The Utilization of Critical Care Resources in Pediatric Neurocritical Care Patients

Ryan L. DeSanti, DO[1]
Binod Balakrishnan, MD[2]
Tom B. Rice, MD[2]
Jose A. Pineda, MD[3]
Peter A. Ferrazzano, MD[4]

OBJECTIVES: To define the prevalence of neurologic diagnoses and evaluate the utilization of critical care and neurocritical care (NCC) resources among children admitted to the PICU.

DESIGN: Retrospective cohort analysis.

SETTING: Data submitted to the Virtual Pediatric Systems (VPS) database.

PATIENTS: All children entered in VPS during 2016 (January 1, 2016, to December 31, 2016).

INTERVENTIONS: None.

MEASUREMENTS AND MAIN RESULTS: There were 128,688 patients entered into VPS and were comprised of 24.3% NCC admissions and 75.7% general PICU admissions. The NCC cohort was older, represented more scheduled admissions, and was more frequently admitted from the operating room. The NCC cohort also experienced a greater decline in prehospitalization to posthospitalization functional status and required more frequent use of endotracheal intubation, arterial lines, and foley catheters but had an overall shorter duration of PICU and hospital length of stay with a higher mortality rate. One thousand seven hundred fifteen patients at 12 participating institutions were entered into a novel, pilot NCC module evaluating sources of secondary neurologic injury. Four hundred forty-eight patients were manually excluded by the data entrant, leaving 1,267 patients in the module. Of the patients in the module, 75.8% of patients had a NCC diagnosis as their primary diagnosis; they experienced a high prevalence of pathophysiologic events associated with secondary neurologic insult (ranging from hyperglycemia at 10.5% to hyperthermia at 36.8%).

CONCLUSIONS: In children admitted to a VPS-contributing PICU, a diagnosis of acute neurologic disease was associated with greater use of resources. We have identified the most common etiologies of acute neurologic disease in the 2016 VPS cohort, and such admissions were associated with significant decrease in functional status, as well as an increase in mortality.

KEY WORDS: epidemiology; outcomes; pediatric intensive care; pediatric neurocritical care

Children with acute neurologic disease represent 10–20% of pediatric critical care admissions (1–3). These children require significant hospital resources including the frequent need for mechanical ventilation, gastrostomy tube placement, cerebral spinal fluid (CSF) diversion, and ongoing rehabilitation that leads to a higher cost and prolonged hospital stay (2–5). In addition, such children are at increased risk of morbidity and mortality (2, 5–7).

Given the burden of pediatric neurologic critical illness, there is increasing interest in providing specialized care for these children but neurocritical care (NCC) research to identify and implement best clinical practices remains sparse (8). Most treatment recommendations and clinical protocols are based

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RESEARCH IN CONTEXT

- Children with neurologic disease represent a large proportion of pediatric critical care admissions.
- Given the burden of pediatric neurologic critical illness, there is increasing interest in providing specialized care but benchmarking and research identifying best clinical practices remain sparse.
- Little is known about neurocritical care (NCC) clinical practice across institutions that care for these patients.

on level II evidence or expert consensus (8–13). Since little is known about the practice of critical care for children with primary neurologic disease, we aimed to use a large multi-institutional PICU database (Virtual Pediatric Systems [VPS]) to better define the prevalence of neurologic diagnoses and the utilization of critical care and NCC resources among children admitted to the PICU to help inform research, quality improvement and process improvement (QI/PI) priorities. As a secondary aim, we analyzed data from a pilot NCC module (NCC[m]) built within the VPS database during the study period to capture higher granularity patient data, including high-risk physiologic derangements associated with secondary neurologic injury.

METHODS

In this retrospective cohort analysis, we analyzed data submitted to VPS during 2016 (patient discharge date January 1, 2016, to December 31, 2016). VPS is an online database that uses standardized clinical definitions, data quality control, and data analysis through the collection of prospective observational data of PICU admissions from 135 hospitals (123 hospitals during the study period) (14). Data validation is performed by both individual sites and VPS with an interrater reliability of greater than 95% (14).

Study Comparisons

Patients were grouped into a general PICU cohort and a NCC cohort using the institution supplied primary diagnosis (**Supplemental Table 1**, http://links.lww.com/PCC/C94). Data used for our assessment included: patient demographics at admission and discharge, as well as critical care and NCC resource utilization. General critical care resources included: mechanical ventilation (invasive and noninvasive); establishment of an invasive feeding tube; use of a foley catheter, arterial line, central venous line (including peripherally inserted central catheters), and extracorporeal therapies (renal replacement, plasmapheresis, and extracorporeal membrane oxygenation); and need for cardiopulmonary resuscitation. NCC resources included: seizure monitoring (one time electroencephalogram, continuous electroencephalogram, and seizure mapping); imaging (CT and MRI) (body part imaged is not differentiated within VPS); neuroprotective therapies (therapeutic hypothermia and pentobarbital coma); intracranial pressure (ICP) monitoring; and neurosurgical interventions (CSF sampling, CSF diversion, intrathecal device placement, and relevant operating room [OR] procedures including endovascular procedures).

