




Quality Improvement in Neurocritical Care: a Review of the Current Landscape and Best Practices

Navaz Karanjia, MD^{1, *} 
Venkataditya Dugyala, MD²
Casey Olm-Shipman, MD³
Abhijit V. Lele, MBBS, MD, MSCR, FNCS⁴

Address

^{1,1}Neurocritical Care Division, Departments of Neurosciences, Neurosurgery, and Anesthesiology, University of California San Diego School of Medicine, San Diego, CA 92103, USA

Email: nkaranjia@gmail.com

²Neurocritical Care Division, Department of Neurosciences, University of California San Diego School of Medicine, San Diego, CA, USA

³Neurocritical Care Division, Departments of Neurology and Neurosurgery, University of North Carolina School of Medicine, Chapel Hill, NC, USA

⁴Neurocritical Care Service, Department of Anesthesiology and Pain Medicine, Harborview Medical Center, University of Washington, Seattle, WA, USA

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Abstract

Purpose of Review The field of neurocritical care (NCC) has grown such that there is now a substantial body of literature on quality improvement specific to NCC. This review will discuss the development of this literature over time and highlight current best practices with practical tips for providers.

Recent Findings There is tremendous variability in patient care models for NCC patients, despite evidence showing that certain structural elements are associated with better outcomes. There now also exist evidence-based recommendations for neurocritical care unit (NCCU) structure and processes, as well as NCC-specific performance measure (PM)

sets; however, awareness of these is variable among care providers. The evidence-based literature on NCC structure, staffing, training, standardized order sets and bundles, transitions of care including handoff, prevention of bounce backs, bed flow optimization, and inter-hospital transfers is growing and offers many examples of successful performance improvement initiatives in NCCUs.

Summary NCC providers care for patients with life-threatening conditions like intracerebral and subarachnoid hemorrhages, ischemic stroke, and traumatic brain injury, which are associated with high morbidity, complexity of treatment, and cost. Quality improvement initiatives have been successful in improving many aspects of NCC patient care, and NCC providers should continue to update and standardize their practices with consideration of this data. More research is needed to continue to identify high-risk and high-cost NCCU structures and processes and strategies to optimize them, validate current NCC PMs, and encourage clinical adoption of those that prove to be associated with improved outcomes.

Abbreviations

QI	Quality improvement
IT	Information technology
EHR	Electronic health records

Introduction

Neurocritical care (NCC) is a multidisciplinary subspecialty at the crossroads of neurology, neurosurgery, and critical care that is dedicated to the treatment of patients who are critically ill with life-threatening neurologic and neurosurgical diseases. It has matured as a distinct subspecialty over the past two decades, evidenced by the formation of dedicated neuro-ICUs (NCCUs) to take care of its target population, the designation of neurointensivists and nurses specially trained in NCC, the formation of its international society (the Neurocritical Care Society, NCS) in 2002, the creation of a distinct board certification, neurocritical care fellowship through the United Council of Neurologic Subspecialties (UCNS) in 2005 and through Accreditation Council For Graduate Medical Education (ACGME) in 2020, unique clinical and translational research networks, and the publication of clinical guidelines and performance measures (PMs) for neurocritical care pathologies.

Our understanding of implementation science and quality improvement (QI) has simultaneously advanced via research—e.g., the Institute of Medicine (IOM)'s "Crossing the Quality Chasm" [1] and the Agency for Healthcare Research and Quality (AHRQ)'s "Making

Healthcare Safer," which shed light on the most common threats to patient safety [2]—and national initiatives like the Centers for Medicare and Medicaid Services (CMS)'s Hospital Inpatient Quality Reporting Program. In "Crossing the Quality Chasm," the IOM established six domains of health care quality—safe, effective, patient-centered, timely, efficient, and equitable; this analytical framework has been widely adopted in QI programs and PM development [3]. Currently, CMS defines quality improvement as "the framework used to systematically improve care. Quality improvement seeks to standardize processes and structure to reduce variation, achieve predictable results, and improve outcomes for patients, healthcare systems, and organizations. The structure includes technology, culture, leadership, and physical capital; the process includes knowledge capital (e.g., standard operating procedures) or human capital (e.g., education and training) [4]."

