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RESEARCH

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The LINK—Lombardia NeuroIntensive care Network

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Abstract

Background Despite serving over 10 million inhabitants, neurocritical care across the Lombardy region of Italy (from here on Lombardia) remains fragmented and insufficiently mapped, underscoring the need for a structured regional network. This study aimed to evaluate current resources and explore pathways for integration and development.

Methods In 2024, along with other initiatives, a web-based survey was performed, focusing on hospitals with neurosurgical capabilities and intensive care units (ICUs) to identify variations in service delivery and adherence to evidence-based practices, guiding quality improvement across centers.

Results Responses were obtained from 19 acute care hospitals with neurosurgical facilities within the regional health service. Ten hospitals (52%) host dedicated neuro-ICUs, including five (26%) that also admit pediatric patients, accounting for a total of 85 beds. In the remaining nine hospitals (47%), neurocritical care is delivered within general ICUs without dedicated beds. Continuous in-house neurosurgical coverage is available in 9 centers (47%), while the others rely on a 24/7 on-call model. All 19 centers (100%) report 24/7 availability of neurologists and neuroradiologists, either in-house or on call. However, access to advanced diagnostic and monitoring technologies remains heterogeneous across sites.

Participating centers identified a clear need for standardized protocols and clinical pathways to improve care quality and support evidence-based practices. Priority areas defined by the clinicians include neuroprognostication, end-of-life care and donor management, pediatric neurocritical care, neurointerventional procedures, management of delayed cerebral ischemia following subarachnoid hemorrhage, and post-discharge follow-up. To address these gaps, several multidisciplinary working groups have been established.

Conclusion Neurocritical care in Lombardia remains highly heterogeneous, with bed availability significantly below international benchmarks. The establishment of a regional network seeks to enhance the quality and equity of care for neurocritical patients, while also fostering clinical research, data sharing, and multidisciplinary collaboration across centers.

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Keywords Neurocritical care, Neurocritical care network, Harmonizing neurointensive care neurointensive/neuroendovascular facilities, Lombardia critical care, Italian National Health System, Regional Health System, Integrated Trauma Care System

Introduction

Neurocritical care (NCC) is a multidisciplinary field dedicated to the management of patients with life-threatening neurological or neurosurgical conditions. Over the past two decades, NCC has evolved into a distinct subspecialty worldwide, with the establishment of specialized neurological/neurosurgical intensive care units (neuro-ICUs), dedicated training pathways for neurointensivists and nurses, and the development of evidence-based guidelines and performance measures. In the United States (US), this evolution has been formalized through the foundation of the Neurocritical Care Society (NCS) in 2002 and the introduction of board-certified fellowships (UCNS in 2005 and ACGME in 2020) [1].

In Europe, the growth of NCC has been more heterogeneous, with substantial variability in the organization, staffing, and availability of specialized units across countries. Nonetheless, European centers are increasingly engaging in collaborative research efforts and in the development of standardized protocols and training frameworks to improve quality of care and promote integration of neurocritical care into broader intensive care systems.

Although Italy does not have a nationally accredited fellowship program in this field, structured educational initiatives—from academic institutions and scientific societies—represent promising, albeit still partial, steps toward developing advanced and systematic training opportunities.

Lombardia, one of Italy's 20 administrative regions, has a population of approximately 10 million, making it the second most populous region in the European Union and the second by nominal gross domestic product (GDP) [2, 3]. Over recent decades, the decentralization of Italy's National Health Service (Servizio Sanitario Nazionale, SSN) has led to significant variability in regional health services (RHSs) [4, 5]. Lombardia's healthcare system follows a mixed model, combining public hospitals and privately accredited facilities to deliver care. The regional health service comprises 97 acute care hospitals, 19 of which are equipped with neurointensive or neuroendovascular capabilities [6]. Lombardia's RHS has organized an Integrated Trauma Care System (SIAT [7, 8]). For neurosurgical interventions, the regional system designates 6 Specialized Trauma Centers (CTS) and 13 Neurosurgery Regional Trauma Centers (CTZ-NCH). CTSs are fully equipped centers providing 24/7 care for all injury types, including multi-system issues. CTZ-NCHs also treat neuro traumatological cases. Both should have neurosurgical intensive care beds, whether dedicated or not. Similarly Lombardia's RHS has organized a Regional Stroke Network considering two levels of assistance (Level I and Level II), taking into account the qualification of the staff working in stroke units, the adequacy of infrastructure, the number of total and monitored beds, radiological diagnostic capacity, the presence of written protocols for diagnosis, treatment, rehabilitation, prevention, and follow-up, and, finally, the volume of patients treated [8].

In Lombardia's RHS, there is currently no formal definition or structured network linking intensive care units with neurosurgical or neurological capabilities. Against this backdrop, our study aims to provide a comprehensive overview of the organization, resources, and operational capacity of neurocritical care services across the region. We specifically assessed the geographic distribution of neurocritical care units, identified service gaps in terms of availability and infrastructure, and pinpointed priority areas for improvement. Through the systematic mapping of existing facilities, our goal is to shed light on present limitations and to guide strategic enhancements for a coordinated regional neurocritical care network.