Secondary diagnoses included all nonprimary diagnoses (most frequent are reported). Preadmission and discharge functional status were quantified using the Pediatric Overall Performance Category (POPC) and Pediatric Cerebral Performance Category (15). Both are optional data fields in VPS and are reported only for patients with documented scores. Illness severity was assessed using both Pediatric Index of Mortality-3 (PIM-3) and Pediatric Risk of Mortality-3 (PRISM-3) (16, 17). PIM-3 is a mandatory data field, while PRISM-3 is optional (units that collect optional data fields collect that data for all patients) and are reported only for patients with collected data. PICU length of stay (LOS) was determined from the reported physical LOS (collected in hours and converted to days for reporting) and mortality from the hospital outcome. Standardized mortality rate and LOS were determined by taking the actual mortality rate or LOS and dividing by the PIM-3 and/or PRISM-3 predicted mortality or LOS, respectively.

Neurologic diagnoses were grouped into nine categories—traumatic brain injury (TBI), seizure/status epilepticus, infectious, ischemic encephalopathy, vascular/stroke, oncologic, inflammatory/neuromuscular, neurosurgical, and other neurologic disorders (Supplemental Table 1, http://links.lww.com/PCC/

C94). Remote neurologic injury; neurologic injury sustained during the hospitalization; and neurologic diseases or injury not considered the primary cause of admission were not included in this portion of the study. Subanalysis was completed separately evaluating unscheduled and scheduled admissions as these may have different risk profiles and hospital needs.

Outcomes

The prevalence of primary neurologic diagnoses, admission characteristics, and discharge characteristics were the primary study outcomes. Secondary outcomes included the utilization of critical care and NCC resources, and the frequency of physiologic derangements associated with secondary neurologic injury among patients in the NCC module.

NCC Module

The NCC module was a voluntary research module within VPS that was piloted during 2016, our period of retrospective study (14). The module was developed to provide actionable, comparative data for the purposes of identifying best practices and benchmarking to advance the quality of services provided to critically ill children with acute neurologic disorders and injuries, and focused on collection of data markers of conditions associated with secondary neurologic injury (14). Twelve sites participated, comprising 14 unique PICUs (two sites had more than one PICU), with data analyzed separately as a convenience sample. Patients admitted with a primary or nonprimary neurologic diagnosis, defined by one of 65 predefined NCC diagnoses (Supplemental Table 1, http://links.lww.com/PCC/C94) were eligible for inclusion in the module, which automatically opened when a patient had a discharge date January 1, 2016, to December 31, 2016, and a diagnosis from the inclusion list. NCC patients in the module are differentiated from patients in the entire VPS cohort by designating NCC(m).

Collected module data included prehospital management (medication and fluid administration), emergency department management (medication, fluid, and blood product administration), PICU management (fluid and blood product administration), Pediatric Intensity Level of Therapy (PILOT) score, and pathophysiologic variables associated with secondary neurologic injury including the presence of hypoxia, clinical and/or electrographic seizures, hypothermia and/or hyperthermia, hypoglycemia and/or hyperglycemia, intracranial hypertension, and low cerebral perfusion pressure (CPP). The type/volume of fluids and blood products administered, net fluid balance, PILOT score, presence/absence of ICP monitor, lowest tissue oxygen saturation, and highest/lowest temperature, sodium, glucose, ICP, and CPP were recorded in the module dataset. Medications administered in the PICU were not collected.

The PILOT score is a 38-point scale developed to quantify daily ICP-directed therapeutic effort in pediatric TBI with higher scores representing more intense therapy (18); PILOT scores were collected only for TBI patients and the use of individual therapies are reported (yes/no). The highest/lowest sodium and glucose are reported only for neurotrauma patients as published guidelines with recommendations for management existed at the time of module development.

Statistical Analysis

Descriptive statistics are presented as medians with interquartile range (IQR) or means with SD. Comparison between individual categorical variables was done using two-sample test for equality of proportions with continuity correction. The Wilcoxon rank-sum test with continuity correction was used to compare the medians and the Welch two-sample *t* test was used to compare the means of continuous variables. All *p* values were two-sided with significance set at *p* value of less than 0.05 and correction of *p* values for multiple comparisons using Bonferroni correction ($\alpha/[n]$ variables); exact *p* values are presented (the lowest *p* value the statistical software reports is $< 2.2 \times 10^{-16}$). R Version 3.6.3 (R Foundation for Statistical Computing, Vienna, Austria) was used to analyze the data. The University of Wisconsin-Madison institutional review board (IRB) approved the study with waiver of consent given use of de-identified data (IRB 2019-1130; approved November 11, 2019); data are reported using Strengthening the Reporting of Observational Studies in Epidemiology guidelines (19).