Subspecialties like stroke and critical care have had a head start in QI research; over the last two decades, stroke has seen a plethora of disease-specific guidelines [5–7] and certifications from the American Heart Association/American Stroke Association (AHA/ASA) and The Joint Commission (TJC) [8] that support

evidence-based structures and processes that improve stroke patient outcomes [9] and mature databases and performance improvement programs, including measure sets, like the AHA/ASA's Get With The Guidelines-Stroke Program [10]. There has similarly been advancement in critical care QI with evidence for improved outcomes with intensivist-led ICU staffing [11] and structure models [12] and processes like early goal-directed therapy for sepsis and daily spontaneous breathing trials, published in guidelines and promoted in toolkits like the ICU Liberation Bundle from the Society for Critical Care Medicine (SCCM) [13]. Over the same timeframe, the field of NCC has matured from its initial focus on the benefits of subspecialty

NCC providers on NCC patient outcomes [14, 15]. NCC QI-related publications have grown to include detailed NCCU structure recommendations by the NCS [16], evidence-based NCC-specific guidelines [17, 18–25] performance measure sets from organizations like the NCS and AHA, and a variety of publications investigating optimal NCCU structure, staffing, education, and process improvement. Additionally, the NCS created its Quality Committee in 2016, for further advancement of NCC QI initiatives and research.

This narrative review will provide an overview of the NCC QI literature and highlight current best practices.

Current State

The PRINCE study was the first to shed light on how neurocritical care is delivered across the globe; a point prevalence study of 257 centers from 47 countries showed that the most common diagnoses of patients admitted to neurocritical care units (NCCUs) include acute ischemic stroke, intracerebral hemorrhage (ICH), subarachnoid hemorrhage (SAH), traumatic brain and spinal cord injuries, neuromuscular weakness, status epilepticus, and hypoxic-ischemic injury [26] and that the specialty of the provider caring for these patients varies widely. In the USA, 21% of providers caring for NCC patients on the day of the study identified their specialty as NCC; 38% were pulmonary critical care medicine (PCCM), 16% anesthesia critical care (ACC), 5% surgical critical care (SCC), 2.5% neurosurgery, and 17% other. Depending on the geographic area, one non-intensivist was the primary provider caring for 3 to 10 patients. The NCCUs in the study reported the use of disease-specific treatment protocols 40–90% of the time, depending on the pathology [26, 27]. Given the high morbidity and cost associated with these conditions, a large number of evidence-based guidelines available for them, and the diversity of providers caring for them, it is reasonable to assume that QI techniques, and the standardization and attention to outcomes they bring, could play a significant role in optimizing NCC patient care.

The current state of QI efforts in NCCUs was largely unknown until a survey published by Lele et al. in 2020 showed that of 225 NCS respondents, a dedicated NCC QI program was reported by 45%, and the presence of dedicated NCC QI personnel by 44%, despite a dedicated hospital-wide QI program being reported by 88% [28]. The most self-reported barrier to QI efforts was insufficient resources from the hospital or academic departments. Awareness of NCC-specific PMs among respondents was 88% for comprehensive stroke (CSTK), 57% for Trauma Quality Improvement Program (TQIP), and 54% for the American Academy of Neurology (AAN) Inpatient and Emergent Neurology Measure Set [28]. Since then, the NCS Quality Measurement Set

was published in 2019; although we do not know the level of awareness of these in the NCC community, the data indicate that there is room to increase awareness of existing NCC PMs and expand NCC QI resources.

Structure

This variability in organizational structures and patient care models, as well as geographic variation in access to care, has the potential to exacerbate health disparities [29]. Numerous studies have demonstrated that organizational factors such as NCC team expertise, and a center's volume and experience treating certain NCC conditions, influence the quality of care delivered. In a study by Suarez et al. the introduction of an NCC team led by a neurointensivist was associated with a significant reduction in mortality and length of stay (LOS) [15]. Kramer et al. performed a systematic review of NCC patient care models and found lower mortality and improved neurologic outcomes in specialty NCCUs [30]. Additional benefits of neurointensivist-led teams include cost savings [30, 31] and decreased need for ventriculoperitoneal shunts in SAH patients [32].

