.

Table 2 Respondents reporting “Always” or “Often” when asked if different invasive and noninvasive monitoring techniques were utilized for unique patient populations, disease states, or medical therapies

Invasive and noninvasive monitoring techniques utilized for unique patient populations	AL	CVL	Swan-Ganz catheters	Capnography	PICCO	BIS	NIRS
Postoperative cardiac patients	34/34 (100%)	34/34 (100%)	0/34 (0%)	26/34 (76%)	1/29 (3%)	2/32 (6%)	28/34 (82%)
Preoperative single ventricle	16/31 (52%)	19/31 (61%)	0/31 (0%)	12/31 (39%)	0/26 (0%)	1/29 (3%)	15/31 (48%)
Postoperative single ventricle	33/33 (100%)	33/33 (100%)	0/33 (0%)	36/33 (79%)	1/28 (4%)	2/31 (6%)	28/33 (85%)
Cardiopulmonary resuscitation	26/42 (62%)	27/42 (64%)	0/42 (0%)	29/42 (69%)	0/37 (0%)	1/40 (3%)	11/42 (26%)
ECMO	41/41 (100%)	39/41 (95%)	0/41 (0%)	24/41 (59%)	0/36 (0%)	4/39 (10%)	19/41 (46%)
Ventilator management	13/42 (31%)	27/42 (64%)	0/42 (0%)	34/42 (81%)	0/37 (0%)	0/40 (0%)	9/42 (21%)
Shock	39/42 (93%)	39/42 (93%)	0/42 (0%)	26/42 (62%)	2/37 (5%)	1/40 (3%)	14/42 (33%)
Sepsis	30/42 (71%)	28/42 (67%)	0/39 (0%)	21/42 (50%)	2/37 (5%)	0/39 (0%)	13/42 (31%)
Severe traumatic brain injury	42/42 (100%)	37/42 (88%)	0/42 (0%)	30/42 (71%)	0/37 (0%)	2/40 (5%)	5/41 (12%)
Intraventricular hemorrhage	27/39 (69%)	24/39 (62%)	0/42 (0%)	20/39 (51%)	0/34 (0%)	0/37 (0%)	2/39 (5%)
Patient transport	1/42 (2%)	4/40 (10%)	0/42 (0%)	20/42 (48%)	0/36 (0%)	0/38 (0%)	0/42 (0%)
Obtain mixed venous saturation	–	26/42 (62%)	0/41 (0%)	–	–	–	–
Non-invasive ventilation	–	–	–	–	–	–	2/42 (5%)
Procedures	–	–	–	–	–	–	2/39 (5%)
Feeding intolerance	–	–	–	–	–	–	2/42 (5%)
Necrotizing enterocolitis	–	–	–	–	–	–	5/39 (13%)

Abbreviations: AL, arterial lines; BIS, bispectral index; CVL, central venous catheters; ECMO, extracorporeal membrane oxygenation; NIRS, near-infrared spectroscopy; PICCO, pulse index continuous cardiac output monitoring.

(–): The utilization of invasive and noninvasive monitoring was not assessed.

interpretation, while 81% of fellowship directors agreed that fellows should master SG waveform and data interpretation ($p < 0.001$ for SG catheter compared with either arterial or central venous catheters; ►Fig. 1). Reasons provided by PDs for fellows placing less than five SG catheters during their fellowship included reliance on other invasive monitoring (98% of respondents), reliance on noninvasive monitoring (90%), nurses in the intensive care unit not trained in use of

SG catheters (36%), and SG catheters not available in their unit (10%).