RESULTS

There were 128,688 patients entered into VPS during 2016 and were comprised of 24.3% NCC admissions and 75.7% general PICU (non-NCC) admissions (**Supplemental Fig. 1**, http://links.lww.com/PCC/C94). From the 12

NCC(m) participating sites, 1,715 patients of 5,716 (30.0%) with a NCC(m) eligible diagnosis had data entered; 448 (26.1%) were manually excluded by the site data entrant, leaving 1,267 (73.9%) patients in the module (**Supplemental Fig. 2**, http://links.lww.com/PCC/C94). Among NCC(m) patients, 961 (75.8%) had a NCC diagnosis as their primary diagnosis, while 306 (24.2%) had a non-NCC diagnosis as their primary diagnosis (the NCC qualify diagnosis was a secondary diagnosis) (**Supplemental Table 2**, http://links.lww.com/PCC/C94). Characteristics of module participating sites are detailed in **Supplemental Table 3** (http://links.lww.com/PCC/C94).

Entire VPS Dataset

The admission diagnoses of all children entered into VPS and of children with a primary NCC admission diagnosis are shown (**Supplemental Table 4**, http://links.lww.com/PCC/C94). Respiratory diseases (30.8%), neurologic diseases (24.3%), cardiovascular diseases (10.7%), and injuries/poisonings (7.3%) were the most common admission diagnoses among all patients, while seizure disorders (24.0%), TBI (15.9%), neurosurgical disorders (13.7%), and spinal cord anomalies (10.6%) were the most common NCC admission diagnoses. Admission and discharge characteristics of the two groups are shown in **Table 1** (additional characteristics in **Supplemental Table 5**, http://links.lww.com/PCC/C94). A primary neurologic diagnosis was associated with being older (52.5% vs 43.3% ≥ 6 yr old; difference, 9.2%; 95% CI, 8.50–9.78%; $p < 2.2 \times 10^{-16}$), having a scheduled PICU admission (33.1% vs 21.2%; difference, 11.9%; 95% CI, 11.3–12.5%; $p < 2.2 \times 10^{-16}$), and being more frequently admitted from the OR or postanesthesia care unit (37.5% vs 23.4%; difference, 14.2%; 95% CI, 13.5–14.8%; $p < 2.2 \times 10^{-16}$). They also had a shorter PICU and hospital LOS while exhibiting worse functional outcomes (mean discharge POPC change from baseline, –0.39 [SD, 1.01] vs –0.17 [SD, 0.63]), difference 0.22 (95% CI, 0.20–0.24; $p < 2.2 \times 10^{-16}$); increase to greater than moderate disability (4.5% vs 1.0%; difference, 3.5%; 95% CI, 3.1–4.0%; $p < 2.2 \times 10^{-16}$) and higher mortality (4.1% vs 2.6%; difference, 1.5% (95% CI, 1.2–1.7%; $p < 2.2 \times 10^{-16}$); and PIM-3 standardized mortality rate 5.94 (IQR, 4.10–27.33 vs 3.66 [IQR], 2.18–10.83; $p < 2.2 \times 10^{-16}$). Utilization of critical care and NCC resources in the cohorts is shown in **Table 2**.

Patients with a primary neurologic diagnosis were more likely to undergo endotracheal intubation (28.5% vs 25.8%; difference, 2.6%; 95% CI, 2.1–3.3%; $p < 2.2 \times 10^{-16}$), arterial line placement (36.4% vs 21.1%; difference, 15.3%; 95% CI, 14.7–15.9%; $p < 2.2 \times 10^{-16}$), and foley catheter placement (51.8% vs 32.0%; difference, 19.8%; 95% CI, 19.0–20.5%; $p < 2.2 \times 10^{-16}$) but less likely to have a central venous line placed (25.9% vs 36.0%; difference, 10.2%; 95% CI, 9.6–10.7%; $p < 2.2 \times 10^{-16}$). Patients with a primary neurologic disorder also underwent more CT (60.6% vs 15.1%; difference, 45.5%; 95% CI, 44.2–46.8%; $p < 2.2 \times 10^{-16}$) and MRI (49.4% vs 7.0%; difference, 42.3%; 95% CI, 41.1–43.6%; $p < 2.2 \times 10^{-16}$) imaging (Table 2). Results of subgroup analysis separating unscheduled admissions from scheduled admissions were no different; however, unscheduled admissions exhibited higher resource utilization, morbidity, and mortality than scheduled admissions (**Table 3**; and **Supplemental Table 6**, http://links.lww.com/PCC/C94).