The relationship between patient volume and clinical outcome has also been demonstrated in several NCC conditions. For example, Connolly et al. reported that for SAH, low-volume centers (treating < 10 cases per year) had worse outcomes compared to high-volume centers (treating > 35 cases per year) [7]. Diringer et al. demonstrated that ICH admission to centers with neurosurgical and NCC services with relatively high volumes of ICH cases was associated with increased survival [33]. High-volume (versus low-volume) ischemic stroke thrombectomy centers have also been associated with better survival and functional outcomes [34]. Given these volume-outcome associations, TJC includes the presence of an NCCU as part of the infrastructure necessary to achieve designation as a comprehensive stroke center [35]. For low-volume hospitals, the American Stroke Association recommends processes be in place to facilitate the transfer of stroke patients to experienced high-volume centers with neurosurgical and NCC capabilities when needed [36••]. For traumatic brain injury (TBI), Grieve et al. found that early transfer of TBI patients to a specialist neuroscience center was associated with reduced mortality and higher quality of life compared to late or no transfer and that management of patients in a dedicated NCCU versus general ICU was likely more cost-effective [37].

As such, several NCC disease conditions may benefit from care in a dedicated NCCU due to illness severity and the need for highly specialized resources. Some of these disease conditions include (but are not limited to):

- Large hemispheric and cerebellar strokes that may require hemicraniectomy or suboccipital craniectomy
- Severe aneurysmal SAH and ICH requiring external ventricular drain (EVD), decompression or clot evacuation, and/or aneurysm coil embolization or clip ligation
- Refractory status epilepticus requiring continuous electroencephalogram (EEG) monitoring

- Severe TBI requiring intracranial pressure monitoring, intracranial hypertension management, and/or decompression

Because getting NCC patients to the right level of care is now recommended in certain circumstances, it is important to design systems that recognize the capabilities of individual institutions and that leverage local resources and clinical networks to get patients the best care possible. For acute stroke, stroke program certification standards—i.e., TJC’s Comprehensive, Thrombectomy-Capable and Primary Stroke Center designations—provide a framework for ensuring care is delivered in the best environment, as well as establish structural benchmarks that promote data-driven performance improvement [38]. The ASA’s 2019 “Recommendations for the Establishment of Stroke Systems of Care” details how EMS and hospitals should use the TJC designations to triage stroke patients from the field and for hospital-to-hospital transfer to ensure stroke patients get to the best care as fast as possible [36••]. Recognizing a need for a similar framework for other NCC disease conditions, the NCS published “Standards for Neurologic Critical Care Units” in 2018 [39]. These standards represent best practice structural measures; categorize NCCUs as level I, II, or III based on level of care capability; and describe the key personnel, processes, and infrastructure required for each:

- Level I NCCUs are equipped to deliver comprehensive services for the care of the most complex patients, including advanced monitoring, surgical and medical therapies, fellowship-trained neurointensivists, and physician and APP training capability.
- Level II NCCUs are those with the capacity to deliver comprehensive neurocritical care delivery, though may not be equipped with the same degree of advanced monitoring or dedicated neurocritical care fellowship-trained personnel as compared to a Level I NCCU.
- Level III NCCUs are resourced to evaluate and stabilize neurological emergencies and facilitate transfer to level I and II centers.