Noninvasive Monitoring

Capnography is the most commonly reported noninvasive monitoring technology, with common, but not universal utilization (►Table 2). Capnography was most likely to be utilized in ventilator management, per respondents

Table 3 Respondents reporting number of lines placed per fellow during their fellowship

Catheter type	Overall N = 42	Small PICU N = 18	Large PICU N = 21	p-Value	Small fellowship N = 16	Large fellowship N = 23	p-Value
Arterial lines	50 (30, 90)	63 (40, 100)	50 (30, 74)	0.15	88 (54, 100)	40 (30, 50)	0.001 ^a
Central venous lines	60 (40, 100)	68 (40, 121)	50 (38, 94)	0.33	93 (46, 124)	50 (40, 80)	0.05 ^a
Swan-Ganz catheters	0 (0, 1)	0 (0, 1)	0 (0, 1)	0.08	0 (0, 1)	0 (0, 1)	0.10

Abbreviations: IQR, interquartile range; N, number; PICU, pediatric intensive care unit.

Note: All variables are reported as median (IQR).

^aStatistically significant.

Fig. 1 Respondents reporting “Strongly Agree” or “Agree” when asked if fellows should master the placement and the wave interpretation of arterial, central venous, and Swan-Ganz.

(►Fig. 2). Likewise, capnography was the most utilized monitoring during transport (►Table 2). NIRS is also used in many intensive care units (ICUs), but reported more frequently in postoperative cardiac patients than for other populations ($p < 0.001$, ►Fig. 2). Other noninvasive monitoring is rarely used, including BIS.

Responses by Institution and Fellowship Program Size

We observed minimal differences in reported use of monitoring technologies based on either number of ICU beds or size of fellowship program. Compared with large institutions and fellowship programs, small institutions (20 vs. 0%, $p = 0.01$) and small fellowship programs (24 vs. 0%, $p = 0.006$) were more likely to report using central venous lines for monitoring during patient transport (►Table 4). Smaller fellowship programs reported fellows placing more arterial lines during their fellowship when compared with larger fellowship programs (median 88 vs. 40, $p = 0.001$; ►Table 3). No other statistically significant differences were noted between responses based on the size of institution or program.

Respondents from centers with a dedicated pediatric cardiac ICU were more likely to state that they “Always” or

Fig. 2 Respondents reporting “Always” or “Often” when asked if capnography was utilized for unique patient populations, disease states, or medical therapies by PICU and fellowship size. PICU, pediatric intensive care unit; CPR, cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; IVH, intraventricular hemorrhage; PICU, pediatric intensive care unit; SV, single ventricle; TBI, traumatic brain injury.

“Often” used capnography and NIRS to monitor postoperative cardiac patients (91 vs. 50%, $p = 0.008$ and 91 vs. 67%, $p = 0.08$, respectively) including single ventricle patients (91 vs. 58%, $p = 0.03$ and 95 vs. 67%, $p = 0.03$). Respondents from these institutions also revealed that central venous lines were more commonly used to monitor extracorporeal membrane oxygenation (ECMO) patients (100 vs. 88% answering “Always” or “Often”, $p < 0.05$) and less likely to state that central venous lines were used to monitor sepsis patients (54 vs. 88%, $p = 0.02$). Otherwise, there were no statistical differences in responses from centers with or without a dedicated pediatric cardiac intensive care unit.

Discussion

Over the past several years, the use of noninvasive monitoring has substantially advanced the practice of critical care medicine, but the use of this technology in academic medical centers has not been thoroughly described. While some noninvasive monitoring, such as pulse oximetry, has become a standard of care and essential to the optimal monitoring of critically ill children, other modalities are increasing in utilization, but may not be routine.¹⁵ This is the first multi-institutional survey study that describes the use of invasive and noninvasive monitoring across academic PICUs in the United States.