Methods

Study objectives

The primary aim was to systematically assess and characterize the medical resources, technological infrastructure, and organizational setup of neurocritical care units across Lombardia, with a focus on identifying gaps and variations in service delivery.

A secondary aim was to identify interventions and strategic priorities focused at enhancing the quality of care, harmonizing clinical practices, and promoting the widespread implementation of evidence-based approaches within the neurocritical care network of the Lombardia.

Study design and population

In 2024, an online survey was administered, targeting all ICUs and identifying hospitals with neurosurgical and neuroradiological capabilities across the Lombardia. According to Lombardia's RHS regional decree n°12/162/23 and following update, we obtained responses from:

Specialized Trauma Centers—CTS- n°6.

- Ospedale di Circolo di Varese (ASST dei Sette Laghi), Varese
- Ospedale di Niguarda (ASST Grande Ospedale Metropolitano Niguarda), Milano
- Ospedale Papa Giovanni XXIII di Bergamo (ASST Papa Giovanni XXIII), Bergamo
- Ospedale San Gerardo di Monza (Fondazione IRCCS S. Gerardo dei Tintori), Monza
- Policlinico San Matteo di Pavia (Fondazione IRCCS Policlinico San Matteo), Pavia
- Spedali Civili di Brescia (ASST degli Spedali Civili di Brescia), Brescia

Regional Trauma Centers with neurosurgery—CTZ with NCH- n°12:

- Fondazione Poliambulanza di Brescia, Brescia
- IRCCS Humanitas di Rozzano, Milano
- IRCCS Ospedale San Raffaele, Milano
- Ospedale "Carlo Poma" (ASST di Mantova), Mantova
- Ospedale Alessandro Manzoni di Lecco (ASST di Lecco), Lecco
- Ospedale di Cremona (ASST di Cremona), Cremona
- Ospedale di Legnano (ASST Ovest Milanese), Legnano
- Ospedale E. Morelli di Sondalo (ASST della Valtellina e dell'Alto Lario), Sondalo
- Ospedale San Carlo (ASST Santi Paolo e Carlo), Milano
- Ospedale Sant'Anna di Como (ASST Lariana), Como
- Policlinico di Milano (Fondazione IRCCS Ca' Granda Ospedale Maggiore Policlinico), Milano Ospedale Fatebenefratelli e Oftalmico (ASST Fatebenefratelli Sacco), Milano

We also received responses from Fondazione IRCCS Neurologico Carlo Besta, Milano, a recognized center of excellence for the research, diagnosis, and treatment of neurological and neurosurgical diseases in both adults and children not inserted in the emergency system. The CTZ with neurosurgical capabilities at Ospedale Moriggia Pelascini in Gravedona did not participate in the survey. As a privately operated facility, it is not actively integrated into the regional emergency care network.

The study adhered to the Consensus-Based Checklist for Reporting of Survey Studies (CROSS, see ESM 1) [9]. This study did not require formal ethical approval, as it involved a voluntary survey among healthcare professionals focused exclusively on institutional organization and clinical infrastructure. No patient data, identifiable information, or sensitive personal data were collected. In accordance with the European General Data Protection Regulation (GDPR) and national regulations, research that does not involve human participants or personal health information is exempt from submission to an ethics committee.

Data collection

Data were collected using a Google Sheets form and supplemented with phone interviews involving the Head of Department at each center. The survey covered four domains: logistics, radiological facilities, point-of-care monitoring, and future developments (see ESM2 for details).

In the logistics domain, ICUs were classified as either "neurological" (neuro-ICU) or "general" (gen-ICU). Neuro sub-intensive units (neuro-SUB) were included only if led by ICU staff. Pediatric neuro-ICUs (neuro-ICU pedia) were defined as units admitting at least 15 patients per year under 5 years of age.

Availability of medical, surgical, and radiological services was categorized as "24/7 in-house," "24/7 on-call," "12/5" (Monday to Friday), or "not available." The same classification was applied to imaging resources.

For point-of-care monitoring, availability was recorded as "routinely used," "occasionally used," "being implemented," or "not available."

In the future developments domain, each center was asked to indicate three key priorities for improving neurocritical care within the regional health system.

Statistical analysis

Continuous variables were summarised using medians and interquartile range [IQR], categorical variables using number and percentages. Data were analysed using Microsoft Excel software and R software (version 4.0.3).

Results

Survey participation and ICU typology

Findings are summarized according to the main domains of the survey (Table 1). Responses were obtained from 19 hospitals in Lombardia.

Among these, 10 centers (52%) have dedicated neuro-ICUs comprising a total of 85 beds. Four of these centers (40%) also operate neuro-SUBs with 16 beds. In 9 centers (48%), neurocritical patients are managed within gen-ICUs without dedicated beds. Five neuro-ICUs (26%) admit pediatric patients (Fig. 1).