The NCS NCCU standards provide detailed recommendations on inter-professional care and teamwork, quality and safety infrastructure and processes, clinical operations and administration, equipment, and education and training. It is recommended that an interprofessional team in a level I or II NCCU include neurointensivists, neurosciences nurses, advanced practice providers and/or resident and fellow trainees, pharmacists, respiratory therapists, dietitians, physical and occupational therapists, social workers, and others depending upon local resources. A level I NCCU should have a leadership structure consisting of an NCC fellowship-trained medical director, a nurse manager, and a hospital administrative leader. A level I NCCU should also have a dedicated clinical operations committee that regularly liaises with hospital administration, as well as established practices for reviewing PMs to inform QI initiatives. Protocols and care pathways should be developed in collaboration with stakeholders (such as neurosurgery, neurology, stroke, emergency department, and nursing) and be informed by evidence, guideline recommendations, or PMs (often endorsed by medical societies or governmental agencies, i.e., CMS and AHRQ). Depending on the level of NCCU and

services provided, NCC-specific equipment may include electroencephalography (EEG), external ventricular drains (EVDs), intracranial pressure monitors, transcranial dopplers, other multimodal monitoring equipment, and targeted temperature management devices.

The development of a culture of safety is also central to achieving high reliability of care within the NCCU. Leadership supporting adverse event reporting may be helpful in promoting a just culture within the NCCU. Likewise, the incorporation of closed-loop communication strategies may be helpful in flattening professional hierarchies, improving communication, and creating a safe non-retaliatory environment in which staff feels supported in sharing concerns [41].

Formal QI education and training are now widely available and can help advance a QI program. The Institute for Healthcare Improvement (IHI) Open School provides free online teaching modules utilizing the improvement method framework. Likewise, online training in Lean Six Sigma methodology is available, which focuses on improving value through waste reduction and workflow optimization. In addition, an increasing number of health organizations now offer programs to medical staff and trainees, embedding core QI concepts within the context of local systems.

In the development of an NCC QI program, a structured approach may be helpful. Elements to consider (Table 1) include defining priorities, structure and leadership, information technology, resource allocation, data collection and analysis, and data dissemination.

Processes

Standardizing processes of care, including knowledge through operating procedures and personnel through education and training, has long been shown to improve ICU care as highlighted below. In general critical care, the SCCM's "ICU Liberation Campaign" promotes a bundle of evidence-based strategies including spontaneous awakening and breathing trials and early mobility to reduce harm from common ICU conditions like pain, delirium, and sedation [42]. Implementation of the ICU Liberation Bundle has been associated with a 72% decrease in next-day mechanical ventilation, 68% reduction in in-hospital death within 7 days, 46% decrease in ICU readmissions, 40% decrease in next-day delirium, and 36% decrease in the likelihood of being discharged to a nursing home and rehab facility [43••]. In the NCCU, these interventions offer similar benefits but should be adapted to the NCC patient population. For example, daily sedation holds and spontaneous breathing trials may not be advisable for patients with elevated intracranial pressure [44], and delirium screening/treatment pathways may need to be adapted in NCC patients as neurologic pathologies such as vasospasm can mimic delirium.

Bundles for prevention of hospital-acquired infections (HAIs) such as catheter-associated urinary tract infections (CAUTIs), catheter-associated line infections (CLABSIs), and ventilator-associated events (VAEs) have also been a focus of research since they lead to excess morbidity, mortality, and resource consumption, and immobilized, ventilator-dependent ICU patients have a

Table 1 Elements to consider in designing a neurocritical care quality improvement program

Domain	Considerations
Define priorities	<ul style="list-style-type: none"> ● Prioritize NCC QI (in addition to other clinical QI processes) ● Establish clinical and operational goals ● Craft mission/vision statement with stakeholder input ● Prioritize safe, effective, patient-centered, timely, effective, efficient, equitable care
Structure and leadership	<ul style="list-style-type: none"> ● Identify QI director/officer ● Establish connection to senior departmental/hospital leadership (vertical alignment) ● Establish connection to allied services, i.e., neurology, neurosurgery, emergency department, nursing, pharmacy, social work, therapy services,* etc. (horizontal alignment) ● Identify and invite stakeholders to form an NCC QI committee
Information technology	<ul style="list-style-type: none"> ● Adapt health-care IT services specifically for NCC QI ● Synergize QI efforts for all neurocritical care pathologies across the health system
Resource allocation	<ul style="list-style-type: none"> ● Attain dedicated time, staff, and fiscal resources for NCC QI from the department and/or institution
Data collection and analysis	<ul style="list-style-type: none"> ● Consider analytics early in the planning process ● Assess data needs and gaps (from EHR, mortality reports, etc.) ● Identify data sources ● Define the frequency of data collection and analysis ● Define NCC performance measures (including existing PMs, i.e., GWTG, and developing institution-specific PMs if needed) ● Apply national and local benchmarks to PM ● Compare PM performance to benchmarks
Data dissemination	<ul style="list-style-type: none"> ● Establish a methodology for data dissemination (dashboard, recurring team meetings) ● Include stakeholders* to recurring meetings
Program sustainability	<ul style="list-style-type: none"> ● Incentivize NCC QI efforts at the departmental/institutional level (financial, non-clinical time, credit toward academic promotion)

