


ORIGINAL WORK



Surge Capacity in the COVID-19 Era: a Natural Experiment of Neurocritical Care in General Critical Care

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Abstract

Background: COVID-19 surges led to significant challenges in ensuring critical care capacity. In response, some centers leveraged neurocritical care (NCC) capacity as part of the surge response, with neurointensivists providing general critical care for patients with COVID-19 without neurologic illness. The relative outcomes of NCC critical care management of patients with COVID-19 remain unclear and may help guide further surge planning and provide broader insights into general critical care provided in NCC units.

Methods: We performed an observational cohort study of all patients requiring critical care for COVID-19 across four hospitals within the Emory Healthcare system during the first three surges. Patients were categorized on the basis of admission to intensive care units (ICUs) staffed by general intensivists or neurointensivists. Patients with primary neurological diagnoses were excluded. Baseline demographics, clinical complications, and outcomes were compared between groups using univariable and propensity score matching statistics.

Results: A total of 1141 patients with a primary diagnosis of COVID-19 required ICU admission. ICUs were staffed by general intensivists ($n = 1071$) or neurointensivists ($n = 70$). Baseline demographics and presentation characteristics were similar between groups, except for patients admitted to neurointensivist-staffed ICUs being younger (59 vs. 65, $p = 0.027$) and having a higher $\text{PaO}_2/\text{FiO}_2$ ratio (153 vs. 120, $p = 0.002$). After propensity score matching, there was no correlation between ICU staffing and the use of mechanical ventilation, renal replacement therapy, and vasopressors. The rates of in-hospital mortality and hospice disposition were similar in neurointensivist-staffed COVID-19 units (odds ratio 0.9, 95% confidence interval 0.31–2.64, $p = 0.842$).

Conclusions: COVID-19 surges precipitated a natural experiment in which neurology-trained neurointensivists provided critical care in a comparable context to general intensivists treating the same disease. Neurology-trained neurointensivists delivered comparable outcomes to those of general ICUs during COVID-19 surges. These results further support the role of NCC in meeting general critical care needs of neurocritically ill patients and as a viable surge resource in general critical care.

Keywords: COVID-19, Neurocritical care, Critical care, Neurology

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Introduction

The COVID-19 pandemic has led to significant challenges in ensuring critical care capacity during surges of hospital admissions. Early in the pandemic, it became clear that critical care of patients with COVID-19 is particularly staff intensive and that robust critical care staffing directly correlates with improved patient outcomes [1]. A variety of staffing models have been explored to increase intensive care unit (ICU) capacity with existing staff, ranging from rearranging staff to patient ratios, block scheduling, and using non-critical-care-trained staff to provide supervised critical care to meet surge demands [2, 3].

The role of subspecialty critical care services in meeting COVID-19 surge demands has not been well characterized. Neurocritical care (NCC) has recently emerged as a novel critical care subspecialty to care for neurologically ill patients, with demonstrable improvement in outcomes [4–6]. Under the American College of Graduate Medical Education, physicians are eligible for a 2-year NCC training program and certification after completion of an accredited residency in neurology, neurosurgery, anesthesia, pediatric neurology, internal medicine, or emergency medicine. Conversely, physicians with preexisting critical care board certifications (from a wider variety of base specialties) can then qualify for and be board certified in NCC after a 1-year fellowship program. Practically, however, NCC is now largely provided by neurology-trained neurointensivists who undergo 2 years of dedicated critical care and NCC training after a 4-year residency in neurology. Although the role of NCC is well established in large centers, disagreement remains about the added value of NCC, particularly with neurologists managing nonneurological critical needs of neurocritically ill patients [5].

Nevertheless, acute needs for ICU capacity led some centers to leverage NCC as part of the COVID-19 surge response, using NCC teams to care for patients with COVID-19 without neurologic illness. The relative outcomes of subspecialty critical care management of patients with COVID-19 remain unclear and may help guide further surge planning as well as provide broader insights into general critical care provided in NCC units.

Here we report and compare the outcomes of critically ill patients with COVID-19 admitted to ICUs staffed by general intensivists versus neurointensivists across four hospitals in a single health care system during the first three COVID-19 surges.