Staffing and emergency surgical capacity

In-house 24/7 neurosurgical coverage is available in 9 of the 19 hospitals (47%), including 8 out of 10 neuro-ICU centers and 1 of 9 gen-ICU centers. The remaining centers rely on 24/7 on-call neurosurgeons. Neurologists are present in-house 24/7 in all neuro-ICUs, but only in 6 of 9 gen-ICUs (67%). All 19 hospitals provide neuroradiology

Table 1 Neurointensive/neuroendovascular facilities among intensive care units in Lombardia

		NEURO-ICU *n* = 10	**GENERAL-ICU *n* = 9**
Neuro-dedicated beds		85	0
Neuro-sub intensive beds		16	0
Pediatric admission		5 (50)	0 (0)
		NEURO-ICU *n* = 10	GENERAL-ICU *n* = 9
Neurosurgery *n* (%)		10 (100)	9 (100)
	24/7 in house	8 (80)	1 (11)
	24/7 on call	2 (20)	8 (89)
	12/5	0 (0)	0 (0)
	Not available	0 (0)	0 (0)
Neurology *n* (%)		10 (100)	9 (100)
	24/7 in house	10 (100)	6 (67)
	24/7 on call	0 (0)	3 (33)
	12/5	0 (0)	0 (0)
	Not available	0 (0)	0 (0)
Neuroradiology *n* (%)		10 (100)	9 (100)
	24/7 in house	1 (10)	1 (11)
	24/7 on call	9 (90)	8 (89)
	12/5	0 (0)	0 (0)
	Not available	0 (0)	0 (0)
OR emergency		10 (100)	9 (100)
	24/7 in house	7 (70)	4 (44)
	24/7 on call	3 (30)	5 (56)
	12/5	0 (0)	0 (0)
	Not available	0 (0)	0 (0)
OR emergency neuro		6 (60)	4 (44)
	24/7 in house	0 (0)	0 (0)
	24/7 on call	6 (60)	2 (22)
	12/5	0 (0)	2 (22)
	Not available	0 (0)	0 (0)
		NEURO-ICU *n* = 10	GENERAL-ICU *n* = 9
CT neuro *n* (%)		10 (100)	9 (100)
	24/7 in house	8 (80)	9 (100)
	24/7 on call	2 (20)	0 (0)
	12/5	0 (0)	0 (0)
	Not available	0 (0)	0 (0)
CT perfusion *n* (%)		9 (90)	8 (89)
	24/7 in house	5 (50)	6 (67)
	24/7 on call	3 (30)	2 (22)
	12/5	1 (10)	0 (0)
	Not available	1 (10)	1 (11)
MRI neuro *n* (%)		10 (100)	9 (100)
	24/7 in house	5 (50)	4 (44)
	24/7 on call	5 (50)	4 (44)
	12/5	0 (0)	1 (11)
	Not available	0 (0)	0 (0)
DSA neuro *n* (%)		10 (100)	7(78)
	24/7 in house	0 (0)	0 (0)
	24/7 on call	9 (90)	7 (78)
	12/5	1 (10)	0 (0)

Table 1 (continued)

		NEURO-ICU $n=10$	GENERAL-ICU $n=9$
	Not available	0 (0)	2 (22)
DSA body *n* (%)		9 (90)	7 (78)
	24/7 in house	0 (0)	0 (0)
	24/7 on call	9 (90)	7 (78)
	12/5	0 (0)	0 (0)
	Not available	1 (10)	2 (22)
		NEURO-ICU $n=10$	GENERAL-ICU $n=9$
qEEG *n* (%)		10 (100)	3 (33)
	Routinely	6 (60)	2 (22)
	Occasionally	0 (0)	1 (11)
	Implementing	2 (20)	2 (22)
	Not available	2 (20)	4 (44)
Invasive ICP monitoring *n* (%)		10 (100)	9 (100)
	Routinely	10 (100)	9 (100)
	Neurosurgeon positioning	7 (70)	6 (67)
	Neurointensivist positioning	1 (10)	0 (0)
	Both	2 (20)	3 (33)
Brain echography *n* (%)		10 (100)	6 (67)
	Routinely	10 (100)	5 (56)
	Occasionally	0 (0)	1 (11)
	Implementing	0 (0)	3 (33)
	Not available	0 (0)	0 (0)
		NEURO-ICU $n=10$	GENERAL-ICU $n=9$
Pupillometry *n* (%)		9 (90)	4 (44)
	Routinely	5 (50)	4 (44)
	Occasionally	0 (0)	0 (0)
	Implementing	1 (10)	1 (11)
	Not available	4 (40)	4 (44)
$PbtO_2$ *n* (%)		2 (20)	1 (11)
	Routinely	1 (10)	0 (0)
	Occasionally	1 (10)	1 (11)
	Implementing	2 (20)	1 (11)
	Not available	6 (60)	7 (78)

Centers are categorized in two types of ICU (neuro-ICU and general-ICU) according to type of patients admitted

ICU intensive care unit, *OR* operating room, *CT* computed tomography, *DSA*, digital subtraction angiography, *ICP* intracranial pressure, *MRI* magnetic resonance imaging, *$PbtO_2$* brain tissue oxygen tension, *qEEG* quantitative electroencephalography

support 24/7, either in-house or on-call. A dedicated emergency neurosurgical operating room is available 24/7 on-call in 6 of 10 neuro-ICUs (60%) and in 2 of 9 gen-ICUs (22%) (Fig. 2).