Neurocritical Care Module

Seizure disorders (52.0%), TBI (17.4%), neurosurgical disorders (15.7%), and ischemic encephalopathy (12.8%) were the most common primary diagnoses of patients entered in the NCC(m) (**Table 4**). The admission diagnoses included these and also respiratory tract diseases (5.4%) and sepsis (3.0%) (Supplemental Table 2, http://links.lww.com/PCC/C94). Of the 1,267 patients entered in the module, 1,261 had data identifying physiologic derangements associated with secondary neurologic injury (**Table 5**). Events associated with secondary neurologic injury were common and ranged from hyperglycemia (glucose > 200 mg/dL) occurring in 10.5% of patients with neurotrauma to hyperthermia (temperature > 38°C) occurring in 38.6% of patients without neurotrauma. Among patients with an ICP monitor (3.2%), intracranial hypertension (ICP > 20 mm Hg) or low CPP (< 40 mm Hg) occurred commonly (69.2% and 52.0%, respectively). PILOT score data, fluid and blood product administration are presented (**Supplemental Tables 7** and **8**, http://links.lww.com/PCC/C94). Given the low rate of eligible patients entered in the module (30%), we compared patients entered into the module with patients who were eligible (based on their diagnoses) but not entered (**Supplemental Table 9**, http://links.lww.com/PCC/C94) and found a clinically insignificant difference in PICU LOS and hospital LOS and similar mortality.

TABLE 1.
Admission and Discharge Characteristics of the PICU and Neurocritical Care Cohorts in the Virtual Pediatric Systems 2016 Database

Study Variables	PICU Cohort, *n* = 97,462	Neurocritical Care Cohort, *n* = 31,226	*p*[a]
Admission characteristics			
Sex, *n* (%)[b]			
Male	53,609 (55.0)	17,264 (55.3)	0.3865
Age, *n* (%)			
< 1 mo	4,289 (4.4)	476 (1.5)	**$< 2.2 \times 10^{-16}$**
1–24 mo	32,218 (33.1)	8,147 (26.1)	**$< 2.2 \times 10^{-16}$**
2–5 yr	18,743 (19.2)	6,223 (19.9)	0.006902
6–11 yr	16,275 (16.7)	6,641 (21.3)	**$< 2.2 \times 10^{-16}$**
12–18 yr	21,922 (22.5)	8,530 (27.3)	**$< 2.2 \times 10^{-16}$**
> 18 yr	4,015 (4.1)	1,209 (3.9)	0.05558
Scheduled admission, *n* (%)			
Yes	20,621 (21.2)	10,322 (33.1)	**$< 2.2 \times 10^{-16}$**
No	76,841 (78.8)	20,904 (66.9)	**$< 2.2 \times 10^{-16}$**
Patient origin, *n* (%)[b]			
ED	33,131 (34.0)	10,239 (32.8)	**9.25×10^{-5}**
Floor	17,434 (17.9)	2,851 (9.1)	**$< 2.2 \times 10^{-16}$**
Operating room/post-anesthesia care unit	22,796 (23.4)	11,723 (37.5)	**$< 2.2 \times 10^{-16}$**
Outside hospital ED	16,530 (17.0)	4,920 (15.8)	**7.02×10^{-7}**
Home/outpatient facility	2,978 (3.1)	574 (1.8)	**$< 2.2 \times 10^{-16}$**
Discharge characteristics			
PICU LOS, d, median (IQR)	1.79 (0.93–3.97)	1.41 (0.89–2.94)	**$< 2.2 \times 10^{-16}$**
Standardized LOS ratio[e], median (IQR)	0.65 (0.36–1.25)	0.71 (0.40–1.43)	**$< 2.2 \times 10^{-16}$**
Hospital LOS, d, median (IQR)	4.41 (2.09–10.58)	4.00 (2.09–8.66)	**$< 2.2 \times 10^{-16}$**
Mortality, *n* (%)[d]	2,508/96,067 (2.6)	1,259/31,002 (4.1)	**$< 2.2 \times 10^{-16}$**
Death by neurologic criteria, *n* (%)[c,d]	174/919 (18.9)	439/734 (59.8)	**$< 2.2 \times 10^{-16}$**
Withdrawal of support, *n* (%)[c,d]	871/1,370 (63.6)	478/579 (82.6)	**$< 2.2 \times 10^{-16}$**
Pediatric Index of Mortality-3 SMR, median (IQR)[e]	3.66 (2.18–10.83)	5.94 (4.10–27.33)	**$< 2.2 \times 10^{-16}$**
Pediatric Risk of Mortality-3 SMR, median (IQR)[c,e]	5.73 (3.02–8.78)	13.85 (6.53–22.00)	**$< 2.2 \times 10^{-16}$**
PICU disposition, *n* (%)[b]			
Floor/another unit in the hospital	70,825 (72.7)	23,021 (73.7)	**0.0003649**
Home	21,815 (22.4)	6,429 (20.6)	**2.75×10^{-11}**
Care facility	1,610 (1.7)	296 (0.9)	**$< 2.2 \times 10^{-16}$**

ED = emergency department, IQR = interquartile range, LOS = length of stay, SMR = standardized mortality ratio.

[a]Corrected $p < 0.0021$ statistically significant (bold) after adjustment for multiple comparisons.

[b]Other/unspecified in Supplemental Table 5 (http://links.lww.com/PCC/C94).

[c]Optional Virtual Pediatric Systems data field (units that collect these data category collect it for all patients).