This survey, with a response rate of 66%, demonstrated that the majority of responding academic PICUs were utilizing a range of both invasive and noninvasive monitoring techniques to monitor critically ill pediatric patients especially capnography and NIRS. Capnography provides a simple and convenient method to obtain clinically useful information, such as dead space to tidal volume, ventilation index, and quality of chest compression.¹⁶ Therefore, it was not surprising to find that most respondents had positive opinions regarding the use of capnography in the PICU and stating that they utilized this technology in a wide range of disease states and medical therapies (►Fig. 3). However, 31% of responders reported that they did not always use capnography during cardiopulmonary resuscitation (CPR), despite

Table 4 Respondents reporting “Always” or “Often” when asked if central venous lines were utilized for unique patient populations, disease states, or medical therapies by PICU and fellowship size

Central line utilization for unique patient populations	Overall N = 42	Small PICU N = 20	Large PICU N = 22	p-Value	Small Fellowship N = 17	Large Fellowship N = 25	p-Value
Postoperative cardiac patients	34/34 (100%)	15/15 (100%)	19/19 (100%)	1.0	12/12 (100%)	22/22 (100%)	1.0
Preoperative single ventricle	19/31 (61%)	7/14 (50%)	12/17 (71%)	0.24	6/11 (55%)	13/20 (65%)	0.57
Postoperative single ventricle	33/33 (100%)	14/14 (100%)	19/19 (100%)	1.0	11/11 (100%)	22/22 (100%)	1.0
Cardiopulmonary resuscitation	27/42 (64%)	13/20 (65%)	14/22 (64%)	0.93	10/17 (59%)	17/25 (68%)	0.54
ECMO	39/41 (95%)	17/19 (89%)	22/22 (100%)	0.07	16/17 (94%)	23/24 (96%)	0.80
Ventilator management	27/42 (64%)	14/20 (70%)	13/22 (59%)	0.46	9/17 (53%)	18/25 (72%)	0.21
Shock	39/42 (93%)	19/20 (95%)	20/22 (91%)	0.60	15/17 (88%)	24/25 (96%)	0.34
Sepsis	28/42 (67%)	15/20 (75%)	13/22 (59%)	0.27	13/17 (76%)	15/25 (60%)	0.26
Severe traumatic brain injury	37/42 (88%)	19/20 (95%)	18/22 (82%)	0.17	16/17 (94%)	21/25 (84%)	0.30
Intraventricular hemorrhage	24/39 (62%)	13/20 (65%)	11/19 (58%)	0.65	9/17 (53%)	15/22 (68%)	0.33
Patient transport	4/40 (10%)	4/20 (20%)	0/20 (0%)	0.01 ^a	4/17 (24%)	0/23 (0%)	0.006 ^a
Obtain mixed venous saturation	26/42 (62%)	11/20 (55%)	15/22 (68%)	0.38	9/17 (53%)	17/25 (68%)	0.33

Abbreviations: ECMO, extracorporeal membrane oxygenation; PICU, pediatric intensive care unit.

^aStatistically significant. **Fig. 3** Respondents reporting “Always” or “Often” when asked if NIRS was utilized for unique patient populations, disease states, or medical therapies by PICU and fellowship size. CPR, cardiopulmonary resuscitation; ECMO, extracorporeal membrane oxygenation; IVH, intraventricular hemorrhage; PICU, pediatric intensive care unit; NEC, necrotizing enterocolitis; NIV, noninvasive ventilation; SV, single ventricle; TBI, traumatic brain injury.

2010 Pediatric Advanced Life Support Guidelines that recommended the use of this technology during CPR.¹⁷ Moreover, only 71% of responders reported using capnography all the time while managing severe traumatic brain injury, where capnography use is recommended and offers a continuous, dynamic, and bedside noninvasive monitoring that is readily available and tolerated well even by young infants.^{8,18} Similarly, many responders had positive opinions regarding the use of NIRS in the PICU, but despite this view, NIRS implementation was variable and limited to patients with high severity of illness (► Fig. 3). These results are consistent with the findings of Hoskote et al⁶ who reported that despite a lack of standardized protocols for use, pediatric intensivists preferentially use NIRS for high-risk patient groups, such as high-risk postoperative cardiac patients and ECMO.