Radiological facilities

All centers offer 24/7 in-house access to neurological computed tomography (CT) scans. CT perfusion is available in-house 24/7 in 5 of 10 neuro-ICUs (50%) and 6 of 9 gen-ICUs (67%). It is available 24/7 on-call in an additional 3 neuro-ICUs (30%) and 2 gen-ICUs (22%), while 2 centers (10.5%) do not provide CT perfusion (Fig. 3).

Magnetic resonance imaging (MRI) is accessible 24/7 in-house in 5 neuro-ICUs (50%) and 4 gen-ICUs (44%), with an additional 5 neuro-ICUs and 4 gen-ICUs offering it 24/7 on-call. One gen-ICU (11%) lacks weekend MRI availability.

Neuro digital subtraction angiography (neuro-DSA) is not available in-house 24/7 at any center but is provided 24/7 on-call in 9 neuro-ICUs (90%) and 7 gen-ICUs (78%). One neuro-ICU offers neuro-DSA on a 12/5 schedule, while 2 gen-ICUs do not provide the service.

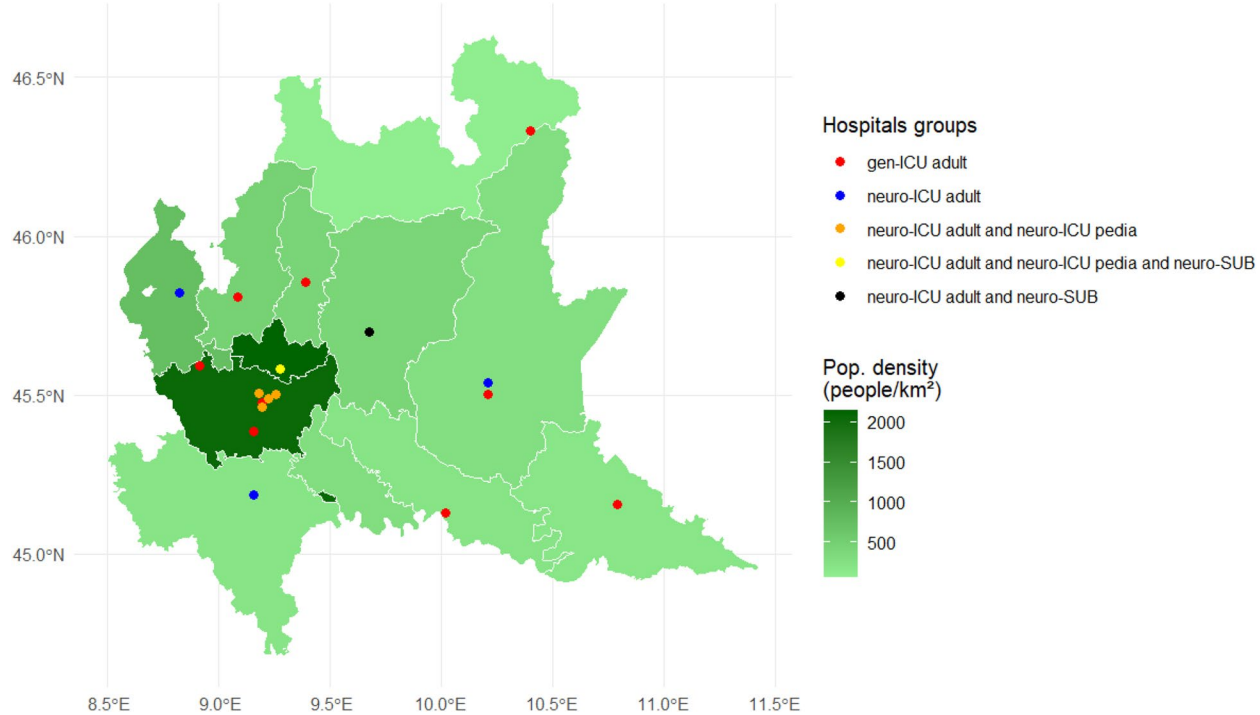

Fig. 1 Geographical distribution of neurocritical care centers in Lombardia (10 neuro-ICUs and 9 general ICUs). The background color scale represents population density by province (inhabitants/km^2). Darker green shades indicate higher population density. Centers are identified according to patient admission and the medical staff involved as follows: adult neuro-dedicated ICU with common admissions > 18 years old (neuro-ICU adult); adult general ICU with common admissions > 18 years old (gen-ICU adult); pediatric neuro-dedicated ICU with more than 15 patients admitted per year (neuro-ICU pedia); and sub-intensive neuro unit led by ICU staff (neuro-SUB). Colored dots indicate hospitals according to ICU type. At least one ICU facility is present in each province of the region. Legend: red = gen-ICU adult; blue = neuro-ICU adult; orange = neuro-ICU adult and neuro-ICU pedia; yellow = neuro-ICU adult, neuro-ICU pedia, and neuro-SUB; black = neuro-ICU adult and neuro-SUB

Body-DSA is available 24/7 on-call in 9 neuro-ICUs (90%) and 7 gen-ICUs (78%) but is not available in 1 neuro-ICU and 2 gen-ICUs.