[d]Number of patients collected is not equal to the entire cohort, reported as: number with outcome/number with outcome recorded (%) (the outcome reported for "death by neurologic criteria" and "withdrawal of support" is mortality; categories are not mutually exclusive and reflect the percentage of deaths in subjects with this additional information provided).

[e]Calculated as: observed LOS or mortality/predicted LOS or mortality.

TABLE 2.
Critical Care Resources Used by the PICU and Neurocritical Care Cohorts in the Virtual Pediatric Systems 2016 Database

Study Variables	PICU Cohort	Neurocritical Care Cohort	*p*[a]
General critical care resources			
Mechanical ventilation			
Noninvasive (high-flow nasal cannula, continuous positive airway pressure, bilevel positive airway pressure ventilation)[b,c], *n* (%)	38,883/72,173 (53.9)	3,324/22,841 (14.6)	**$< 2.2 \times 10^{-16}$**
Endotracheal intubation, *n* (%)	25,158/97,462 (25.8)	8,899/31,226 (28.5)	**$< 2.2 \times 10^{-16}$**
Invasive mechanical ventilation, *n* (%)	31,360/97,462 (32.2)	9,536/31,226 (30.5)	**6.56×10^{-8}**
Ventilator days, median (IQR)	2.16 (0.70–5.81)	1.13 (0.39–3.81)	**$< 2.2 \times 10^{-16}$**
New tracheostomy[b,c], *n* (%)	670/44,747 (1.5)	174/14,854 (1.2)	0.004069
Feeding tube, *n* (%)			
New gastrostomy tube[b,c]	600/46,636 (1.3)	130/15,082 (0.9)	**3.33×10^{-5}**
New jejunostomy tube[b,c]	91/46,636 (0.2)	3/15,082 (0.0)	**2.91×10^{-6}**
Foley catheter[b,c], *n* (%)	20,306/63,417 (32.0)	10,872/20,997 (51.8)	**$< 2.2 \times 10^{-16}$**
Foley catheter days, median (IQR)	1.42 (0.79–3.02)	0.96 (0.65–1.97)	**$< 2.2 \times 10^{-16}$**
Arterial line, *n* (%)	20,600/97,462 (21.1)	11,376/31,226 (36.4)	**$< 2.2 \times 10^{-16}$**
Arterial line days, median (IQR)	2.01 (0.92–5.05)	0.89 (0.69–1.94)	**$< 2.2 \times 10^{-16}$**
Central venous line, *n* (%)	35,132/97,462 (36.0)	8,081/31,226 (25.9)	**$< 2.2 \times 10^{-16}$**
Central venous line days, median (IQR)	3.88 (1.71–8.41)	3.23 (1.45–7.23)	**$< 2.2 \times 10^{-16}$**
Renal replacement therapy[b,c], *n* (%)	2,579/69,512 (3.7)	255/22,470 (1.1)	**$< 2.2 \times 10^{-16}$**
Plasmapheresis[b,c], *n* (%)	569/45,331 (1.3)	335/14,727 (2.3)	**$< 2.2 \times 10^{-16}$**
Cardiopulmonary resuscitation[b,c], *n* (%)	1,159/60,839 (1.9)	226/18,679 (1.2)	**2.61×10^{-10}**
Extracorporeal membrane oxygenation, *n* (%)	823/97,462 (0.8)	64/31,226 (0.2)	**$< 2.2 \times 10^{-16}$**
Neurocritical care-specific resources			
Neurologic monitoring[b,c], *n* (%)			
Seizure mapping	2/49,973 (0.0)	120/16,726 (0.7)	**$< 2.2 \times 10^{-16}$**
Electroencephalogram, one time	742/39,647 (1.9)	1,314/12,826 (10.2)	**$< 2.2 \times 10^{-16}$**
Continuous electroencephalogram	1,004/39,647 (2.5)	1,924/12,826 (15.0)	**$< 2.2 \times 10^{-16}$**
CT scan	3,151/20,819 (15.1)	3,891/6,419 (60.6)	**$< 2.2 \times 10^{-16}$**
MRI	1,465/20,819 (7.0)	3,170/6,419 (49.4)	**$< 2.2 \times 10^{-16}$**
Intracranial pressure monitoring	407/61,119 (0.7)	2,394/20,368 (11.8)	**$< 2.2 \times 10^{-16}$**
Neuroprotective therapies[b,c], *n* (%)			
Therapeutic hypothermia	55/33,314 (0.2)	69/11,102 (0.6)	**6.7×10^{-15}**
Pentobarbital coma	13/33,314 (0.0)	77/11,102 (0.7)	**$< 2.2 \times 10^{-16}$**
Neurosurgical interventions[b,c], *n* (%)			
New cerebral spinal fluid diversion (ventriculoperitoneal/ventriculoatrial shunt)	143/49,973 (0.3)	1,131/16,726 (6.8)	**$< 2.2 \times 10^{-16}$**
New intrathecal device	413/49,973 (0.8)	223/16,726 (1.3)	**6.96×10^{-9}**
Spinal fluid sampling–lumbar puncture, shunt tap, etc.	971/42,887 (2.3)	941/14,118 (6.7)	**$< 2.2 \times 10^{-16}$**
Neurosurgical intervention	1,532/49,973 (3.1)	8,131/16,726 (48.6)	**$< 2.2 \times 10^{-16}$**
Neuroendovascular intervention	20/34,648 (0.1)	104/11,336 (0.9)	**$< 2.2 \times 10^{-16}$**

IQR = interquartile range.