As the concept of bringing the ICU to the critically ill patients during transport is becoming widely adopted,¹⁹ it was not surprising to find that almost half of the PDs reported using capnography for monitoring during transport. Hansen et al²⁰ reported that specialty transport teams utilized ventilation monitoring more often than nonspecialized ground transport while transporting intubated patients

with severe traumatic brain injury. They found that such teams were more likely to obtain blood gas and to use capnography. They concluded that using both blood gas and EtCO₂ is required for optimal ventilation monitoring during transport. Except for arterial and central venous lines, which were mainly utilized by small fellowships (►Table 4), no other monitoring tools during transport were reported.

In addition, we found that arterial and central venous catheters remain widely used in the management of critically ill children, but other invasive monitors, such as SG catheters and PiCCO catheters, were used only sparingly. Patterns of invasive monitoring were consistent across ICU sizes, however, PDs in smaller fellowship programs reported that fellows placed more arterial and central femoral lines compared with larger fellowships (►Table 3). The etiology of this difference is not entirely clear, but may be related to availability of the technology in smaller programs, familiarity and historical dependence on invasive lines in the most critically ill patients, or other factors. Of interest, most PDs reported that mastery of SG catheter placement was not a necessary skill for fellows. However, they indicated that fellows should be able to interpret SG data (►Fig. 1). These results are consistent with published data in adults, which demonstrate that SG catheter use has decreased significantly over time.^{21–23} Wiener et al²² demonstrated that over a 10-year period, SG catheter use decreased by 65% in the United States. The rationale for that decline was similar to what PDs reported in our survey. While the use of SG catheters has significantly declined, select patients may still be managed with a SG catheter, and this may explain why the majority of PDs felt that fellows should be able to decipher SG catheter waveforms and have integrated different invasive waveform analyses into the fellows' curriculum.

Limitations of this study include reporting bias, but the effect of this may be minimized by the large response rate. This survey represents a large sample size of 42 fellowship programs, representing 66% of all PCCM fellowship programs in the United States. Also, this survey primarily measures perception regarding the utilization of different monitoring technologies rather than objective measures of actual use. Finally, our survey did not include other monitoring modalities such as point-of-care ultrasound and cerebrovascular pressure reactivity index.

This survey revealed variable use of noninvasive monitoring despite the controversies and lack of accepted management guidelines that defines the standard of care for such technologies when compared with invasive monitoring. Therefore, further investigation is warranted to fully elucidate the current use of noninvasive monitoring, how monitoring strategies may affect patient outcomes and the standard of care for the use of these monitors.

Conclusion

Despite widespread use of both invasive and noninvasive monitoring in academic pediatric critical care units across the United States, this study demonstrates signifi-

ficant variability in the use of noninvasive monitoring compared with invasive monitoring. Moreover, PCCM PDs report substantial variability in the use of these technologies to manage different disease conditions and educate learners. Finally, this survey demonstrates that to some extent, noninvasive monitoring, such as NIRS and capnography, has been adopted into routine clinical practice. Further investigation is needed to define the standard of care for the use of noninvasive monitors as practitioners attempt to optimize care while minimizing risks and complications.

Note

The study was conducted at the Duke University Medical Center.

Conflict of Interest

None.

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Appendix A

Current Use of Invasive and Noninvasive Monitors in Academic Pediatric Intensive Care Units

Noninvasive Monitoring in Pediatric Critical Care Units

How frequently do you use arterial line monitoring in:

	Always	Often	Sometimes	Rarely	Never	N/A
(1) Post-operative cardiac management	☐	☐	☐	☐	☐	☐
(2) PRE-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(3) POST-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(4) Cardiopulmonary resuscitation	☐	☐	☐	☐	☐	☐
(5) ECMO	☐	☐	☐	☐	☐	☐
(6) Ventilator management	☐	☐	☐	☐	☐	☐
(7) Shock	☐	☐	☐	☐	☐	☐
(8) Sepsis	☐	☐	☐	☐	☐	☐
(9) Severe traumatic brain injury	☐	☐	☐	☐	☐	☐
(10) Intraventricular hemorrhage	☐	☐	☐	☐	☐	☐
(11) Patient transport	☐	☐	☐	☐	☐	☐

