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NEUROCRITICAL CARE SOCIETY

ORIGINAL WORK

Neurocritical Care Organization in the Low-Income and Middle-Income Countries

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Abstract

Background: This study aimed to assess the organization, infrastructure, workforce, and adherence to protocols in neurocritical care across low- and middle-income countries (LMICs), with the goal of identifying key gaps and opportunities for improvement.

Methods: We conducted a cross-sectional survey of 408 health care providers from 42 LMICs. The survey collected data on the presence of dedicated neurointensive care units, workforce composition, access to critical care technologies, and adherence to evidence-based protocols. Data were analyzed using descriptive statistics, and comparisons were made across different geographical regions (East Asia and the Pacific, Europe and Central Asia, Latin America and the Caribbean, the Middle East and North Africa, and South Asia and sub-Saharan Africa) and economic strata [low-income countries (LICs), lower middle-income countries (LoMICs), and upper middle-income countries (UMICs)].

Results: Only 36.8% of respondents reported access to dedicated neurointensive care units: highest in the Middle East (100%), lowest in sub-Saharan Africa (11.5%), highest in LoMICs (42%), and lowest in LICs (13%). Access to critical care technologies, such as portable computed tomography scanners (9.3%; UMICs 11%, LICs 0%) and tele-intensive care unit services (14.9%; UMICs 19%, LICs 10%), was limited. Workforce shortages were evident, with many institutions relying on anesthesia residents for 24-h care. Adherence to protocols, including those for acute ischemic stroke (61.7%) and traumatic brain injury (55.6%), was highest in Latin America and the Caribbean (72% and 73%, respectively) and higher in UMICs (66% and 60%, respectively) but remained low in LICs (22% and 32%, respectively).

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Conclusions: The study highlights critical gaps in infrastructure, workforce, and technology across LMICs, yet it also underscores the potential for improvement. Strategic investments in neurointensive care unit capacity, workforce development, and affordable technologies are an unmet need in resource-limited settings. These findings offer a road map for policymakers and global health stakeholders to prioritize neurocritical care and reduce the disparities in patient outcomes globally.

Keywords: Low-income countries, Middle-income countries, Neurocritical care, Intensive care unit, Protocols, Organization

Introduction

Neurocritical care (NCC) has rapidly evolved over the past few decades as a distinct subspecialty of critical care medicine. This growth is driven by evidence showing that patients with acute brain injuries have improved outcomes when treated in dedicated units by a team specialized in NCC. Although NCC has become well-established in high-income countries (HICs), it remains in its early stages in many low- and middle-income countries (LMICs) [1–4].

Significant disparities exist between HICs and LMICs regarding access to essential resources, such as intensive care unit (ICU) beds, neuroimaging, clinical laboratories, neurosurgical capacity, and medications for managing complex neurological conditions. In LMICs, there is an acute shortage of health care workers trained to manage neurologic emergencies, with subspecialized NCC expertise largely absent [1]. These resource limitations create barriers to delivering effective NCC, and limited information exists regarding the current state of NCC capacity in LMICs [3, 5–7].

Although the Point Prevalence in Neurocritical Care (PRINCE) study, conducted by the Neurocritical Care Society (NCS), aimed to provide a global overview of NCC practices, its findings primarily reflected the experience of large academic centers in high-resource settings, with minimal representation from LMICs [8, 9]. In particular, only 13.3% of participation came from Asian countries, and no data were collected from Africa. Given this underrepresentation, the results of the PRINCE studies cannot be fully extrapolated to LMICs, where the challenges are markedly different.

Our study focuses exclusively on NCC practices in resource-limited settings to address this gap. By expanding upon the PRINCE study findings and contextualizing them for LMICs, we aim to understand the organization of NCC in these countries. Although not all hospitals where NCC is rendered were included, we believe this study would provide valuable insights into resource allocation, disease burden, and potential areas for research. Ultimately, this information may help LMICs prioritize resources and develop strategies to improve care for patients with neurological injuries, who often face higher morbidity and mortality compared to those in HICs. The primary objective of our study was to understand the organization of NCC in the LMICs. We hypothesized that access to and infrastructure of NCC services are limited in LMICs.

Methods

Ethics Approval

Ethical approval for this study was obtained from the Institute Ethics Committee (IEC) at the All India Institute of Medical Sciences, New Delhi, India. Participating institutes in the various LMICs sought clearance from their respective ethics committees, facilitated by the national coordinators who received the final protocol, IEC approval letter, and related documents.

Survey Design

We adapted the Case Report Form originally developed for the PRINCE study by the NCS [8, 9].The Case Report Form was reviewed by the steering committee, which included authors from the original study and representatives from participating LMICs, who provided suggestions and necessary modifications to contextualize the form for resource-limited settings (Appendix 1). The steering committee consisted of experts in NCC, global health, epidemiology, and public health. Members were selected based on their expertise in the field and their involvement in the design and review of the study.

Study Participants

This survey targeted health care workers involved in NCC in various hospital settings across LMICs. Multiple responses from different respondents within the same hospital were permitted. All participants were asked to provide their names and affiliations before completing the survey, ensuring transparency and allowing us to acknowledge all respondents as collaborators in the study.

Survey Distribution

The survey was conducted over 3 months using a chain sampling method. National representatives from LMICs recruited participants through informal networking, emails, and social media platforms, including WhatsApp groups and critical care society mailing lists. The national representatives were identified based on their involvement with professional societies, health organizations, or academic institutions focusing on NCC or critical care in LMICs. These individuals were selected for their expertise and connections with their countries' health care systems, allowing them to distribute the survey to relevant institutions and colleagues. These individuals were identified for their expertise and their ability to distribute the survey to relevant institutions within their countries. Although these representatives were not necessarily formally designated by national societies, they were influential figures in their professional communities. It is important to note that although we aimed to represent a broad range of low-income countries (LICs) and middle-income countries (MICs), the sample may not fully encompass all countries within these groups. Some countries may have been underrepresented because of the absence of an identified representative with the relevant connections. Study data were collected using Google Forms, which enabled real-time collaboration and automatic data entry into a central spreadsheet for analysis. Because of the diversity of methods used to disseminate the details of the study, we do not know the total number of invitation recipients.

Study Design

This was an observational study in which the participation was voluntary and uncompensated. Representatives from each LMIC disseminated the survey link to critical care centers and institutions in their countries. Participation was open to all health care professionals working in NCC. "Working in NCC" was defined as health care providers who manage neurocritical patients, regardless of whether they work in a dedicated NCC unit. This includes physicians and other health care providers involved in the care of neurocritical patients in general ICUs, emergency departments, or other settings.

Statistical Analysis

Data were analyzed using Stata (18.0, StataCorp LP, College Station, TX). Descriptive statistics were used to summarize the data. Differences in NCC practices among world regions were assessed using the Kruskal–Wallis test, whereas economic status–based differences based on World Bank classification [10] were analyzed using Pearson's χ^2 test. We classified countries according to the World Bank's income categories, which include LICs, lower middle-income countries (LoMICs), and upper middle-income countries (UMICs). For this study, we have focused on countries within the LIC, LMIC, and UMIC categories, which are collectively referred to as non-high-income countries (non-HICs). The world was divided into six geographical regions, following the World Bank classification: East Asia and the Pacific, Europe and Central Asia, Latin America and the Caribbean, the Middle East and North Africa, South Asia, and sub-Saharan Africa [10]. Given the exploratory nature of this study, a priori sample size calculations and power analyses were not conducted. All P values were two-tailed, with values below 0.05 considered statistically significant.