Adapted from the “Developing and Implementing a QI Plan” guide from the US Department of Health and Human Services Health Resources and Services Administration [41]

high risk of HAIs. NCC patients additionally have nervous system dysfunction making them subject to aspiration, urinary retention, frequent transports for procedures and radiologic exams, etc., which can make them even more vulnerable to HAIs. One study aimed at reducing HAIs in the NCCU after finding that incidence remained high despite routine preventative bundles. They created additional interventions including (a) reviewing urinary catheter use on daily rounds, continuously questioning the ongoing need for a catheter; (b) re-educating personnel in insertion and maintenance; and (c) placing a mobile CT in the NCCU since they found correlations between frequency of transport for brain imaging and respiratory and urinary infections. Over 18 months, VAEs decreased by 48%, urinary catheter use by 46%, CAUTIs from 11/1000 catheter days to 6.2, total HAIs by 53%, ICU LOS by 1.5 days, and risk-adjusted mortality by 11%. Key drivers were decreased urinary catheter use and decreased transport for imaging [45].

Prevention of ventriculostomy-related infections (VRIs) in patients with EVDs is an issue particular to NCCUs and has been widely published. Overall the literature demonstrates that implementation of a comprehensive EVD bundle with stakeholder input that emphasizes aseptic technique throughout the EVDs lifespan can significantly reduce VRI rates and that rates approaching 0 are possible [46]. The NCS guideline on EVD management recommends the use of an EVD bundle that “includes aseptic insertion, limits manipulation of the closed system, and standardizes dressings and weaning [23].” Although there are publications on the prevention of other NCCU-specific infections, like craniotomy site infections and meningitis after TBI, the literature there is less robust [46].

Another way of standardizing processes of care is through the use of standardized pathology-specific order sets, which are a class I recommendation from the AHA for stroke patients [47••] as they improve adherence to best practices [48]. For TBI, McCredie et al. showed that protocolized care pathways reduce risk-adjusted in-hospital mortality (OR 0.77, $p = 0.009$) [49]. Order sets may also be targeted to improve specific aspects of care; for example, one study found that the implementation of an electronic order set for anticoagulant reversal cut the time to administration of reversal agent by almost half, resulting in significantly more accurate dosing (29.4 vs. 92.9%; $p < 0.01$) and reduction in time to INR testing from 164 to 85 min ($p = 0.001$) [50].

Bedside rounding tools and standardized handoffs have also been shown to improve information transfer and may influence patient, provider, and organizational outcomes [50, 51]. In 2010, TJC established standards for healthcare provider handoff that mandate the opportunity for discussion between the giver and receiver of information [50–52], and ACGME required that medical training programs “must design, implement, and institutionalize structured handover processes to ensure the continuity of care and patient safety [53].” Specifically in the NCCU, Gunter et al. [54] describe implementing an electronic multidisciplinary rounding tool to facilitate team communication, which improved nursing shift change handoff. Another prospective assessment that introduced a standardized NCC provider handoff demonstrated an improved clinical information exchange [55]. Multiple studies have examined postoperative neurosurgical handoff in the NCCU; one introduced a structured handoff using the IPASS format. Direct observations before and after demonstrated improved communication of airway concerns (47.1% vs. 92.3%, $p < 0.001$), hemodynamic concerns (70.6% vs. 97.1%, $p = 0.001$), intraoperative events (52.9% vs. 100%, $p < 0.001$), neurological exam (76.5% vs. 100%, $p < 0.001$), vital sign goals (70.6% vs. 100%, $p < 0.001$), and required postoperative studies (76.5% vs. 100%, $p < 0.001$) [56•]. Before and after surveys demonstrated significantly improved perceptions of handoffs as organized, efficient, comprehensive, and safe, with a mean handoff time of 4.4 min [56•].