[a]Corrected $p < 0.0017$ statistically significant (bold) after adjustment for multiple comparisons.

[b]Optional Virtual Pediatric Systems data field (units that collect these data category collect it for all patients).

[c]Number of patients collected is not equal to the entire cohort; reported: number with procedure/number with procedure recorded (%).

WHAT THIS STUDY ADDS

- In the 2016 Virtual Pediatric Systems (VPS) PICU cohort, children with a primary neurologic diagnosis compared with those without, were older, represented more scheduled admissions, and were more frequently admitted from the operating room; they also had a shorter PICU and hospital length of stay but higher mortality.
- Among patients entered in a VPS NCC pilot module, physiologic events associated with secondary neurologic injury were common. These ranged from hyperglycemia occurring in 10.5% of patients with neurotrauma to hyperthermia occurring in 38.6% of patients without neurotrauma.
- NCC clinical practice will benefit from high granularity multicenter data.

DISCUSSION

Children with primary neurologic disease require substantially more resources than children without neurologic disease (5). Similar to others, we have identified the most common etiologies of primary neurologic disease requiring admission to the PICU (1, 2, 5). We have also found that such admissions, when compared with those without neurologic disease, are associated with both an increase in mortality and a decrease in functional status among survivors. The 2016 VPS dataset has identified more children with neurologic disease cared for in the PICU than other published reports and a lower mortality rate (2, 3), likely a reflection of differences in sampling/inclusion criteria (i.e., high number of scheduled admissions, postoperative patients, and inclusion of spinal cord anomalies, congenital brain malformations, and other less commonly classified neurologic diseases [syncope, headache, pseudotumor cerebri, autonomic disorders, and other/unclassified changes in mental status and CNS conditions]). These differences were less pronounced when examining only unscheduled patient admissions. Among a convenience sample of NCC(m) participating institutions, we identified a high frequency of pathophysiologic events associated with secondary neurologic injury.

The growth of pediatric NCC as a subspecialty is increasingly recognized as providing disease-specific benefit by focusing specialized care on high-risk patients (20). NCC services have primarily focused on providing this care to children with TBI, spinal cord injury, stroke, cardiopulmonary arrest, status epilepticus, CNS infections, and tumors (20). There is evidence that such services improve care and outcomes in pediatric TBI by optimizing timely delivery of value-added care through improvements in communication, education, and QI/PI initiatives (20–23). However, the current pediatric NCC focus has not included a significant proportion of patients who could potentially benefit from this specialized care. Neurosurgical disorders and spinal cord anomalies are two of the top four most common admission diagnoses in the VPS database, together accounting for 24.3% of NCC admissions. Future NCC research, QI/PI initiatives, and care protocols may consider focusing on these unique populations.

Likewise, given the high proportion of NCC patients managed with invasive technology for a short period of time, clinicians may consider ways to mitigate unnecessary utilization of these invasive devices. Although, given the fact that almost one-half of the study population underwent neurosurgical intervention, it is probable that many of these devices were used during the perioperative period and thus have little ability for their use to be further limited. Finally, given the high occurrence rate of potentially avoidable physiologic derangements associated with secondary neurologic injury reported in the NCC(m) patients, NCC QI/PI initiatives to reduce these insults may decrease the risk of worse neurologic outcomes and provide value-added care for patients.

There are several limitations related to use of retrospective database studies. Although utilization of the VPS data-enabled broad, population-level analyses, we sacrificed inclusion of highly granular clinical data. We chose to group patients by their primary diagnosis but it is possible that acute neurologic diagnoses were not included in the NCC cohort; however, given the low utilization of NCC resources and low number of secondary neurologic diagnoses in the general PICU cohort, we believe this was limited. Documentation bias may play a role in the accuracy of database entered data, in particular, there was a large amount of optional data not entered, and the accuracy