Results

Response to the Survey

A total of 408 respondents from 42 LMICs and 347 sites participated in the survey (Fig. 1, Appendix 2). The highest representation of the respondents was from India (71; 17.4%), followed by Indonesia (35; 8.6%), Nepal (28; 6.9%), Ethiopia (27; 6.6%), and Pakistan (27; 6.6%). According to the geographic location, 131 (32.1%) respondents were from South Asia, 128 (31.4%) were from Latin America and the Caribbean, 70 (17.2%) were from East Asia and the Pacific, 52 (12.8%) were from sub-Saharan Africa, 25 (6.1%) were from Europe and Central Asia, and 2 (0.5%) were from the Middle East and North Africa. According to the economic status of the countries, the majority of respondents were from UMICs (193; 47.3%), followed by LoMICs (184; 45.1%) and LICs (31; 7.6%).

Institutional Characteristics

The overall characteristics of participating institutions are tabulated in Table 1. There was a significant variation in the distribution of the type of institution across the LMICs. Most respondents in different regions worked in government teaching institutes, whereas in the South Asian countries, they represented private teaching hospitals. Most of them lived in cities with more than 1 million inhabitants. A significant variation was noted in the number of beds in institutions across all the regions, ranging from less than 250 beds to 750 beds. A significant variation was noted in availability of dedicated neuro-ICUs across the six geographical regions, ranging from 11.5% in sub-Saharan Africa to 100% in the Middle East and North Africa (Table 2). Nearly 42% of respondents in the LoMICs worked in dedicated neuro-ICUs. The majority of respondents worked in mixed medical–surgical ICUs across all regions. A similar pattern was noted in the LICs, LoMICs and UMICs. The facilities for the in-house tele-ICU also varied significantly across the geographic regions but not among the LICs, LoMICs and

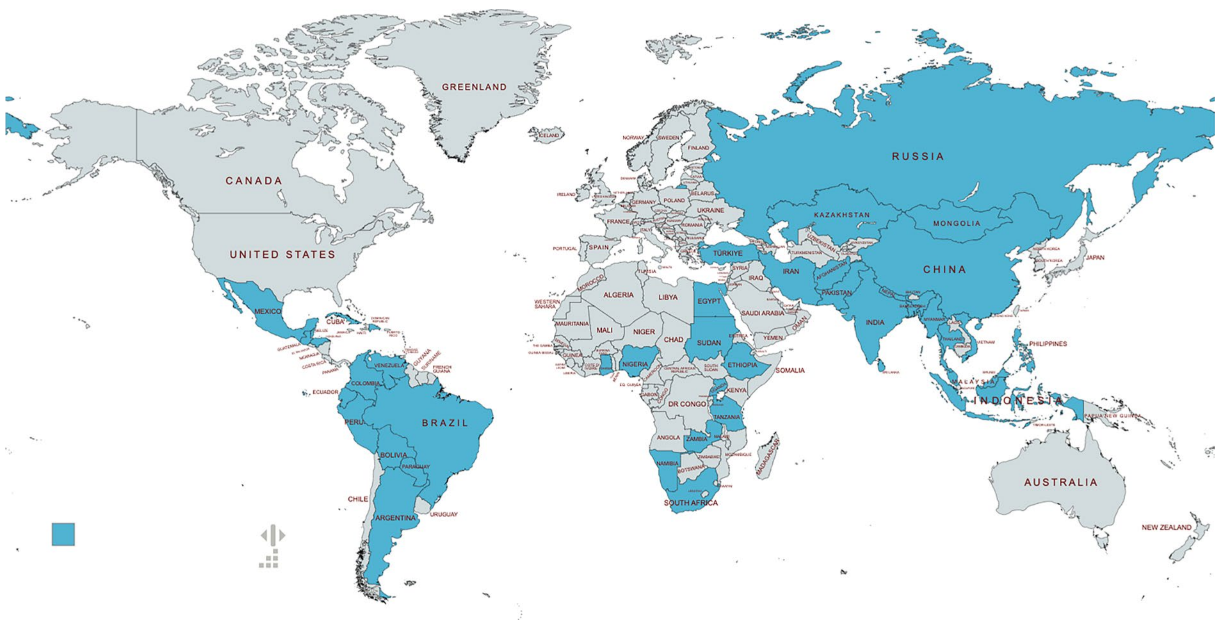

Fig. 1 Representation of low- and middle-income countries in various geographical regions

UMICs (Table 3). Variations in the type of intensivists and residency programs across various LMICs have been tabulated (Tables 2 and 3).

Staffing and Resource Allocation

There were several remarkable findings in resource allocation across the LMICs worldwide (Table 4). The 24-h availability of physicians in the ICU varied across the LMICs and was lowest in the East Asia and Pacific region. It was mainly the anesthesia residents who were available 24 h in the ICU in all geographical regions except Europe and Central Asia. The respondents from this region reported the availability of pulmonary consultants for 24 h. Sub-Saharan Africa reported the lowest availability of dedicated physiotherapists and respiratory therapists. The Middle East and North Africa reported the nonavailability of advanced practice providers (APPs). In general, most respondents reported the nurse to patient ratio in the intensive care as 1:2 both during daytime and nighttime. However, the nurse to patient ratio was 1:3, both during daytime and nighttime, in Europe and Central Asia (Table 4).

The availability of anesthesia residents 24 h in the ICU was reported by the majority of the respondents in the LICs, LoMICs, and UMICs (Table 3). NCC residency was reported by only a small percentage of respondents in the LoMICs and UMICs. Only a small percentage of respondents (6–18%) reported the availability of in-house tele-ICUs and telemedicine for remote hospitals across the LMICs. Most respondents reported a nurse to patient ratio of 1:2 during daytime and nighttime. Less than 50% of respondents reported availability of a dedicated pharmacist. Among the LMICs, the availability of a dedicated physiotherapist, respiratory therapist, and APPs was lowest in the LICs. The availability of portable computed tomography (CT) scanners was less than 11% in the UMICs and 9.2% in the LoMICs. It was not available in the LICs. Around 45% of respondents reported the presence of a dedicated transport team in their institutes, compared to only 19% in the LICs (Table 3).

Technological Resources

Access to critical care technologies, such as portable CT scanners and tele-ICU services, was limited across LMICs. Only 9.3% of respondents reported the availability of portable CT scanners, with a higher prevalence in UMICs (19.3%) compared to LICs (0%) (Table 4). Similarly, tele-ICU services were available in only 14.9% of institutions overall, with the highest availability in UMICs (21.3%) (Table 4).

Comparison of Neuro-ICUs and Non-neuro-ICUs Regarding Reported use of Protocols and Guidelines

Overall, dedicated neuro-ICUs reported greater use of protocols than non-neuro-ICUs. For example, American

Table 1 Overall data from low- and middle-income countries ($n=408$)