NCCU patients are vulnerable to rapid returns to the ICU after transfer to a floor service (“bouncing back”). As these patients may experience increased mortality and longer hospital stays, multiple studies have focused on bounce-back prevention. One center found that unplanned transfers to the NCCU were common and associated with high mortality (17%) [57]. At another

institution, the bounceback rate within 48 h of NCCU downgrade was 4.7%, with the most common causes for bounceback being a respiratory failure and sepsis/hypotension; this rate decreased to 3.6% after implementation of an intervention where patients were identified as “high risk” or “low risk” for a bounceback, and “high risk” patients underwent enhanced handoff including interdisciplinary communication and rapid assessment [58]. Another study implementing a transfer checklist for patients transferring out of the NCCU (including ICU course, action items, and a systems-based checklist) demonstrated significantly decreased LOS (8.6 vs. 5.4 days, $p=0.003$), low ICU readmission rate, improved provider perceptions of safety, and decreased time spent executing the transfer [59•].

Inter-hospital transfers (IHT) have been the subject of many studies due to their complexity and financial impact. One prospective study of an intervention to improve the transfer process for nontraumatic ICH and SAH patients (including clinical guideline dissemination, transfer process redesign, electronic patient arrival notification, shared electronic imaging, and EHR improvements) found significant improvements in the emergency department (ED) boarding time (223 min pre-intervention vs. 93 post-intervention, $p=0.001$), and ED LOS (300 vs. 150 min, $p\leq 0.0001$) [60•]. Another group used failure mode and effect analysis (FMEA) to optimize IHT for ICH patients admitted to the NCCU and was able to reduce ED LOS from 300 to 149 min ($p<0.01$) [61•]. One institution aiming to increase NCCU transfer volume by optimizing bed utilization evaluated the impact of a Reserved Bed Pilot Program; they found reserving NCCU beds for NCC patients, and using non-NCCU beds for other ICU overflows, significantly increased neurosciences transfer volume (13%) and decreased declines due to capacity (58%) [62•].

QI strategies for other NCCU processes, such as the transition to comfort care [31], clinical documentation strategies to optimize risk-adjusted outcomes [63], palliative care consultation [63, 64], and DVT chemoprophylaxis [65], have also been published.

Performance Measures

There are numerous critical care-specific PMs that may be tracked by institutions. One example is hand hygiene, which significantly reduces HAI transmission [66], and as such is often enforced hospital-wide. In a review of 3014 citations, Berenholtz et al. identified the following: six measures associated with patient outcomes (ICU mortality, ICU LOS > 7 days, average ICU LOS, average days on mechanical ventilation, suboptimal pain management, and patient/family satisfaction), six process measures (effective pain assessment, appropriate blood transfusion use, prevention of ventilator-associated pneumonia, appropriate sedation, peptic ulcer prophylaxis, and deep venous thrombosis prophylaxis), four access measures (rate of delayed admissions, rate of delayed discharges, canceled surgical cases, and ED bypass hours), and 3 complication measures (rate of unplanned ICU readmission, rate of CLABSI, and rate of resistant infections) [67]. Other general critical care PMs

include rates of HAIs [68] such as CLABSI, CAUTI, surgical site infections (SSI), and ventilator-associated events (VAE), 30-day mortality [69], mortality index (observed/expected ratio) [70], in-hospital falls [71], adherence to daily rounding checklist [28], percentage of point-of-care glucose values > 180 mg/dl, ICU LOS, head-of-bed elevation, lung-protective ventilation, early and adequate antibiotic therapy, and early enteral nutrition [72].