Methods

This retrospective review was approved by the Emory Institutional Review Board. We reviewed all adult

patients admitted to four hospitals within the Emory Healthcare system with a primary diagnosis of COVID-19 requiring critical care. ICUs were divided into two groups based on staffing with nonneurointensivists (herein described as general intensivists) versus neurointensivists. This distinction is practical. Neurology-trained neurointensivists are the only intensivists who are not eligible to sit for any other critical board certification (general, surgical, medical, or anesthetic) at the end of their critical care training program. Every other discipline can do so through a variety of training paths. For instance, eligibility for medical, surgical, or anesthetic critical care fellowship requires completion of a residency in internal medicine, emergency medicine, general surgery, obstetrics and gynecology, neurosurgery, orthopedic surgery, otolaryngology, or urology. Completion of one of the other critical care fellowships then makes a potential trainee eligible for NCC training. Given this distinction for critical care board eligibility, we dichotomized ICUs along similar lines, recognizing that general intensivists reflect a broad array of board certifications and subspecialty expertise.

General ICUs were composed of typical medical and surgical ICUs staffed by critical care physicians trained in internal medicine, pulmonology, surgery, anesthesia, and emergency medicine, with an associated team of advanced practice providers (APPs) and nurses. During surges, expansion ICUs were staffed by a mixture of physicians, APPs, and nurses on the basis of availability. Practically, for some of the expansion ICUs, this meant cobbling an interdisciplinary staff from a variety of teams, thus complicating the ability to make further comparisons within the general critical care cohort.

In contrast, the Emory University Hospital NCC service opened and internally staffed a dedicated COVID-19 ICU during the first three COVID-19 surges. The service typically supports 54 neurointensive care beds across two hospitals and has its own dedicated pool of physicians, APPs, and nurses, all of whom are subspecialized in NCC. During the first three COVID-19 surges, the NCC service used this integrated interdisciplinary neurocritical team to internally staff a dedicated COVID-19 surge ICU. Pharmacy support was largely via the existing NCC pharmacy team. The notable exception was that the respiratory therapy team cross-covered across multiple ICUs. In all but six cases, patients were admitted with a primary diagnosis of COVID-19 to a physically separate, NCC-staffed ICU that was only open during surges; none of these patients had a primary neurologic diagnosis. The other six patients were admitted to a preexisting NCC ICU (without a neurological diagnosis) because of capacity limitations. Staffing shortages were similarly challenging for the NCC

service as they were for all other services. Staffing was similarly facilitated across all ICUs by increasing shift availability for all staff and by temporarily increasing ratios of patients to staff where necessary. In some cases, non-NCC nurses cross-covered in the surge ICU run by the neurointensive care team. NCC physicians were all neurology-trained neurointensivists. Three of the 13 neurointensivists had dual training: one in internal medicine, one in critical care anesthesia, and one in critical care anesthesia and internal medicine.

The NCC-staffed surge ICU closed during nonsurge periods, so only admissions during surges were compared [7]. Surge periods in our region were defined as previously reported, with surges 1, 2, and 3 defined as March 13 through April 30, 2020; July 1 through August 31, 2020; and December 1 through January 31, 2021, respectively [7].

Patients were categorized on the basis of the staffing of the initial ICU to which they were admitted. Patients were admitted to ICUs purely on the basis of bed availability at the time, with three exceptions. Patients transferred in for, or already requiring, extracorporeal membrane oxygenation (ECMO) on admission only went to one ICU. To avoid sampling bias, all patients with COVID-19 requiring ECMO on presentation or admitted to the cardiac care unit were excluded from further analysis. Patients who later progressed to requiring ECMO were included. Second, the cardiac care unit preferentially admitted patients with COVID-19 with baseline or complex cardiac disease; therefore, these patients were excluded from further analysis. Third, patients who were admitted with a primary neurologic diagnosis in the setting of also having COVID-19 were admitted to the neurointensive care unit and were excluded from further analysis. Outside of these three selection criteria, patients were triaged on the basis of bed availability without any consideration for what team was staffing a given surge ICU. Within these inclusion criteria, sicker patients were not systematically triaged away from the neurointensive-care-staffed COVID-19 ICU. Patient demographics, clinical presentations, and clinical outcomes were extracted from the electronic medical record. The Sequential Organ Failure Assessment score and PaO₂/FiO₂ ratio were determined at ICU admission. Poor outcomes were defined as a composite outcome of in-hospital mortality or hospice disposition.

Ordinal and categorical data were presented as medians with interquartile ranges. Comparison outcomes among groups were made using Fisher's exact test and Wilcoxon rank-sum testing as appropriate. Weighted analyses were performed with causal inference analysis through propensity-score-based methods

in the R package Toolkit for Weighting and Analysis of Nonequivalent Groups ("twang") [8]. Propensity score weights were estimated by gradient boosting and then analyzed using binary logistic regression of the weighted data. All patients were included in the weighted analysis, with differential weights assigned to each patient on the basis of their propensity score. All statistical analyses were done in R (version 4.1.2).