Point-of-care neuromonitoring

Pupillometry is used routinely in 5 neuro-ICUs (50%) and 4 gen-ICUs (44%), is being implemented in 2 centers (10.5%) and is not available in 8 centers (42%).

Intracranial pressure (ICP) monitoring is routinely performed in all centers, typically by neurosurgeons. Brain ultrasonography is routinely used in all neuro-ICUs and in 5 gen-ICUs (56%).

Brain tissue oxygenation ($PbtO_2$) monitoring is used routinely or occasionally in only 2 neuro-ICUs (20%) and 1 gen-ICU (11%) and is unavailable in 13 centers (68%).

Quantitative electroencephalography (qEEG) is used routinely in 6 neuro-ICUs (60%) and 2 gen-ICUs (22%), occasionally in 1 gen-ICU (11%), and is being implemented in 4 centers (2 neuro-ICUs and 2 gen-ICUs). It is not available in 2 neuro-ICUs (20%) and 4 gen-ICUs (44%) (Fig. 4).

Future priorities and network development

All centers (19/19, 100%) identified standardized protocols for prognosis as a top priority. Other frequently cited priorities included end-of-life care (17/19, 89%), pediatric neurocritical care (17/19, 89%), and neuro-anaesthesia (16/19, 84%). Additional areas of focus include improving the diagnosis and treatment of delayed cerebral ischemia (DCI) post-subarachnoid hemorrhage (14/19, 74%) and standardizing follow-up care for acute brain injury (13/19, 68%).

Beyond protocol development, participating centers emphasized the need to strengthen training programs and promote collaborative research. By aligning on shared standards, expanding education, and fostering regional cooperation, the Lombardia neuroIntensive care NetworK (LINK) (ESM3) aims to improve neurocritical care quality and equity across Lombardia.