	Value
Type of institutions, *n* (%)	
Government teaching	220 (53.9)
Government nonteaching	32 (7.8)
Private teaching	102 (25)
Private nonteaching	52 (12.8)
Faith based	2 (0.5)
Number of hospital beds, *n* (%)	
< 250	118 (28.9)
251–500	123 (30.2)
501–750	48 (11.8)
751–1000	58 (14.2)
> 1000	61 (14.9)
City population, *n* (%)	
< 100,000	10 (2.5)
100,000–250,000	46 (11.3)
251,000–500,000	36 (8.2)
501,000–750,000	36 (8.2)
751,000–1 million	41 (10.1)
> 1 million	239 (58.6)
Dedicated neuro-ICU, *n* (%)	150 (36.8)
Type of non-neuro-ICU, *n* (%)	
Surgical	55 (13.5)
Medical	58 (14.2)
Both medical and surgical	233 (57.1)
Type of intensivist, *n* (%)	
Neurointensivist	107 (26.2)
Pulmonary and critical care	105 (25.7)
Anesthesiologist	205 (50.3)
Surgery	22 (5.4)
Physician[a]	140 (34.3)
Neurologist	128 (31.4)
Neurosurgery	182 (44.6)
ICU beds, median (range)	20 (1–900)
Neuro-ICU beds, median (range)	5 (0–300)
Neurological patients, median (range)	146 (0–4,800)
Physician available 24 h, *n* (%)	333 (81.6)
Consultant	195 (47.8)
Resident	220 (53.9)
Fellow	71 (17.4)
Medical officer	171 (41.9)
Type of physician available 24 h, *n* (%)	
Neurology resident	72 (17.7)
Neurosurgery resident	86 (21.1)
Internal medicine	126 (30.9)
General surgery	72 (17.7)
Emergency medicine	68 (16.7)
Anesthesia resident	176 (43.1)
Neurocritical care consultant	74 (18.1)
Pulmonary consultant	85 (20.8)
Anesthesia consultant	147 (36)
Surgery consultant	52 (12.8)
Neurosurgery consultant	68 (16.8)
Neurology residency, *n* (%)	182 (44.6)
Neurosurgery residency, *n* (%)	193 (47.3)
Critical care fellowship, *n* (%)	252 (61.8)
Neurocritical care residency, *n* (%)	55 (13.5)
In-house tele-ICU, *n* (%)	61 (14.9)
Telemedicine for remote hospitals, *n* (%)	51 (12.5)
Daytime nurse/patient ratio, *n* (%)	
1:1	93 (22.8)
1:2	192 (47.1)
1:3	84 (20.6)
1:4	39 (9.6)
Nighttime nurse/patient ratio, *n* (%)	
1:1	67 (16.4)
1:2	173 (42.4)
1:3	107 (26.2)
1:4	61 (14.9)
Dedicated pharmacist, *n* (%)	172 (42.2)
Dedicated physiotherapist, *n* (%)	255 (62.5)
Dedicated respiratory therapist, *n* (%)	179 (43.9)
Dedicated APPs, *n* (%)	130 (31.9)
Physician extenders, *n* (%)	
Nurse practitioners	44 (10.8)
Physician assistant	67 (16.4)
Advanced practice nurse	31 (7.6)
Portable CT scanner, *n* (%)	38 (9.3)
Dedicated transport team, *n* (%)	175 (42.9)

APP, advanced practice provider, CT, computed tomography, ICU, intensive care unit

[a] Internal medicine trained physician

Heart Association (AHA) acute ischemic stroke guidelines were reportedly more commonly used in neuro-ICUs (71.3%) compared to non-neuro-ICUs (56.2%) (Tables 5 and 6). Similarly, traumatic brain injury guidelines were more likely to be used in neuro-ICUs (66%) than in non-neuro-ICUs (49.6%) (Tables 5 and 6). The availability of specialized staff and protocols for managing elevated intracranial pressure and external ventricular drains was also significantly higher in neuro-ICUs (Tables 5 and 6).

Protocols and Guidelines use by Economic Strata and Geographic Regions

The adherence to protocols across LMICs showed considerable variation (Tables 7 and 8). For acute ischemic stroke, 61.7% of respondents followed the AHA guidelines, with the highest adherence in UMICs (66.3%),

Table 2 Characteristics of registered sites according to various geographical locations

	R1 ($n=70$)	R2 ($n=25$)	R3 ($n=128$)	R4 ($n=2$)	R5 ($n=131$)	R6 ($n=52$)	*P* value
Type of institutions							
Government teaching	38 (54.3)	15 (60)	85 (66.4)	2 (100)	37 (28.2)	43 (82.7)	< 0.0001
Government nonteaching	16 (22.9)	6 (24)	8 (6.3)	0 (0)	1 (0.8)	1 (1.9)	
Private teaching	5 (7.1)	1 (4)	27 (21.1)	0 (0)	66 (50.4)	3 (5.8)	
Private nonteaching	11 (15.7)	3 (12)	8 (6.3)	0 (0)	27 (20.6)	3 (5.8)	
Faith based	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (3.9)	
City population							
< 100,000	3 (4.3)	0 (0)	6 (4.7)	0 (0)	1 (0.8)	0 (0)	0.048
100,000–250,000	7 (10)	5 (20)	20 (15.6)	0 (0)	9 (6.9)	5 (9.6)	
251,000–500,000	8 (11.4)	0 (0)	13 (10.2)	0 (0)	11 (8.4)	4 (7.7)	
501,000–750,000	11 (15.7)	1 (4)	13 (10.2)	0 (0)	10 (7.6)	1 (1.9)	
751,000–1 million	6 (8.6)	3 (12)	17 (13.3)	0 (0)	13 (9.9)	2 (3.9)	
> 1 million	35 (50)	16 (64)	59 (46.1)	2 (100)	87 (66.4)	40 (76.9)	
Number of hospital beds							
< 250	15 (21.4)	5 (20)	53 (41.4)	0 (0)	37 (28.2)	8 (15.4)	< 0.0001
251–500	18 (25.7)	4 (16)	51 (39.8)	1 (50)	34 (25.9)	15 (28.9)	
501–750	9 (12.9)	6 (24)	6 (4.7)	0 (0)	20 (15.3)	7 (13.5)	
751–1000	14 (20)	6 (24)	7 (5.5)	0 (0)	18 (13.7)	13 (25)	
> 1000	14 (20)	4 (16)	11 (8.6)	1 (50)	22 (16.8)	9 (17.3)	
Dedicated neuro-ICU	23 (32.9)	19 (76)	46 (35.9)	2 (100)	54 (41.2)	6 (11.5)	< 0.0001
Type of non-neuro-ICU							
Surgical	7 (10)	3 (12)	7 (5.5)	0 (0)	28 (21.4)	10 (19.2)	0.005
Medical	9 (12.9)	1 (4)	11 (8.6)	0 (0)	28 (21.4)	9 (17.3)	0.038
Both medical and surgical	39 (55.7)	8 (32)	97 (75.8)	0 (0)	53 (40.5)	36 (69.2)	< 0.0001
Type of intensivist							
Neurointensivist	18 (25.7)	8 (32)	38 (29.7)	1 (50)	41 (31.3)	1 (1.9)	0.002
Pulmonary and Critical care	6 (8.6)	4 (16)	45 (35.2)	1 (50)	41 (31.3)	8 (15.4)	< 0.0001
Anesthesiologist	50 (71.4)	19 (76)	15 (11.7)	2 (100)	79 (60.3)	40 (76.9)	< 0.0001
Surgery	4 (5.7)	2 (8)	6 (4.7)	0 (0)	9 (6.9)	1 (1.9)	0.795
Physician[a]	8 (11.4)	4 (16)	78 (60.9)	0 (0)	31 (23.7)	19 (36.5)	< 0.0001
Neurologist	30 (42.9)	9 (36)	30 (23.4)	0 (0)	44 (33.6)	15 (28.9)	0.086
Neurosurgery	33 (47.1)	14 (56)	47 (36.7)	2 (100)	60 (45.8)	26 (50)	0.162
Neurology residency	38 (54.3)	19 (76)	54 (42.2)	2 (100)	53 (40.5)	16 (30.8)	0.001
Neurosurgery residency	35 (50)	16 (64)	63 (49.2)	2 (100)	54 (41.2)	23 (44.2)	0.182
Critical care fellowship	37 (52.9)	20 (80)	92 (71.9)	1 (50)	79 (60.3)	23 (44.2)	0.002
Neurocritical care residency	8 (11.4)	7 (28)	16 (12.5)	0 (0)	24 (18.3)	0 (0)	0.007
In-house tele-ICU	10 (14.3)	10 (40)	20 (15.6)	0 (0)	16 (12.2)	5 (9.6)	0.012
Telemedicine for remote hospitals	7 (10)	13 (52)	13 (10.2)	0 (0)	14 (10.7)	4 (7.7)	< 0.0001

Data are presented as *n* (%)

ICU, intensive care unit, R1, East Asia and the Pacific, R2, Europe and Central Asia, R3, Latin America and the Caribbean, R4, the Middle East and North Africa, R5, South Asia, R6, sub-Saharan Africa

[a] Internal medicine trained physicians

the lowest adherence in LICs (22.6%), and the highest adherence in Latin America and the Caribbean (72% and 73%, respectively). Similarly, the use of guidelines for subarachnoid hemorrhage (SAH) and intracerebral hemorrhage (ICH) was more prevalent in UMICs, with 35.8% following the NCS guidelines for SAH and 48.7% following the AHA guidelines for ICH. Europe and Central Asia reported the highest use of the NCS SAH guidelines (60%), whereas Latin America and the Caribbean reported the highest use of the AHA SAH guidelines (54%) and the AHA ICH guidelines (53%).