The subspecialty nature of neurocritical care and its growing body of evidence-based practices has prompted the creation of NCC-specific PMs: stroke measures from TJC and the AHA/ASA, inpatient and emergency neurology measures from the AAN, NCC measures from the NCS, and TBI measures from the Trauma Quality Improvement Program. Table 2 shows the current published PM sets relevant to NCC patients [73, 74••, 75–77].

Optimally, PMs are associated with patient outcomes and can be used to improve them. One of the earliest examples of this in critical care is utilizing a pre-procedure checklist to reduce CLABSI [78]. After first being tested at Johns Hopkins Medical Institutions, its use became widespread across hospitals in the USA [79] and is now a PM reportable to CMS [80]. According to the AHRQ's national scorecard on Hospital-Acquired Conditions (2014–2017), patient care with associated PMs improved in the year 2017 compared to 2014: 37% fewer *Clostridium difficile* infections, 17% fewer venous thromboembolism cases, 13% fewer VAPs, 6% fewer CLABSIs, and 5% fewer CAUTIs and falls in hospitals, attributed to tracking these PMs [71]. Among the NCC measures, hospitals that adopted the GWTG measures significantly decreased mortality within 6 months and at 1 year (HR 0.89, $p=0.001$; HR 0.92, $p=0.0005$) and increased discharges home at 1 year (HR 1.06, $p=0.06$) compared to those that did not [81]. Another study looking at stroke patients receiving thrombectomy directly admitted (DA) versus secondarily transferred (ST) from a primary stroke center found that DA patients achieved good outcomes significantly more than ST patients (42.2% vs. 30.9%, $p<0.001$), and median discharge mRS was lower 3 vs. 4, $p<0.001$) [82•]. Although none of the listed NCC measures are currently reportable to CMS, it seems probable that patient care would be positively impacted if those NCC PMs that prove to be robust in improving outcomes were adopted by hospitals and CMS in the future.

Tracking a large number of PMs can be difficult; a PM dashboard can be helpful in visually organizing and monitoring the progress of QI initiatives [83–85]. Important steps in creating a PM dashboard are determining the type of dashboard and defining its purpose, assembling the team, writing objectives, establishing PMs to include, setting PM benchmarks, defining each PMs specifications, developing a data collection plan [86], determining how the dashboard will be displayed, establishing a dissemination plan [87], developing a plan to review the dashboard and act on the findings, gathering baseline data, determining a pilot period, and monitoring and continuing to explore new PMs to include [85]. Quality tools commonly used in dashboards include run charts, control charts, bar graphs, or pie charts [86].