How frequently do you use central venous line monitoring:

	Always	Often	Sometimes	Rarely	Never	N/A
(12) Post-operative cardiac management	☐	☐	☐	☐	☐	☐
(13) PRE-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(14) POST-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(15) Cardiopulmonary resuscitation	☐	☐	☐	☐	☐	☐
(16) ECMO	☐	☐	☐	☐	☐	☐
(17) Ventilator management	☐	☐	☐	☐	☐	☐
(18) Shock	☐	☐	☐	☐	☐	☐
(19) Sepsis	☐	☐	☐	☐	☐	☐
(20) Severe traumatic brain injury	☐	☐	☐	☐	☐	☐
(21) Intraventricular hemorrhage	☐	☐	☐	☐	☐	☐
(22) Patient transport	☐	☐	☐	☐	☐	☐
(23) Obtain mixed venous saturations (SvO2)	☐	☐	☐	☐	☐	☐

Appendix A**How frequently do you use pulmonary artery/Swan catheters in:**

	Always	Often	Sometimes	Rarely	Never	N/A
(24) Post-operative cardiac management	☐	☐	☐	☐	☐	☐
(25) PRE-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(26) POST-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(27) Cardiopulmonary resuscitation	☐	☐	☐	☐	☐	☐
(28) ECMO	☐	☐	☐	☐	☐	☐
(29) Ventilator management	☐	☐	☐	☐	☐	☐
(30) Shock	☐	☐	☐	☐	☐	☐
(31) Intraventricular hemorrhage	☐	☐	☐	☐	☐	☐
(32) Sepsis	☐	☐	☐	☐	☐	☐
(33) Severe traumatic brain injury	☐	☐	☐	☐	☐	☐
(34) Patient transport	☐	☐	☐	☐	☐	☐
(35) Obtain mixed venous saturations (SvO2)	☐	☐	☐	☐	☐	☐

How frequently do you use capnography and/or NICO (Non-Invasive Cardiac Output) monitors in:

	Always	Often	Sometimes	Rarely	Never	N/A
(36) Post-operative cardiac management	☐	☐	☐	☐	☐	☐
(37) PRE-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(38) POST-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(39) Cardiopulmonary resuscitation	☐	☐	☐	☐	☐	☐
(40) ECMO	☐	☐	☐	☐	☐	☐
(41) Ventilator management	☐	☐	☐	☐	☐	☐
(42) Shock	☐	☐	☐	☐	☐	☐
(43) Sepsis	☐	☐	☐	☐	☐	☐
(44) Severe traumatic brain injury	☐	☐	☐	☐	☐	☐
(45) Intraventricular hemorrhage	☐	☐	☐	☐	☐	☐
(46) Patient transport	☐	☐	☐	☐	☐	☐

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How frequently do you use PiCCO (Pulse index Continuous Cardiac Output) monitors in:

	Always	Often	Sometimes	Rarely	Never	N/A
(47) Post-operative cardiac management	☐	☐	☐	☐	☐	☐
(48) PRE-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(49) POST-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(50) Cardiopulmonary resuscitation	☐	☐	☐	☐	☐	☐
(51) ECMO	☐	☐	☐	☐	☐	☐
(52) Ventilator management	☐	☐	☐	☐	☐	☐
(53) Shock	☐	☐	☐	☐	☐	☐
(54) Sepsis	☐	☐	☐	☐	☐	☐
(55) Severe traumatic brain injury	☐	☐	☐	☐	☐	☐
(56) Intraventricular hemorrhage	☐	☐	☐	☐	☐	☐
(57) Patient transport	☐	☐	☐	☐	☐	☐

How frequently do you use Bispectral index (BIS) in:

	Always	Often	Sometimes	Rarely	Never	N/A
(58) Post-operative cardiac management	☐	☐	☐	☐	☐	☐
(59) PRE-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(60) POST-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(61) Cardiopulmonary resuscitation	☐	☐	☐	☐	☐	☐
(62) ECMO	☐	☐	☐	☐	☐	☐
(63) Ventilator management	☐	☐	☐	☐	☐	☐
(64) Shock	☐	☐	☐	☐	☐	☐
(65) Sepsis	☐	☐	☐	☐	☐	☐
(66) Severe traumatic brain injury	☐	☐	☐	☐	☐	☐
(67) Intraventricular hemorrhage	☐	☐	☐	☐	☐	☐
(68) Patient transport	☐	☐	☐	☐	☐	☐

Near Infrared Spectroscopy (NIRS)

- (69) Are you familiar with near infrared spectroscopy (NIRS)?
- ☐ Not familiar
☐ Somewhat familiar
☐ Mostly familiar
☐ Very familiar
- (70) Do you use NIRS in any of your ICUs ?
- ☐ Yes
☐ No

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How frequently do you use NIRS in:

	Always	Often	Sometimes	Rarely	Never	N/A
(71) Post operative cardiac management	☐	☐	☐	☐	☐	☐
(72) PRE-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(73) POST-operative single ventricle patients	☐	☐	☐	☐	☐	☐
(74) Cardiopulmonary resuscitation	☐	☐	☐	☐	☐	☐
(75) ECMO	☐	☐	☐	☐	☐	☐
(76) Feeding tolerance	☐	☐	☐	☐	☐	☐
(77) Necrotizing enterocolitis	☐	☐	☐	☐	☐	☐
(78) Ventilator management	☐	☐	☐	☐	☐	☐
(79) Patients on non-invasive ventilation (CPAP, BiPAP, High flow)	☐	☐	☐	☐	☐	☐
(80) Shock	☐	☐	☐	☐	☐	☐
(81) Sepsis	☐	☐	☐	☐	☐	☐
(82) Severe traumatic brain injury	☐	☐	☐	☐	☐	☐
(83) Intraventricular hemorrhage	☐	☐	☐	☐	☐	☐
(84) Patient Transport	☐	☐	☐	☐	☐	☐
(85) Procedures	☐	☐	☐	☐	☐	☐

How many NIRS do you have in your ICUs?

	One device per bed	Less than one device per bed	Don't have NIRS	N/A
(86) PICU	☐	☐	☐	☐
(87) PCICU	☐	☐	☐	☐
(88) Mixed unit	☐	☐	☐	☐

If you use NIRS frequently (always, often or sometimes), do you think:

	Strongly agree	Agree	Disagree	Strongly disagreed
(89) NIRS decreases the frequency of mixed venous saturation sampling	☐	☐	☐	☐
(90) NIRS decreases the frequency of arterial blood gas sampling	☐	☐	☐	☐
(91) NIRS is easy to use	☐	☐	☐	☐
(92) NIRS improves outcomes	☐	☐	☐	☐
(93) Expense of NIRS outweighs benefit	☐	☐	☐	☐
(94) NIRS changes / directs management	☐	☐	☐	☐

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- (95) If you don't use NIRS in your PICU, why not?
- ☐ Insufficient resources
☐ Don't believe in it
☐ Unfamiliar with technology
☐ Others
- (96) Are you interested in learning more about NIRS?
- ☐ Yes
☐ No
- (97) If you are interested in learning more about NIRS do you prefer:
- ☐ Online reading materials
☐ Live lectures
☐ Others
- (98) In what subspecialty did you train? (check all that apply)
- ☐ Pediatric Critical Care
☐ Pediatric Cardiology
☐ Pediatric Anesthesia
☐ Pediatric Pulmonology
☐ Neonatology
- (99) How many total beds do you have in your PCICU? _____
- (100) How many total beds do you have in your PICU? _____
- (101) If you have one mixed unit, how many total beds do you have in your ICU? _____
- (102) How many total PCCM faculty do you have in your program? _____
- (103) How many total PCCM fellows do you have in your program? _____