Table 3 Overall data categorized according to the economic status of LMICs

	LICs ($n = 31$)	LoMICs ($n = 184$)	UMICs ($n = 193$)	P value
Type of institutions				
Government teaching	26 (83.9)	78 (42.4)	116 (60.1)	
Government nonteaching	1 (3.2)	2 (1.1)	29 (15)	
Private teaching	2 (6.5)	70 (38)	30 (15.5)	
Private nonteaching	2 (6.5)	32 (17.4)	18 (9.3)	
Faith based	0 (0)	2 (1.1)	0 (0)	< 0.01
Number of hospital beds				
< 250	6 (19.4)	50 (27.2)	62 (32.1)	
251–500	11 (35.5)	50 (27.2)	62 (32.1)	
501–750	4 (12.9)	27 (14.7)	17 (8.8)	
751–1000	7 (22.6)	23 (12.5)	28 (14.5)	
> 1000	3 (9.7)	34 (18.5)	24 (12.4)	0.23
City population				
< 100,000	0 (0)	3 (1.6)	7 (3.6)	
100,000–250,000	4 (12.9)	14 (7.6)	28 (14.5)	
251,000–500,000	3 (9.7)	14 (7.6)	19 (9.8)	
501,000–750,000	1 (3.2)	13 (7.1)	22 (11.4)	
751,000–1 million	0 (0)	18 (9.8)	23 (11.9)	
> 1 million	23 (74.2)	122 (66.3)	94 (48.7)	0.03
Dedicated neuro-ICU	4 (12.9)	77 (41.9)	69 (35.8)	0.01
Type of non-neuro-ICU				
Surgical	8 (25.8)	33 (17.9)	14 (7.3)	0.001
Medical	3 (9.7)	39 (21.2)	16 (8.3)	0.001
Both medical and surgical	20 (64.5)	82 (44.6)	131 (67.9)	< 0.01
Type of intensivist				
Neurointensivist	0 (0)	55 (29.9)	52 (26.9)	0.002
Pulmonary and critical care	3 (9.7)	53 (28.8)	49 (25.4)	0.07
Anesthesiologist	27 (87.1)	99 (53.8)	79 (40.9)	< 0.01
Surgery	0 (0)	13 (7.1)	9 (4.7)	0.23
Physician[a]	8 (25.8)	56 (20.4)	76 (39.4)	0.11
Neurologist	4 (12.9)	69 (37.5)	55 (28.5)	0.01
Neurosurgery	12 (38.7)	87 (47.3)	83 (43)	0.56
Physician available 24 h	27 (87.1)	145 (78.8)	161 (83.4)	0.37
Consultant	11 (35.5)	95 (51.6)	89 (46.1)	0.2
Resident	21 (67.7)	95 (51.6)	104 (53.9)	0.25
Fellow	2 (6.5)	41 (22.3)	28 (14.5)	0.03
Medical officer	3 (9.7)	70 (38)	98 (50.8)	< 0.01
Type of physician available 24 h				
Neurology resident	2 (6.5)	33 (17.9)	37 (19.2)	0.22
Neurosurgery resident	3 (9.7)	33 (17.9)	50 (25.9)	0.05
Internal medicine	10 (32.3)	61 (33.2)	55 (28.5)	0.61
General surgery	3 (9.7)	32 (17.4)	37 (19.2)	0.43
Emergency medicine	9 (29)	17 (9.2)	42 (21.8)	0.001
Anesthesia resident	18 (58.1)	87 (47.3)	71 (36.8)	0.03
Neurocritical care consultant	0 (0)	36 (19.6)	38 (19.7)	0.02
Pulmonary consultant	2 (6.5)	27 (14.7)	56 (29)	< 0.01
Anesthesia consultant	10 (32.3)	72 (39.1)	65 (33.7)	0.49
Surgery Consultant	2 (6.5)	13 (7.1)	37 (19.2)	0.001
Neurosurgery Consultant	4 (12.9)	19 (10.4)	45 (23.3)	0.003

Table 3 (continued)

	LICs ($n = 31$)	LoMICs ($n = 184$)	UMICs ($n = 193$)	*P* value
Neurology residency	8 (25.8)	80 (43.5)	94 (48.7)	0.05
Neurosurgery residency	13 (41.9)	84 (45.7)	96 (49.7)	0.60
Critical care fellowship	15 (48.4)	112 (60.9)	125 (64.8)	0.21
Neurocritical care residency	0 (0)	31 (16.9)	24 (12.4)	0.03
In-house tele-ICU	3 (9.7)	22 (11.9)	36 (18.6)	0.13
Telemedicine for remote hospitals	2 (6.5)	17 (9.2)	32 (16.6)	0.06
Daytime nurse/patient ratio				
1:1	14 (45.2)	42 (22.8)	37 (19.2)	
1:2	15 (48.4)	83 (45.1)	94 (48.7)	
1:3	1 (3.2)	39 (21.2)	44 (22.8)	
1:4	1 (3.2)	20 (10.9)	18 (9.3)	0.02
Nighttime nurse/patient ratio				
1:1	12 (38.7)	28 (15.2)	27 (13.9)	
1:2	13 (41.9)	79 (42.9)	81 (41.9)	
1:3	2 (6.5)	50 (27.2)	55 (28.5)	
1:4	4 (12.9)	27 (14.7)	30 (15.5)	0.02
Dedicated pharmacist	14 (45.2)	67 (36.4)	91 (47.2)	0.10
Dedicated physiotherapist	9 (29)	130 (70.7)	116 (60.1)	< 0.01
Dedicated respiratory therapist	4 (12.9)	75 (40.8)	100 (51.8)	< 0.01
Dedicated APPs	5 (16.1)	42 (22.8)	83 (43)	< 0.01
Portable CT scanner	0 (0)	17 (9.2)	21 (10.9)	0.15
Dedicated transport team	6 (19.4)	83 (45.1)	86 (44.6)	0.02

Data are presented as *n* (%)

APP, advanced practice provider, CT, computed tomography, ICU, intensive care unit, LIC, low-income country, LMICs, low- and middle-income countries, LoMIC, lower middle-income country, UMIC, upper middle-income country

[a] Internal medicine trained physician

Protocols for traumatic brain injury also varied, with 55.6% of respondents following the Brain Trauma Foundation (BTF) guidelines. Use of the guidelines was highest in UMICs (60.1%), lowest in LICs (32.3%), and highest in Europe and Central Asia (72%). Other protocols, such as those for managing sepsis, ventilation-associated pneumonia, and fever management, were followed in most institutions, with slight regional variations.