Results

A total of 1141 patients with a primary diagnosis of COVID-19 were admitted to eight different ICUs across four hospitals within the Emory Healthcare system during the first three COVID-19 surges. Patients were categorized on the basis of the staffing of the to which ICUs they were admitted: general-intensivist-staffed (1071) versus neurointensivist-staffed (70) ICUs. Baseline demographics and presentation characteristics were similar between groups, except for patients admitted to neurointensivist-staffed ICUs being younger (59 vs. 65, $p=0.027$) and having a higher PaO₂/FiO₂ ratio (153 vs. 120, $p=0.002$; Table 1).

Comparison of in-hospital complications revealed comparable rates of mechanical ventilation, tracheostomy, vasopressor use, renal replacement therapy, and ECMO (Table 2). Duration of organ support therapy was similarly comparable (Table 2). Lengths of stay in the ICU and hospital were similar between cohorts, although there was a nonsignificant trend toward longer hospitalizations with patients admitted to neurointensivist-staffed ICUs. Clinical outcomes were similar, with comparable rates of poor outcomes (31.4% vs. 34.2%, $p=0.697$).

Propensity score matching was used to adjust for baseline differences between the cohorts (Supplementary Table 1). In a univariable binary logistic regression analysis of matched cohorts, admission to an NCC ICU did not correlate with the need for mechanical ventilation, tracheostomy, renal replacement therapy, or vasopressors when compared with admission to a general ICU (Table 3). Admission to an NCC ICU did not associate with poor outcomes in a binary logistic regression analysis of propensity-score-matched cohorts (odds ratio 0.9, 95% confidence interval 0.31–2.64, $p=0.842$).

Discussion

Using a multihospital, single-system cohort of patients with COVID-19 requiring critical care, we found that patients admitted to either general-intensivist-staffed or neurointensivist-staffed ICUs had a similar clinical course and outcome. Our experience across both ICU types is comparable to reported ICU mortality, with

Table 1 Baseline demographics and presentation characteristics of patients admitted with a primary diagnosis of COVID-19

Variable	NCC (n = 70)	General (n = 1071)	p value
Age, mean (IQR)	59 (49–75)	65 (54–76)	0.027
Male	38 (54.3%)	606 (56.6%)	0.711
White	24 (34.3%)	347 (32.4%)	0.304
Congestive heart failure	20 (28.6%)	255 (23.8%)	0.387
Arrythmia	28 (40.0%)	447 (41.7%)	0.804
Valvular heart disease	3 (4.3%)	50 (4.7%)	0.999
Peripheral vascular disease	5 (7.1%)	85 (7.9%)	0.999
Hypertension	48 (68.6%)	788 (73.6%)	0.403
Chronic obstructive pulmonary disorder	21 (30.0%)	227 (21.2%)	0.099
Diabetes mellitus	32 (45.7%)	536 (50.0%)	0.538
Hypothyroidism	6 (8.6%)	130 (12.1%)	0.450
Renal insufficiency	24 (34.3%)	351 (32.8%)	0.794
Liver disease	10 (14.3%)	118 (11.0%)	0.432
Obesity	17 (24.3%)	338 (31.6%)	0.231
SOFA score, mean (IQR)	3 (2–9)	3 (2–6.5)	0.473
PaO ₂ /FiO ₂ ratio, mean (IQR)	153 (109–273)	120 (80–195)	0.002

Significant differences are highlighted in bold

IQR interquartile range, NCC neurocritical care unit, PaO₂/FiO₂ partial pressure of oxygen to fraction of inspired oxygen, SOFA sequential organ failure assessment

Table 2 Clinical complications and outcomes stratified by ICU subtype

Variable	NCC (n = 70)	General (n = 1071)	p value
Complications			
Mechanical ventilation	35 (50.0%)	566 (52.8%)	0.711
Duration (days), median (IQR)	12 (9–18)	11 (5–19)	0.339
Tracheostomy	7 (10.0%)	111 (10.4%)	0.999
Vasopressor use	36 (51.4%)	528 (49.3%)	0.805
Duration (days), median (IQR)	5 (3–10)	5 (3–10)	0.611
Renal replacement therapy	17 (24.3%)	245 (22.9%)	0.770
Duration (days), median (IQR)	11 (7–15)	8 (4–15)	0.219
ECMO during hospitalization	1 (1.4%)	5 (0.5%)	0.317
Outcomes			
ICU length of stay (days), median (IQR)	8 (3–15)	6 (3–15)	0.594
Hospital length of stay (days), median (IQR)	16 (10–24)	13 (8–23)	0.166
Poor outcome	22 (31.4%)	366 (34.2%)	0.697
Home	37 (52.9%)	508 (47.4%)	0.390

ECMO extracorporeal membrane oxygenation, ICU intensive care unit, IQR interquartile range, NCC neurocritical care unit

Table 3 Univariable binary logistic regression of propensity score matched cohorts for clinical complications and outcomes

Outcome	Odds ratio (95% confidence interval)	p
Mechanical ventilation	1.09 (0.47–2.52)	0.843
Tracheostomy	0.59 (0.23–1.5)	0.268
Renal replacement therapy	2.06 (0.75–5.7)	0.162
Vasopressor use	1.42 (0.62–3.22)	0.408
Poor outcome	0.9 (0.31–2.63)	0.842

national rates ~ 30% (although international rates vary) [9, 10].