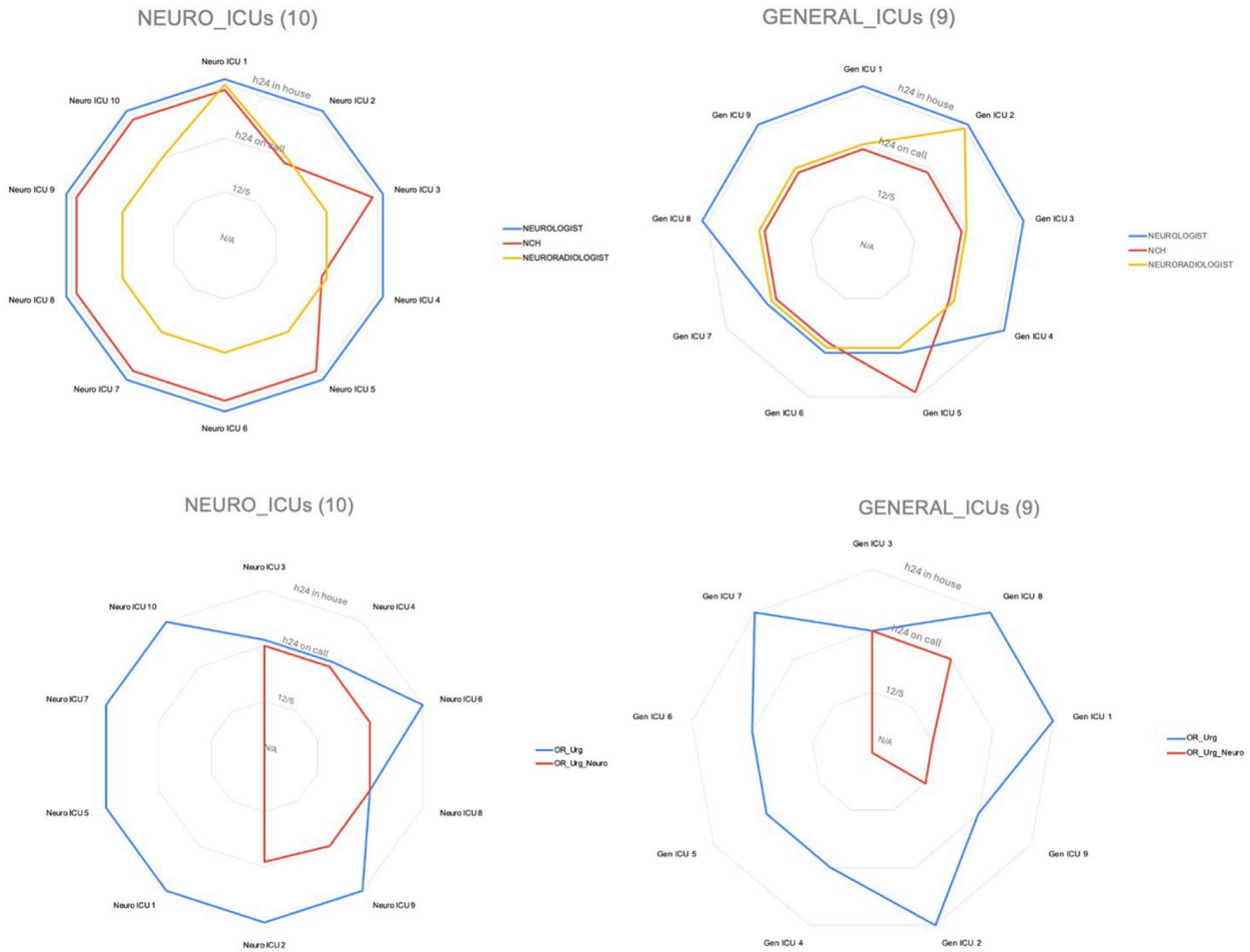

Fig. 2 Logistic area across Lombardia's acute care hospitals with neurosurgical capabilities. Centers are identified progressively according to patient admission and the medical staff involved as follows: adult neuro-dedicated ICU with common admissions > 18 years old (neuro-ICU); adult general ICU with common admissions > 18 years old (gen-ICU). The presence of medical/surgical specialties are defined as follows: "24/7 in-house" availability, meaning services were available every day of the week around the clock; "24/7 on-call" availability, meaning services were available on call every day of the week around the clock; "12/5" availability, meaning services were available from Monday to Friday around the clock, either in-house or on-call; "NA" not available. ICU: intensive care unit; NCH: neurosurgeon; OR: operating room

Discussion

This study provides the first comprehensive evaluation of neurocritical care services across Lombardia and reveals three major findings:

- Significant heterogeneity in logistical, radiological, and neuromonitoring resources.
- A low number of dedicated neuro-ICU beds relative to international standards, and
- Inconsistent access to advanced diagnostic and monitoring technologies.

These disparities persist irrespective of hospitals' formal classification within the regional Integrated Trauma Care System.

The most pronounced differences were observed between hospitals with dedicated neuro-ICUs and those managing neurocritical patients in general ICUs. This variation raises concerns about equitable access to specialized care and highlights the urgent need for a coordinated regional approach, particularly when compared to international benchmarks [10].

Several studies have shown that organizational factors—including the expertise of the neurocritical care team, case volume, and specialization—strongly influence clinical outcomes [11–13]. In the United Kingdom (UK), the Society of British Neurological Surgeons (SBNS) has long promoted centralized models of care, where a limited number of highly specialized centers ensure consistent quality and patient safety [14]. This vision is supported by the British Workforce Plan (2000–2015), which sets minimum standards for