Discussion

This study provides an overview of the organization, resources, and protocols of NCC in the LMICs, revealing significant gaps in infrastructure, workforce, and adherence to standardized protocols. Despite these challenges, our data also highlight key opportunities for improving care delivery and suggest potential areas that can be the priority for global health investment. Our findings show substantial variability in the availability of neuro-ICUs, staffing levels, technological resources, and adherence to guidelines for managing neurological emergencies such as stroke, traumatic brain injury, and ICH. Although our data reflect institutional availability, regional centers may play a role in providing NCC in some areas. Importantly, this study underscores the need for targeted interventions to strengthen NCC capacity in LMICs, particularly in workforce development, technology access, and protocol implementation. These results provide early insights into the organization of NCC, which would be important for policymakers, health ministries, and frontline providers as they make decisions about resource allocation and system reforms.

Global Gaps in NCC Infrastructure

One of the most striking findings from our study is the uneven distribution of dedicated neuro-ICUs across LMICs. Although some regions, such as the Middle East and North Africa, report access to neuro-ICUs with resources like the ones reported by HIC hospitals in the PRINCE study, others, particularly sub-Saharan Africa, face severe shortages, with only one in ten respondents indicating access to dedicated units. This disparity points to a critical need for infrastructure development in regions with low neuro-ICU capacity, as dedicated NCC has been shown to improve outcomes in patients

Table 4 ICU characteristics according to resource allocation in various geographical locations

	R1 ($n = 70$)	R2 ($n = 25$)	R3 ($n = 128$)	R4 ($n = 2$)	R5 ($n = 131$)	R6 ($n = 52$)	P value
Physician available 24 h, n (%)	51 (72.9)	22 (88)	116 (90.6)	2 (100)	102 (77.9)	40 (76.9)	0.018
Consultant	24 (34.3)	13 (52)	66 (51.6)	1 (50)	65 (49.6)	26 (50)	0.278
Resident	34 (48.6)	12 (48)	80 (62.5)	1 (50)	64 (48.9)	29 (55.8)	0.27
Fellow	12 (17.1)	5 (20)	17 (13.3)	1 (50)	31 (23.7)	5 (9.6)	0.114
Medical officer	39 (55.7)	16 (64)	57 (44.5)	0 (0)	44 (33.6)	15 (28.9)	0.001
Type of physician available 24 h, n (%)							
Neurology resident	21 (30)	11 (44)	17 (13.3)	1 (50)	19 (14.5)	3 (5.8)	< 0.0001
Neurosurgery resident	18 (25.7)	10 (40)	28 (21.9)	1 (50)	23 (17.6)	6 (11.5)	0.048
Internal medicine	17 (24.3)	6 (24)	50 (39.1)	1 (50)	32 (24.4)	20 (38.5)	0.067
General surgery	11 (15.7)	8 (32)	28 (21.9)	1 (50)	17 (12.9)	7 (13.5)	0.097
Emergency medicine	5 (7.1)	6 (24)	34 (26.6)	1 (50)	11 (8.4)	11 (21.2)	< 0.0001
Anesthesia resident	30 (42.9)	19 (76)	34 (26.6)	2 (100)	65 (49.6)	26 (50)	< 0.0001
Neurocritical care consultant	12 (17.1)	8 (32)	29 (22.7)	1 (50)	23 (17.6)	1 (1.9)	0.008
Pulmonary consultant	3 (4.3)	6 (24)	54 (42.2)	1 (50)	19 (14.5)	2 (3.9)	< 0.0001
Anesthesia consultant	29 (41.4)	16 (64)	27 (21.1)	1 (50)	59 (45.0)	15 (28.9)	< 0.0001
Surgery consultant	4 (5.7)	11 (44)	28 (21.9)	1 (50)	4 (3.1)	4 (7.7)	< 0.0001
Neurosurgery consultant	14 (20.3)	8 (32)	30 (23.4)	1 (50)	8 (6.2)	7 (13.5)	0.0001
Dedicated pharmacist, n (%)	42 (60)	10 (40)	47 (36.7)	1 (50)	48 (36.6)	24 (46.2)	0.026
Dedicated physiotherapist, n (%)	40 (57.1)	12 (48)	79 (61.7)	2 (100)	99 (75.6)	23 (44.2)	0.001
Dedicated respiratory therapist, n (%)	14 (20)	10 (40)	85 (66.4)	1 (50)	63 (48.1)	6 (11.5)	< 0.0001
Dedicated APPs, n (%)	23 (32.9)	12 (48)	58 (45.3)	0 (0)	28 (21.4)	9 (17.3)	< 0.0001
Daytime nurse/patient ratio, n (%)							
1:1	24 (34.3)	0 (0)	13 (10.2)	1 (50)	36 (27.5)	19 (36.5)	< 0.0001
1:2	29 (41.4)	11 (44)	64 (50)	1 (50)	63 (48.1)	24 (46.2)	
1:3	9 (12.9)	12 (48)	32 (25)	0 (0)	28 (21.4)	3 (5.8)	
1:4	8 (11.4)	2 (8)	19 (14.8)	0 (0)	4 (3.1)	6 (11.5)	
Nighttime nurse/patient ratio, n (%)							
1:1	15 (21.4)	2 (8)	9 (7)	1 (50)	24 (18.3)	16 (30.8)	< 0.0001
1:2	24 (34.3)	5 (20)	62 (48.4)	0 (0)	62 (47.3)	20 (38.5)	
1:3	19 (27.1)	14 (56)	33 (25.8)	1 (50)	33 (25.2)	7 (13.5)	
1:4	12 (17.1)	4 (16)	24 (18.8)	0 (0)	12 (9.2)	9 (17.3)	
Dedicated transport team, n (%)	24 (34.3)	16 (64)	60 (46.9)	0 (0)	58 (44.3)	17 (32.7)	0.046
Portable CT scanner, n (%)	0 (0)	5 (20)	21 (16.4)	0 (0)	12 (9.2)	0 (0)	< 0.0001
ICU beds, median (range)	20 (3–165)	20 (2–250)	14 (1–900)	85 (70–100)	35 (4–250)	10 (3–40)	0.301
Neurocritical care beds, median (range)	4 (0–40)	7 (0–50)	5 (0–300)	17 (14–20)	8 (0–115)	2 (0–15)	0.301
Neurological patients, median (range)	200 (0–4000)	200 (0–3000)	100 (0–1700)	651 (2–1300)	250 (0–4800)	51 (0–600)	0.301

APP, advanced practice provider, CT, computed tomography, ICU, intensive care unit, R1, East Asia and the Pacific, R3, Latin America and the Caribbean, R5, South Asia, R2, Europe and Central Asia, R4, Middle East and North Africa, R6, sub-Saharan Africa

with acute brain injuries [9, 11–13]. This early finding highlights the importance of investing in the physical infrastructure needed to deliver specialized care, particularly in rural and under-resourced areas. Expanding neuro-ICU availability could be a crucial first step in closing the outcome gap between HICs and LMICs. Local health policymakers, health care administrators, and regional experts should determine the distribution of specialty units. These decisions should be informed by factors such as local health care needs, patient burden, and available resources. A flexible and adaptive approach, with periodic reviews of health care priorities, would allow for a more sustainable distribution of resources.