TABLE 3.
Characteristics of Unscheduled Patient Admissions

Study Variables	PICU Cohort, *n* = 76,841	Neurocritical Care Cohort, *n* = 20,904	*p*[a]
Admission characteristics			
Male sex, *n* (%)	42,288 (55.0)	11,976 (57.3)	**6.055×10^{-9}**
Age, *n* (%)			
< 1 mo	3,200 (4.2)	453 (2.2)	**$< 2.2 \times 10^{-16}$**
1–24 mo	25,028 (32.6)	5,770 (27.6)	**$< 2.2 \times 10^{-16}$**
2–5 yr	14,357 (18.7)	4,714 (22.6)	**$< 2.2 \times 10^{-16}$**
6–11 yr	12,927 (16.8)	4,418 (21.1)	**$< 2.2 \times 10^{-16}$**
12–18 yr	18,428 (24.0)	4,914 (23.5)	0.1563
> 18 yr	2,901 (3.8)	635 (3.0)	**4.58×10^{-7}**
Patient origin, *n* (%)			
Emergency department	33,053 (43.0)	10,204 (48.8)	**$< 2.2 \times 10^{-16}$**
Floor	16,671 (21.7)	2,761 (13.2)	**$< 2.2 \times 10^{-16}$**
Operating room/post-anesthesia care unit	5,383 (7.0)	2,026 (9.7)	**$< 2.2 \times 10^{-16}$**
Outside hospital	19,936 (25.9)	5,546 (26.5)	0.08853
Discharge characteristics			
PICU LOS, d, median (IQR)	1.80 (0.92–4.00)	1.61 (0.86–3.58)	**$< 2.2 \times 10^{-16}$**
Hospital LOS, d, median (IQR)	4.41 (2.14–10.46)	3.69 (1.78–9.98)	**$< 2.2 \times 10^{-16}$**
Mortality, *n* (%)[c]	2,195/76,034 (2.9)	1,216/20,807 (5.8)	**$< 2.2 \times 10^{-16}$**
PICU disposition, *n* (%)			
Floor/another unit in hospital	57,800 (75.2)	14,492 (69.3)	**$< 2.2 \times 10^{-16}$**
Home	14,779 (19.2)	4,744 (22.7)	**$< 2.2 \times 10^{-16}$**
Care facility	1,475 (1.9)	248 (1.2)	**1.138×10^{-12}**
Critical care resource utilization			
General PICU resources[c], *n* (%)			
Endotracheal intubation	17,268/76,841 (22.4)	7,692/20,904 (36.8)	**$< 2.2 \times 10^{-16}$**
Invasive mechanical ventilation	22,524/76,841 (29.3)	8,129/20,904 (33.9)	**$< 2.2 \times 10^{-16}$**
Arterial line	10,156/76,841 (13.2)	4,441/20,904 (21.2)	**$< 2.2 \times 10^{-16}$**
Central line	23,647/76,841 (30.8)	6,166/20,904 (29.5)	**0.0003887**
Foley catheter[b,c]	12,120/49,982 (24.2)	5,517/14,393 (38.3)	**$< 2.2 \times 10^{-16}$**
Neurocritical care resources[b,c], *n* (%)			
Electroencephalogram, one time	691/31,349 (2.0)	1,276/8,632 (14.8)	**$< 2.2 \times 10^{16}$**
Continuous electroencephalogram	904/31,349 (2.9)	1,787/8,632 (20.7)	**$< 2.2 \times 10^{-16}$**
CT scan	2,799/16,574 (16.9)	3,535/4,423 (79.9)	**$< 2.2 \times 10^{-16}$**
MRI	1,239/16,574 (7.5)	2,723/4,423 (61.6)	**$< 2.2 \times 10^{-16}$**
Intracranial pressure monitoring	302/47,569 (0.6)	1,757/13,824 (12.7)	**$< 2.2 \times 10^{-16}$**

IQR = interquartile range, LOS = length of stay.

[a]Corrected $p < 0.0019$ statistically significant (bold) after adjustment for multiple comparisons.

[b]Optional Virtual Pediatric Systems data field (units that collect these data category collect it for all patients).

[c]Number of patients collected is not equal to the entire cohort, reported as: number with outcome/number with outcome recorded (%).

TABLE 4.
Module Qualifying Diagnoses of 1,267 Patients Enrolled in Neurocritical Care Module

Study Variables	No. of Diagnoses (%[a]), *n* = 2,228
Seizure disorders	820 (52.0)
Traumatic brain injuries	330 (17.4)
Neurosurgical disorders	222 (15.7)
Ischemic encephalopathy	221 (12.8)
Other neurologic disorders	191 (14.4)
Stroke/vascular diseases	183 (13.2)
Neuro-oncologic diseases	141 (10.3)
Infectious neurologic diseases	109 (8.0)
Inflammatory/neuromuscular disorders	11 (0.8)

[a]Percent of patients with each diagnosis; mean 1.8 qualifying diagnoses per patient.

of the study data are reliant upon accurate data entry. Data were from a single year, which corresponded to the pilot of the NCC(m) but disease epidemiology may fluctuate year to year. Finally, a low proportion of patients eligible for the NCC(m) were included. This may reflect the burden posed by the more granular data entry. Prospective testing of the NCC(m) will likely identify opportunities to optimize high granularity data collection.