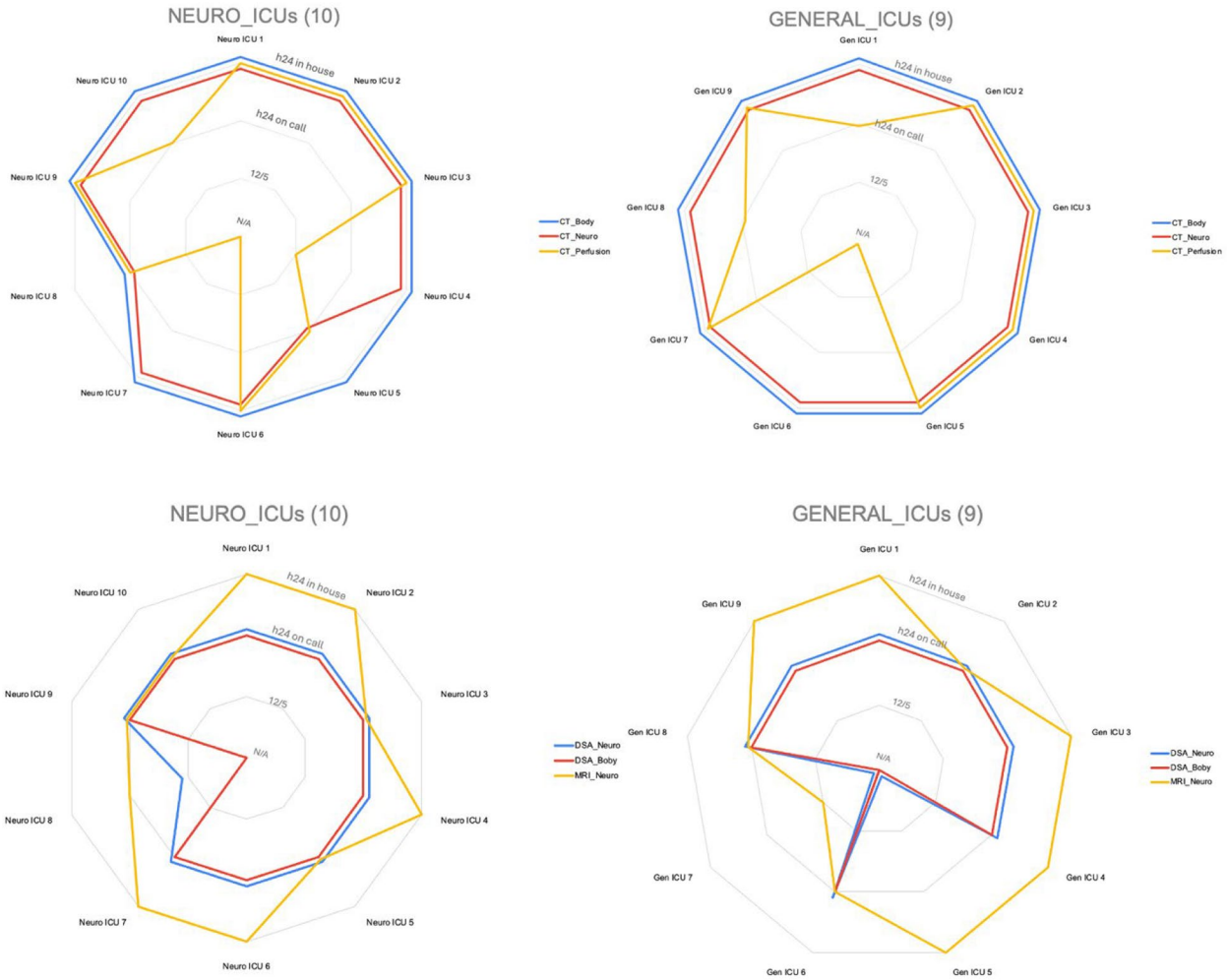

Fig. 3 Radiological area across Lombardia's acute care hospitals with neurosurgical capabilities. Centers are identified progressively according to patient admission and the medical staff involved as follows: adult neuro-dedicated ICU with common admissions > 18 years old (neuro-ICU); adult general ICU with common admissions > 18 years old (gen-ICU). The presence of radiological specialties is defined as follows: "24/7 in-house" availability, meaning services were available every day of the week around the clock. "24/7 on-call" availability, meaning services were available on call every day of the week around the clock. "12/5" availability, meaning services were available from Monday to Friday around the clock, either in-house or on-call. "NA" not available. ICU: intensive care unit; CT: computed tomography; DSA: digital subtraction angiography; MRI: magnetic resonance imaging

neurocritical care, including infrastructure, staffing ratios, and protocol adherence [14, 15].

Compared to the UK and other high-income countries, Lombardia is markedly under-resourced, with only 9 neurocritical care beds per million inhabitants, far below the recommended international benchmark of 30 per million [10, 14–16]. This shortfall underscores the need to expand neuro-ICU capacity and to harmonize clinical pathways across the region.

Similarly, in Germany and France, neurocritical care networks are more centralized and standardized, ensuring broader and more uniform access to advanced technologies (such as qEEG and $PbtO_2$). By contrast, our findings reveal that such modalities are inconsistently available in Lombardia, particularly in gen-ICUs, where their absence may contribute to disparities in decision-making and patient outcomes.

MRI and CT perfusion—essential not only for diagnosis but also for neurocritical monitoring—are also not universally accessible across facilities. This technological variability reinforces the need for a more cohesive regional strategy to ensure equitable access to advanced diagnostics and continuous monitoring tools.

The recent Italian Ministry of Health recommendations to integrate intensive and semi-intensive services into a unified Critical Care Area (CCA) provide a promising

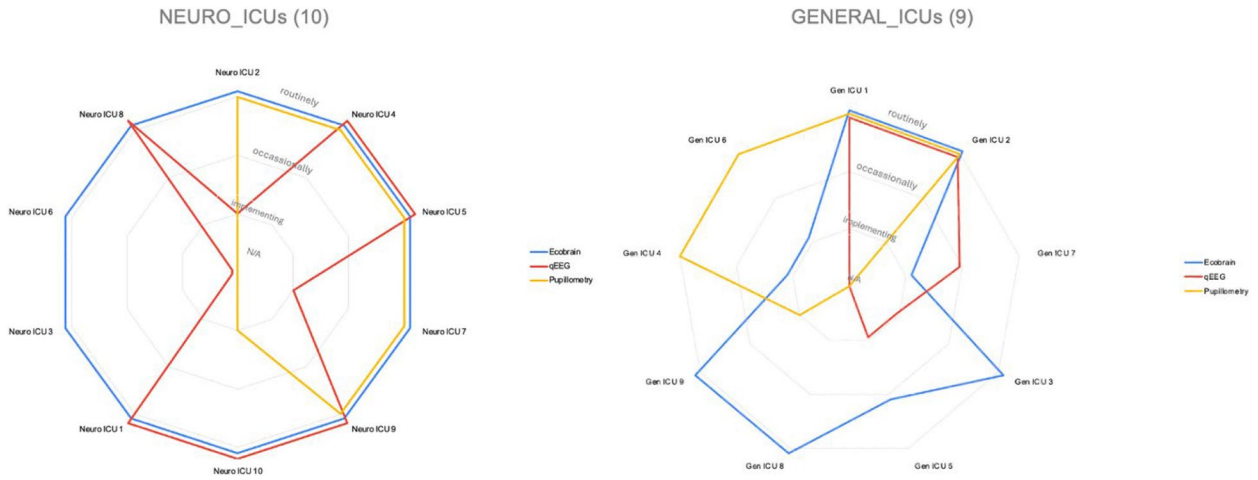

Fig. 4 Point of care (POC) area across Lombardia's acute care hospitals with neurosurgical capabilities. Centers are identified progressively according to patient admission and the medical staff involved as follows: adult neuro-dedicated ICU with common admissions > 18 years old (neuro-ICU); adult general ICU with common admissions > 18 years old (gen-ICU). The presence of radiological specialties is defined as follows: "24/7 in-house" availability, meaning services were available every day of the week around the clock. "24/7 on-call" availability, meaning services were available on call every day of the week around the clock. "12/5" availability, meaning services were available from Monday to Friday around the clock, either in-house or on-call. "NA" not available. ICU: intensive care unit; EEG: electroencephalography; qEEG: quantitative electroencephalography