Workforce Challenges and Opportunities

The survey revealed that staffing remains a significant challenge in many LMICs, with large variations in the availability of 24-h physician coverage, physiotherapists, respiratory therapists, and APPs. Notably, most NCC in

Table 5 Overall data from the low- and middle-income countries in the neuro-ICU and non-neuro-ICU

	Total ($n=408$)	Neuro-ICU ($n=150$)	Non-neuro-ICU ($n=258$)	P value
Region				
East Asia and the Pacific	70 (17.2)	23 (15.3)	47 (18.2)	< 0.01
Europe and Central Asia	25 (6.1)	19 (12.7)	6 (2.3)	
Latin America and the Caribbean	128 (31.4)	46 (30.7)	82 (31.8)	
Middle East and North Africa	2 (0.5)	2 (1.3)	0 (0)	
South Asia	131 (32.1)	54 (36)	77 (29.8)	
Sub-Saharan Africa	52 (12.7)	6 (4)	46 (17.8)	
Type of institution				
Government teaching	220 (53.9)	85 (56.7)	135 (52.3)	0.02
Government nonteaching	32 (7.8)	6 (4)	26 (10.1)	
Private teaching	102 (25)	46 (30.7)	56 (21.7)	
Private nonteaching	52 (12.8)	13 (8.7)	39 (15.1)	
Faith based	2 (0.5)	0 (0)	2 (0.8)	
Number of hospital beds				
< 250	118 (28.9)	33 (22)	85 (32.9)	< 0.01
251–500	123 (30.2)	39 (26)	84 (32.6)	
501–750	48 (11.8)	16 (10.7)	32 (12.4)	
751–1000	58 (14.2)	22 (14.7)	36 (13.9)	
> 1000	61 (14.9)	40 (26.7)	21 (8.1)	
City population				
< 100,000	10 (2.5)	3 (2)	7 (2.7)	0.01
100,000–250,000	46 (11.3)	12 (8)	34 (13.2)	
251,000–500,000	36 (8.2)	10 (6.7)	26 (10.1)	
501,000–750,000	36 (8.2)	7 (4.7)	29 (11.2)	
751,000–1 million	41 (10.1)	12 (8)	29 (11.2)	
> 1 million	239 (58.6)	106 (70.7)	133 (51.6)	
Type of non-neuro-ICU				
Surgical	55 (13.5)	10 (6.7)	140 (93.3)	0.002
Medical	58 (14.2)	9 (6)	49 (18.9)	
Both medical and surgical	233 (57.1)	35 (23.3)	115 (76.7)	
Type of intensivist				
Neurointensivist	107 (26.2)	76 (50.7)	31(12.0)	< 0.01
Pulmonary and critical care	105 (25.7)	43 (28.7)	62 (24)	0.30
Anesthesiologist	205 (50.3)	64 (42.7)	141 (54.6)	0.02
Surgery	22 (5.4)	14 (9.3)	8 (3.1)	0.01
Physician[a]	140 (34.3)	44 (29.3)	96 (37.2)	0.11
Neurologist	128 (31.4)	61 (40.7)	67 (25.9)	0.002
Neurosurgery	182 (44.6)	79 (52.7)	103 (39.9)	0.01
Physician available 24 h	333 (81.6)	133 (88.7)	200 (77.5)	0.01
Consultant	195 (47.8)	76 (50.7)	119 (46.1)	0.38
Resident	220 (53.9)	94 (62.7)	126 (48.8)	0.01
Fellow	71 (17.4)	34 (22.7)	37 (14.3)	0.03
Medical officer	171 (41.9)	59 (39.3)	112 (43.4)	0.42
Type of physician available 24 h				
Neurology resident	72 (17.6)	51 (34)	21 (8.1)	< 0.01
Neurosurgery resident	86 (21.1)	56 (37.3)	30 (11.6)	< 0.01
Internal medicine	126 (30.9)	44 (29.3)	82 (31.9)	0.61
General surgery	72 (17.7)	30 (20)	42 (16.3)	0.34
Emergency medicine	68 (16.7)	28 (18.7)	40 (15.5)	0.41

Table 5 (continued)

	Total ($n = 408$)	Neuro-ICU ($n = 150$)	Non-neuro-ICU ($n = 258$)	*P* value
Anesthesia resident	176 (43.1)	73 (48.7)	103 (39.9)	0.08
Neurocritical care consultant	74 (18.1)	52 (34.7)	22 (8.5)	< 0.01
Pulmonary consultant	85 (20.8)	33 (22)	52 (20.2)	0.66
Anesthesia consultant	147 (36)	50 (33.3)	97 (37.6)	0.39
Surgery consultant	52 (12.8)	26 (17.3)	26 (10.1)	0.03
Neurosurgery consultant	68 (16.8)	34 (22.8)	34 (13.2)	0.01
Neurology residency	182 (44.6)	104 (69.3)	78 (30.2)	< 0.01
Neurosurgery residency	193 (47.3)	107 (71.3)	86 (33.3)	< 0.01
Critical care fellowship	252 (61.8)	117 (78)	135 (52.3)	< 0.01
Neurocritical care residency	55 (13.5)	43 (28.7)	12 (4.7)	< 0.01
In-house tele-ICU	61 (14.9)	32 (21.3)	29 (11.2)	0.01
Telemedicine for remote hospitals	51 (12.5)	28 (18.7)	23 (8.9)	0.004
Daytime nurse/patient ratio				
1:1	93 (22.8)	17 (11.3)	76 (29.5)	< 0.01
1:2	192 (47.1)	84 (56)	108 (41.9)	
1:3	84 (20.6)	32 (21.3)	52 (20.2)	
1:4	39 (9.6)	17 (11.3)	22 (8.5)	
Nighttime nurse/patient ratio				
1:1	67 (16.4)	9 (6)	58 (22.5)	< 0.01
1:2	173 (42.4)	75 (50)	98 (37.9)	
1:3	107 (26.2)	38 (25.3)	98 (37.9)	
1:4	61 (14.9)	28 (18.7)	33 (12.8)	
Dedicated pharmacist	172 (42.2)	71 (47.3)	101 (39.2)	0.11
Dedicated physiotherapist	255 (62.5)	109 (72.7)	146 (56.6)	0.001
Dedicated respiratory therapist	179 (43.9)	85 (56.7)	94 (36.4)	< 0.01
Dedicated APPs	130 (31.9)	54 (36)	76 (29.5)	0.17
Physician extenders				
Nurse practitioners	44 (10.8)	17 (11.3)	27 (10.5)	0.47
Physician assistant	67 (16.4)	26 (17.3)	41 (15.9)	
Advanced practice nurse	31 (7.6)	15 (10)	16 (6.2)	
Portable CT scanner	38 (9.3)	29 (19.3)	9 (3.5)	< 0.01
Dedicated transport team	175 (42.9)	74 (49.3)	101 (39.1)	0.04

Data are presented as *n* (%)

APP, advanced practice provider, CT, computed tomography, ICU, intensive care unit

[a] Internal medicine trained physician

LICs is provided by anesthesia residents, a model that is far from ideal given the complexity of neurological emergencies. The absence of neurointensivists and NCC consultants in many regions further compounds this issue. This workforce gap represents both a challenge and an opportunity. Investments in NCC-specific training programs, fellowships, and continuing education initiatives could help build a sustainable workforce capable of managing these patients. Training programs should be designed for neurointensivists and a multidisciplinary team that includes APPs, nurses, and therapists, all of whom play a critical role in providing NCC.