The NCC(m) was designed to provide comparative data for the purposes of identifying best practices and benchmarking for high-risk patients (14); it was designed to capture a large number of neurologically injured children likely to require specialized NCC services but was not comprehensive of all diagnoses. Triggering of the module by both primary and nonprimary diagnoses led to exclusion of a quarter of potentially eligible patients, as their reason for admission was deemed not related to the qualifying diagnosis. However, this approach led to a curated and highly relevant cohort that describes the care of NCC patients at participating centers. The voluntary nature of the pilot coupled with the large amount of requested data led to a low percentage of eligible patients being entered. Balancing feasibility with the collection of relevant and granular patient-level data, particularly in relation to secondary insults, was a major challenge in the modules' development. Still, this pilot dataset from NCC patients demonstrates a potentially modifiable high frequency of secondary insults that have been associated with worse neurologic injury and outcomes (although the duration of insults was not captured). When coupled with the high volume of neurologic patients managed in the PICU and the high morbidity and mortality they experience, our findings suggest that future refinement of the VPS NCC(m) remains highly relevant.

In conclusion, children with primary neurologic disease require more critical care resources than children without neurologic disease. Consistent with other reports, in this multicenter dataset, we identified the most common etiologies of primary neurologic disease requiring PICU admission in clinical practice. Also, in this population compared with the general PICU population, there was an association with increased morbidity, and among unscheduled admissions, an increase in mortality. Further development and implementation of the VPS NCC(m) could generate high-quality multicenter data that can be used to guide future research, benchmarking and QI/PI priorities.

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1 *Department of Pediatrics, Drexel University College of Medicine, St Christopher's Hospital for Children, Philadelphia, PA.*

2 *Department of Pediatrics, Medical College of Wisconsin, Children's Hospital of Wisconsin, Milwaukee, WI.*

3 *Department of Anesthesiology and Critical Care Medicine, Keck School of Medicine of the University of Southern California, Children's Hospital of Los Angeles, Los Angeles, CA.*

4 *Department of Pediatrics, University of Wisconsin School of Medicine, American Family Children's Hospital, Madison, WI.*

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TABLE 5.
Frequency of Events Associated With Secondary Neurologic Injury in Neurocritical Care Module Patients[a]

Study Variables	All Neurocritical Care Module, *n* = 1,261, *n* (%)	Neurotrauma, *n* = 204, *n* (%)	Nontrauma, *n* = 1,057, *n* (%)
Hypoxia (oxygen saturation < 90%)	302/1,258 (24.0)	35/203 (17.2)	267/1,055 (25.3)
Seizures			
Clinical seizure	225/1,261 (17.8)	18/204 (8.8)	207/1,057 (19.6)
Electrographic seizure	103/1,261 (8.2)	15/204 (7.4)	88/1,057 (8.3)
Temperature dysregulation	591/1,256 (47.1)	79/204 (38.7)	512/1,052 (48.7)
Hypothermia (temperature < 36°C)	240/1,247 (19.2)	42/201 (20.9)	198/1,046 (18.9)
Severe hypothermia (temperature < 32°C)	19/1,247 (1.5)	1/201 (0.5)	18/1,046 (1.7)
Hyperthermia (temperature > 38°C)	461/1,254 (36.8)	56/204 (27.5)	405/1,050 (38.6)
Severe hyperthermia (temperature > 40°C)	32/1,254 (2.6)	4/204 (2.0)	28/1,050 (2.7)
Dysnatremia[b]	49/162 (30.2)	49/162 (30.2)	0/0 (0)
Hyponatremia (sodium < 135 mmol/L)	14/91 (15.4)	14/91 (15.4)	0/0 (0)
Severe hyponatremia (sodium < 125 mmol/L)	0/91 (0)	0/91 (0)	0/0 (0)
Hypernatremia (sodium > 145 mmol/L)	42/161 (26.1)	42/161 (26.1)	0/0 (0)
Severe hypernatremia (sodium > 160 mmol/L)	9/161 (5.6)	9/161 (5.6)	0/0 (0)
Glucose dysregulation[b]	24/154 (15.6)	24/154 (15.6)	0/0 (0)
Hypoglycemia (glucose < 70 mg/dL)	12/80 (15.0)	12/80 (15.0)	0/0 (0)
Hyperglycemia (glucose > 200 mg/dL)	16/153 (10.5)	16/153 (10.5)	0/0 (0)
ICP monitored (yes/total)	40/1,261 (3.2)	14/204 (6.9)	26/1,057 (2.5)
Intracranial hypertension			
ICP > 20 mm Hg	27/39 (69.2)	12/14 (85.7)	15/25 (60.0)
Cerebral perfusion pressure < 40 mm Hg	13/25 (52.0)	7/13 (53.8)	6/12 (50.0)

ICP = intracranial pressure.

[a]Data collected up to PICU day 14 (data collected on median PICU day 1 [interquartile range day 0–3]) and are reported categorically for each patient with complete data for that category.

[b]Data collected only for traumatic brain injury patients; if only one value was collected, it was reported either as a high or low value dependent on the data entrant.

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For information regarding this article, E-mail: desantirl@gmail.com

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