Table 2 Current neurocritical care performance measure sets

Stroke measures	Comprehensive stroke measures	American Heart Association: Get With The Guidelines (Acute Stroke Management) (GWTG)	American Academy of Neurology Inpatient and Emergency Measure Set (AAN)	Neurocritical Care Society Clinical Performance Measures (NCS)	Trauma Quality Improvement Program Traumatic Brain Injury Measures (TQIP)
The Joint Commission (STK)	The Joint Commission (GSK)	With The Guidelines (Acute Stroke Management) (GWTG)	Neurology Inpatient and Emergency Measure Set (AAN)	Neurocritical Care Society Clinical Performance Measures (NCS)	Trauma Quality Improvement Program Traumatic Brain Injury Measures (TQIP)
<ul style="list-style-type: none"> • Venous thromboembolism (VTE prophylaxis) • Assessed for rehabilitation • Discharged on antithrombotic therapy • Anticoagulation therapy for atrial fibrillation/flutter • Thrombolytic therapy • Antithrombotic therapy by end of hospital day 2 • Discharged on statin medication • Stroke education 	<ul style="list-style-type: none"> • National Institutes of Health Stroke Scale (NIHSS) Score Performed for Ischemic Stroke Patients • Modified Rankin Score (mRS) at 90 days • Severity measurement performed for SAH and ICH patients (overall rate) • Procoagulant reversal agent initiation for intracerebral hemorrhage (ICH) • Hemorrhagic transformation (overall rate) • Nimodipine treatment administered • Median time to revascularization • Thrombolysis in cerebral infarction (TICI) post-treatment reperfusion grade) • Arrival time to skin puncture • Modified Rankin Score (mRS) at 90 days: favorable outcome) • Timeliness of reperfusion: arrival time to TICI 2B or higher • Timeliness of reperfusion: skin puncture to TICI 2B or higher 	<ul style="list-style-type: none"> • IV rt-PA by 2 h, treat by 3 h • Early antithrombotics • Venous thromboembolism prophylaxis • Dysphagia screen • Time to intravenous thrombolytic therapy-60 min • National Institutes of Health Stroke Scale reported 	<ul style="list-style-type: none"> • Documentation of brain death • Reduction of urinary catheters for patients with neurological conditions • Delirium risk factor screening and preventative protocol • Non-pharmacological treatment of delirium • Immunosuppressive treatment for GBS • Immunosuppressive therapy for myasthenic crisis • Status epilepticus identification and seizure cessation • Status epilepticus treatment with antiepileptic • EEG for status epilepticus and coma • Discussion and documentation of advanced directives • Discussion and documentation of goals of care • Treatment of bacterial meningitis 	<ul style="list-style-type: none"> • Baseline severity scale in stroke • Admission unit for stroke • Acute interventions in ischemic stroke • Vascular imaging in ischemic stroke • Symptomatic ICH after ischemic stroke intervention • Decompressive craniectomy in ischemic stroke • Coagulopathy reversal in ICH • Avoidance of steroids in ICH • Nimodipine in aneurysmal subarachnoid hemorrhage • Screening for vasospasm, in aneurysmal subarachnoid hemorrhage • Immunomodulatory treatment for Guillain-Barre syndrome • Dexamethasone in bacterial meningitis • Dexamethasone in tuberculous meningitis • Benzodiazepines in status epilepticus • Status epilepticus treatment with anticonvulsant medication • Avoidance of steroids in traumatic brain injury • Targeted temperature management in cardiac arrest • Documentation of external ventricular drain insertion bundle • Venous thrombolism prophylaxis in neurocritical care 	<ul style="list-style-type: none"> • Using the Glasgow Coma Scale • Triage and transport • Goals of treatment • Intracranial pressure monitoring • Management of intracranial hypertension • Advanced neuromonitoring • Surgical management • Tracheostomy • Timing of secondary procedures • Nutritional support • Timing of pharmacologic venous thrombolism prophylaxis • Management considerations for pediatric patients with TBI • Management considerations for elderly patients with TBI • Prognostic decision-making and withdrawal of medical support • Outcome assessment and quality improvement in TBI

Future Directions

The field of neurocritical care has made tremendous strides over the last few decades, and the body of evidence for NCC quality improvement has become robust enough to merit the publication of quality measurement sets and NCCU structure recommendations, as well as documents multiple QI initiatives that have demonstrably improved care at various institutions. More research is needed to continue to identify NCCU structures and processes associated with the highest risks and costs and strategies to optimize them. Because a diversity of providers and care models are responsible for the care of these patients, NCC providers should continue to update and standardize their practice in light of the current NCC QI literature and consider creating or modifying their own NCC QI programs with dashboards using published NCC PMs. More study is needed to validate the measures in these PM sets, encourage the clinical adoption of those that prove associated with outcomes, and codify them via certifications or awards from national organizations and reimbursement strategies by healthcare payers.

Compliance with Ethical Standards

Conflict of Interest

Navaz Karanjia declares that she has no potential conflicts of interest. Venkataditya Dugyala declares that he has no potential conflicts of interest. Casey Olm-Shipman declares that she has no potential conflicts of interest. Abhijit V. Lele reports salary support from LifeCenter Northwest.

Human and Animal Rights and Informed Consent

This article does not contain any studies with human or animal subjects performed by any of the authors.

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References and Recommended Reading

Papers of particular interest, published recently, have been highlighted as:

- Of importance
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