These results are informative on two fronts. First, there have been significant concerns regarding replicating rigorous systems of care in new expansion ICUs to meet surge demands [11]. Despite these challenges, surge ICUs staffed by an integrated NCC team performed comparably and delivered similar outcomes. Our results suggest that an integrated NCC service can be leveraged as part of a broader critical care response to help surge ICU

capacity in times of crisis or when system-wide critical care loadbearing is needed to manage ICU capacity.

Second, COVID-19 surges led to a natural experiment regarding neurointensivists in nonneurologic critical care. Although a dedicated NCC service improves outcomes in neurocritically ill patients, skepticism remains regarding the ability of particularly neurology-trained neurointensivists to deliver nonneurologic critical care [5, 6]. We are aware of no prior studies comparing NCC intensivists with non-NCC intensivists in nonneurologic critical care. COVID-19 surges precipitated a natural experiment in which largely neurology-trained neurointensivists provided critical care in a comparable context to other intensivists treating the same disease. Although this experience reflects one health care system treating a novel disease entity, these results further support the role of NCC in meeting general critical care needs of neurocritically ill patients.

Indeed, our data suggest that board-certified critical care specialists have more skill and knowledge in common than the disparate training paths might imply. To be sure, subspecialty expertise is not interchangeable, but the fundamentals of critical care are universal across disciplines and demonstrably similar in this experience. These data suggest that eligibility for critical care board certification may need to be revisited in an interdisciplinary fashion. In the meantime, these data support the use of neurology-trained neurointensivists as partners in general critical care. For instance, consider hospitals in need of NCC expertise but without enough volume to sustain a dedicated NCC practice. It may be reasonable to leverage a neurology-trained neurointensivist as part of the broader critical care effort to bring needed subspecialty expertise to a health system.

Strengths of our study include a multihospital, single-system design across four hospitals and eight ICUs involving 1141 patients with COVID-19. Nevertheless, our study has several limitations. First, this is a single health care system with an unusually large NCC service (supporting 54 ICU beds) with its own distinct team of physicians, APPs, and nurses. The generalizability of this surge model may be limited to large centers with a robust NCC service. Second, patients managed by the neurointensivists had more favorable ages and PaO₂/FiO₂ ratios, both of which are known predictors of outcomes in COVID-19. Although this was by chance, this is a notable limitation when comparing univariable outcomes. Nevertheless, when we adjusted for these differences with propensity score matching, outcomes remained similar between both cohorts. Third, the outcomes are limited to discharge outcomes and organ support therapy. More subtle differences in long-term pulmonary outcomes, including pulmonary fibrosis and residual pulmonary

capacity, were not assessed and may differ between services. Fourth, generalizability for other critical care illnesses may be limited because all physicians started with the same lack of experience in managing COVID-19. Nevertheless, the foundations of critical care for COVID-19 rest on general principles of critical care. Fifth, two of the 13 neurointensivists in the group were also board certified in internal medicine, and a third was a neurology-trained neurointensivist who also completed a 1-year critical care anesthesia fellowship. Although this subgroup accounted for less than 25% of the NCC team, this could confound the interpretation regarding neurology-trained neurointensivists.

Conclusions

COVID-19 surges precipitated a natural experiment in which neurology-trained neurointensivists provided critical care in a comparable context to general intensivists treating the same disease. Neurology-trained neurointensivists delivered comparable outcomes to those of general ICUs during COVID-19 surges. These results further support the role of NCC in meeting general critical care needs of neurocritically ill patients and as a viable surge resource in general critical care.

Supplementary Information

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Author Contributions

SP and FA designed the project and collected the data. SP, YS, YM, OS, and FA analyzed and interpreted the data. CMC, OBS, and CPF provided interpretation and critical review of the data and manuscript. All authors have approved the final version of the manuscript.

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None.

Conflict of interest

The authors have no conflicts of interest to report.

Ethical approval/informed consent

This research inquiry adheres to ethical guidelines and was approved by the Emory University Institutional Review Board.

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