Adherence to Guidelines and Protocols

The inconsistent use of evidence-based protocols across LMICs presents another major challenge. Our data show that although reported adherence to AHA [14] and BTF guidelines [15] is relatively high in UMICs, it remains low in LICs. For example, one in three LIC respondents reported following BTF guidelines for traumatic brain injury, compared to six in ten in UMICs. This discrepancy underscores the need for capacity-building initiatives focused on guideline dissemination and protocol implementation. Education and training on the use of NCC protocols is crucial. We suggest that education-based

Table 6 Protocols followed in low- and middle-income countries in the NICU and non-NICU

	Total ($n = 408$)	NICU ($n = 150$)	Non-NICU ($n = 258$)	P value
AIS following the AHA guidelines	252 (61.8)	107 (71.3)	145 (56.2)	0.002
AIS following the European guidelines	79 (19.4)	33 (22)	46 (17.8)	0.30
SAH following the NCS guidelines	117 (28.7)	55 (36.7)	62 (24)	0.01
SAH following the AHA guidelines	169 (41.4)	82 (54.7)	87 (33.7)	< 0.01
ICH following the AHA guidelines	174 (42.7)	78 (52)	96 (37.2)	0.004
ICH following the European guidelines	78 (19.1)	33 (22)	45 (17.4)	0.26
SE following the NCS guidelines	180 (44.1)	85 (56.7)	95 (36.8)	< 0.01
MV sedation protocol	285 (69.9)	100 (66.7)	185 (71.7)	0.29
MV weaning protocol	258 (63.2)	93 (62)	165 (63.9)	0.69
Sepsis protocol following SSC guidelines	277 (67.9)	109 (72.7)	168 (65.1)	0.12
TBI following the BTF guidelines	227 (55.6)	99 (66)	128 (49.6)	0.001
IH for comatose survivors of cardiac arrest	123 (30.1)	51 (34)	72 (27.9)	0.19
VAP prevention protocol	279 (68.4)	107 (71.3)	172 (66.7)	0.33
DVT prevention protocol	248 (60.8)	99 (66)	149 (57.8)	0.1
OT for cerebral edema and elevated ICP	171 (41.9)	82 (54.7)	89 (34.5)	< 0.01
Fever management protocol	166 (40.7)	72 (48)	94 (36.4)	0.02
Systemic anticoagulation protocol	162 (39.7)	62 (41.3)	100 (38.8)	0.61
Elevated ICP management	194 (47.6)	84 (56)	110 (42.6)	0.01
EVD management and weaning protocol	133 (32.6)	69 (46)	64 (24.8)	< 0.01
Others	282 (69.1)	115 (76.7)	167 (64.7)	0.01

Data are presented as *n* (%)

AHA, American Heart Association, AIS, acute ischemic stroke, BTF, Brain Trauma Foundation, DVT, deep vein thrombosis, EVD, external ventricular drain, ICH, intracerebral hemorrhage, ICP, intracranial pressure, IH, induced hypothermia, MV, mechanical ventilation, NICU, neurointensive care unit, NCS, Neurocritical Care Society, OT, osmolar therapy, SAH, subarachnoid hemorrhage, SE, status epilepticus, SSC, Surviving Sepsis Campaign, TBI, traumatic brain injury, VAP, ventilator-associated pneumonia

solutions could help improve the implementation of existing guidelines, even in resource-constrained settings. Locally tailored protocols should be prioritized to ensure they are contextually relevant. Governments and health organizations should prioritize the development of accessible context-specific guidelines that account for the resource limitations in many LMICs. Furthermore, technology such as telemedicine and mobile health applications can facilitate real-time guideline adherence, providing frontline providers with decision-support tools that enable evidence-based care. In resource-limited settings, a hub-and-spoke model can be highly effective, whereby larger academic or government hospitals (the "hubs") with advanced medical infrastructure and expertise provide remote support to smaller resource-constrained institutions (the "spokes") in more remote or underserved areas. This model allows high-quality care and consultations from experts in central locations, extending critical care services to peripheral facilities that lack specialized resources. By leveraging telehealth and tele-ICU platforms, this approach can enhance the delivery of NCC in LMICs, bridging gaps in care and improving patient outcomes in regions with limited access to specialized providers.

Technology and Resource Allocation

A key barrier to delivering high-quality NCC in LMICs is the lack of access to technologies that may facilitate care of this patient population, such as portable CT scanners, tele-ICU services, and monitoring devices for intracranial pressure management. Our study found that only 1 in 11 respondents had access to portable CT scanners, with the lowest availability reported in LICs and lower than the 17% reported rate of portable CT scanners from HIC hospitals in the PRINCE study [8]. Similarly, tele-ICU services were available in only one in seven institutions, highlighting a significant gap in technological resources that are critical for managing complex neurological cases. These findings call for increased investment in affordable, scalable technologies that could be deployed to improve NCC in LMICs include mobile health applications, telemedicine platforms, and low-cost monitoring devices. These technologies could help mitigate the challenges posed by limited infrastructure and enhance care delivery. Global health organizations and international donors have a unique opportunity to facilitate technology transfer and provide the necessary tools to enhance diagnostic and monitoring capabilities in LMICs. Expanding access to these technologies can ensure that more patients

Table 7 Protocols followed in various LMICs in various categories of LMICs

Protocol	Total ($n=408$)	LICs ($n=31$)	LoMICs ($n=184$)	UMICs ($n=193$)	*P* value
AIS following the AHA guidelines	252 (61.7)	7 (22.6)	117 (63.6)	128 (66.3)	< 0.01
AIS following the European guidelines	79 (19.4)	4 (12.9)	20 (10.9)	55 (28.5)	< 0.01
SAH following the NCS guidelines	117 (28.7)	1 (3.2)	47 (25.5)	69 (35.8)	< 0.01
SAH following the AHA guidelines	169 (41.4)	3 (9.7)	71 (38.6)	95 (49.2)	< 0.01
ICH following the AHA guidelines	174 (42.7)	3 (9.7)	77 (41.9)	94 (48.7)	< 0.01
ICH following the European guidelines	78 (19.1)	1 (3.2)	24 (13)	53 (27.5)	< 0.01
SE following the NCS guidelines	180 (44.1)	3 (9.7)	87 (47.3)	90 (46.6)	< 0.01
MV sedation protocol	285 (69.9)	21 (67.7)	129 (70.1)	135 (69.9)	0.96
MV weaning protocol	258 (63.2)	15 (48.4)	117 (63.3)	126 (65.3)	0.19
Sepsis protocol following SSC guidelines	277 (67.9)	14 (45.2)	126 (68.5)	137 (70.9)	0.02
TBI following the BTF guidelines	227 (55.64)	10 (32.3)	101 (54.9)	116 (60.1)	0.02
IH for comatose survivors of cardiac arrest	123 (30.2)	2 (6.5)	61 (33.2)	60 (31.1)	0.01
VAP prevention protocol	279 (68.4)	15 (48.4)	135 (73.4)	129 (66.8)	0.02
DVT prevention protocol	248 (60.8)	12 (38.7)	128 (69.6)	108 (55.9)	0.001
OT for cerebral edema and elevated ICP	171 (41.9)	2 (6.5)	81 (44)	88 (45.6)	< 0.01
Fever management protocol	166 (40.7)	3 (9.7)	83 (45.1)	80 (41.5)	0.001
Systemic anticoagulation protocol	162 (39.7)	4 (12.9)	82 (44.6)	76 (39.4)	0.004
Elevated ICP management	194 (47.6)	7 (22.6)	91 (49.5)	96 (49.7)	0.02
EVD management and weaning protocol	133 (32.6)	1 (3.2)	64 (34.8)	68 (35.6)	0.001
Others	282 (69.1)	13 (41.9)	139 (75.5)	130 (67.4)	0.001

Data are presented as *n* (%)

AHA, American Heart Association, AIS, acute ischemic stroke, BTF, Brain Trauma Foundation, DVT, deep vein thrombosis, EVD, external ventricular drain, ICH, intracerebral hemorrhage, ICP, intracranial pressure, IH, induced hypothermia, LIC, low-income country, LMICs, low- and middle-income countries, LoMIC, lower middle-income country, MV, mechanical ventilation, NCS, Neurocritical Care Society, SAH, subarachnoid hemorrhage, SE, status epilepticus, SSC, Surviving Sepsis Campaign, OT, osmolar therapy, TBI, traumatic brain injury, UMIC, upper middle-income country, VAP, ventilator associated pneumonia

receive timely and appropriate care, regardless of their location.

Policy Implications and Path Forward

The findings from this study have important implications for global health policy. Addressing the gaps in NCC will require a coordinated effort that includes financial investment and strong leadership, strategic planning, and collaboration between governments, nongovernmental organizations, and academic institutions. Prioritizing NCC in national health agendas can help catalyze change and direct resources where they are most needed. At the same time, it is essential to engage local communities and health care providers to ensure that solutions are culturally relevant and sustainable.

Policymakers must also recognize that strengthening NCC systems in LMICs is a matter not only of improving patient outcomes but also of promoting equity in global health. Regardless of where they live, every patient with a neurological emergency deserves access to the best possible care. The results of this study should inspire optimism that with targeted interventions, it is possible to build a global NCC system that serves all patients, no matter their geographic or economic circumstances.

Limitations

Although this study provides valuable insights into the state of NCC in LMICs, several limitations must be acknowledged. First, the survey relied on self-reported data, which may be subject to response bias, particularly in regions where resources are limited and there may be pressure to under-report deficits or overstate adherence to protocols. Second, most respondents were from urban academic centers, which may not fully represent the situation in rural or under-resourced areas, where access to specialized care is more limited [16]. We recognize that the sample in this study may not fully represent the diversity of NCC practice across all LICs and MICs. Given the reliance on design and chain sampling methods, the data may be skewed toward the practice settings and networks of those participating in the study design and recruitment process. For example, the high representation of respondents from India (17.4% of the total sample) may not reflect practices in other regions of South Asia or other parts of LICs and MICs. Although 42% of respondents reported working in dedicated NCC units, we acknowledge that these units are not widely available in all regions. Therefore, the overrepresentation of respondents from more developed

Table 8 Protocols followed in various low- and middle-income countries in various geographical regions

	Total (n = 408)	R1 (n = 70)	R2 (n = 25)	R3 (n = 128)	R4 (n = 2)	R5 (n = 131)	R6 (n = 52)	P value
AIS (AHA guidelines)	252 (61.8)	38 (54.3)	19 (76)	93 (72.7)	1 (50)	85 (64.9)	16 (30.8)	< 0.01
AIS (European guidelines)	79 (19.4)	12 (17.1)	16 (64)	33 (25.8)	1 (50)	9 (6.9)	8 (15.4)	< 0.01
SAH (NCS guidelines)	117 (28.7)	19 (27.1)	15 (60)	49 (38.3)	0 (0)	26 (19.9)	8 (15.4)	< 0.01
SAH (AHA guidelines)	169 (41.4)	28 (40)	13 (52)	69 (53.9)	1 (50)	48 (36.6)	10 (19.2)	0.001
ICH (AHA guidelines)	174 (42.7)	28 (40)	13 (52)	67 (52.3)	1 (50)	53 (40.5)	12 (23.1)	0.01
ICH (European guidelines)	78 (19.1)	14 (20)	18 (72)	31 (24.2)	0 (0)	10 (7.6)	5 (9.6)	< 0.01
SE (NCS guidelines)	180 (44.1)	22 (31.4)	13 (52)	73 (57)	1 (50)	58 (44.3)	13 (25)	0.001
MV sedation protocol	285 (69.9)	42 (60)	18 (72)	95 (74.2)	2 (100)	94 (71.8)	34 (65.4)	0.30
MV weaning protocol	258 (63.2)	44 (62.9)	17 (68)	85 (66.4)	2 (100)	84 (64.1)	26 (50)	0.31
Sepsis (SSC guidelines)	277 (67.9)	44 (62.9)	16 (64)	99 (77.3)	2 (100)	91 (69.5)	25 (48.1)	0.005
TBI (BTF guidelines)	227 (55.6)	36 (51.4)	18 (72)	80 (62.5)	1 (50)	74 (56.5)	18 (34.6)	0.01
IH following cardiac arrest	123 (30.2)	22 (31.4)	11 (44)	39 (30.5)	1 (50)	43 (32.8)	7 (13.5)	0.07
VAP prevention protocol	279 (68.4)	42 (60)	16 (64)	91 (71.1)	1 (50)	102 (77.9)	27 (51.9)	0.01
DVT prevention protocol	248 (60.8)	35 (50)	16 (64)	78 (60.9)	2 (100)	94 (71.8)	23 (44.2)	0.004
OT (cerebral edema, ICP)	171 (41.9)	22 (31.4)	14 (56)	64 (50)	1 (50)	59 (45)	11 (21.2)	0.002
Fever management protocol	166 (40.7)	27 (38.6)	15 (60)	50 (39.1)	0 (0)	65 (49.6)	9 (17.3)	0.001
Systemic anticoagulation protocol	162 (39.7)	20 (28.6)	11 (44)	56 (43.8)	1 (50)	63 (48.1)	11 (21.2)	0.007
Elevated ICP management	194 (47.6)	31 (44.3)	11 (44)	71 (55.5)	1 (50)	64 (48.9)	16 (30.8)	0.007
EVD protocol	133 (32.6)	18 (25.7)	13 (52)	43 (33.6)	1 (50)	47 (35.9)	11 (21.2)	0.8
Others	282 (69.1)	48 (68.6)	15 (60)	87 (67.9)	2 (100)	106 (80.9)	24 (46.2)	< 0.01

Data are presented as n (%)

AHA, American Heart Association, AIS, acute ischemic stroke, BTF, Brain Trauma Foundation, DVT, deep vein thrombosis, EVD, external ventricular drain, ICH, intracerebral hemorrhage, ICP, intracranial pressure, IH, induced hypothermia, MV, mechanical ventilation, NCS, Neurocritical Care Society, OT, osmolar therapy, R1, East Asia and the Pacific, R2, Europe and Central Asia, R3, Latin America and the Caribbean, R4, the Middle East and North Africa, R5, South Asia, R6, sub-Saharan Africa, SAH, subarachnoid hemorrhage, SE, status epilepticus, SSC, Surviving Sepsis Campaign, TBI, traumatic brain injury, VAP, ventilator-associated pneumonia

institutions could introduce bias. These limitations should be considered when interpreting the findings, and future studies should aim for a more inclusive and diverse sample that better captures the full range of NCC practices across these countries. Additionally, the relatively low representation from LICs, especially from sub-Saharan Africa, may underestimate the challenges faced in these settings. Furthermore, we were unable to perform a priori sample size calculations because of the study's observational nature, which limits the ability to make generalizable inferences. Moreover, we do not have the total number of invitees and are thus unable to determine the true response rate. It is possible that our response rate may be very low, which could be another source of bias. Given the small sample size from certain regions, we acknowledge that although the study provides valuable insights into NCC in LMICs, the findings should be considered exploratory rather than a comprehensive overview. Despite these limitations, the large geographic scope and diversity of respondents provide a broad snapshot of NCC in LMICs, offering crucial data to guide future research and policy.

Conclusions

In conclusion, this study highlights the challenges and opportunities in advancing NCC in LMICs. The disparities in infrastructure, workforce, and adherence to guidelines underscore the need for targeted investments in these areas. However, the findings also demonstrate that with strategic interventions, including the expansion of neuro-ICU capacity, investment in workforce development, and the integration of scalable technologies, it is possible to improve the quality of NCC in resource-limited settings. This optimistic view should serve as a call to action for global health stakeholders to prioritize NCC in LMICs, ensuring that all patients, regardless of their socioeconomic status or geographic location, have access to life-saving neurological care. By addressing the identified gaps, policymakers, health organizations, and international donors can help build a more equitable and effective global health care system, one that delivers high-quality NCC to those who need it the most.

Supplementary Information

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Conflicts of interest
None of the authors have any conflict of interest.

Ethical Approval/Informed Consent
Ethical approval for this study was obtained from the Institute Ethics Committee (IEC) at the All India Institute of Medical Sciences, New Delhi, India. Participating institutes in the various low- and middle-income countries sought clearance from their respective ethics committees, facilitated by the

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