framework for addressing these disparities [17]. This model, similar to those implemented in The Netherlands, promotes dynamic resource allocation and interdisciplinary coordination. Incorporating pediatric neurocritical care into this system is particularly important, given the limited number of centers in Lombardia with the capacity to care for young children requiring neurointensive support. Likewise, the Italian Society of Anesthesiology, Intensive Care, and Resuscitation and Pain Management (SIAARTI) has identified an urgent need of define and classify the levels of care within the CCA by simplifying and specifying the respective areas of responsibility, staffing requirements, staff privileges, structural requisites, and equipment allocation. The society propose an update of Italian Health Minister decree n° 70 [18], which defines levels of care in Italy, to introduce organizational models based on recognized clinical best practice pathways, providing a definition for high-dependency/step-down units according to levels of care [19].

The identification of shared priorities across neurocritical care centers in Lombardia underscores the growing commitment to harmonize and elevate standards of care in this complex field. The implementation of standardized protocols for prognostication promotes consistency, transparency, and ethical integrity in clinical decision-making, while structured end-of-life care pathways ensure dignity, family-centered communication, and optimal donor identification and management. Strengthening pediatric neurocritical care capacity addresses the unique developmental and neuroprotective needs of children, improving long-term neurological outcomes. Expanding access to neurointerventional procedures and awake surgery enhances treatment precision, reduces delays, and safeguards neurological function in real time. Likewise, a coordinated approach to the prevention and management of DCI following subarachnoid hemorrhage can substantially reduce secondary injury and improve functional recovery. Finally, the establishment of long-term follow-up programs ensures that the impact of neurocritical care extends beyond survival, addressing cognitive, emotional, and functional sequelae while supporting reintegration and quality of life. These priorities reflect broader international trends and are consistent with current quality improvement efforts in neurocritical care [12, 13, 20].

While this study provides the first systematic assessment of neurocritical care services in Lombardia, its most compelling message lies not merely in mapping current heterogeneity but in highlighting the transformative potential of a coordinated regional network. The substantial disparities observed across centers—in terms of staffing models, diagnostic capabilities, and monitoring technologies—underscore a critical need for structural integration and shared governance. In this context, the emerging Lombardia NeuroIntensive Care Network offers a practical and scalable response. By connecting neuro-ICUs and gen-ICUs managing neurocritical patients, the network fosters inter-hospital collaboration that can directly improve care quality. This collaboration can take many forms: consultation on complex cases,

shared clinical protocols for diagnosis and management, and joint training initiatives to standardize competencies across the region. Rather than creating new infrastructure from scratch, the network leverages and aligns existing resources to deliver more consistent, high-quality neurocritical care. Crucially, this network-based approach is not unique to Lombardia. It can serve as a blueprint for other Italian regions or health systems characterized by decentralized governance and variable resource distribution. The model demonstrates that even in the absence of national mandates, a grassroots, clinician-driven initiative can identify shared priorities, reduce unwarranted variability, and enable continuous quality improvement. Moreover, the LINK initiative supports the development of a professional community—spanning intensivists, neurologists, neurosurgeons, radiologists, and nurses—that collectively defines standards of care, generates data, and implements innovation in a coordinated fashion. This integrated approach not only enhances local patient care but also provides a foundation for multicenter research and data-driven health policy.

In summary, this work advocates for a shift in perspective—from isolated institutional performance to interdependent system-level collaboration. The creation and consolidation of neurocritical care networks, adaptable to local needs yet anchored in shared goals, may represent a critical step toward a more equitable, efficient, and learning-oriented healthcare system.

By fostering collaboration and adopting measurable quality indicators, the Lombardia network can not only improve patient outcomes locally but also contribute valuable models for neurocritical care delivery at the national and international level.

Limitations

This study has several limitations. As an observational, survey-based analysis, it is inherently descriptive and hypothesis-generating. The reliance on self-reported data may introduce bias related to local interpretation or institutional culture. Furthermore, the lack of comparable regional studies from Italy or other European healthcare systems limits benchmarking opportunities. Nonetheless, this survey provides a valuable foundation for system-wide evaluation and targeted improvement in neurocritical care across Lombardia.

Conclusions

Lombardia's neurointensive and neuroendovascular facilities remain markedly heterogeneous, with the number of available beds falling well below international benchmarks. Addressing these deficiencies requires a comprehensive strategy: expanding neuro-ICU capacity, implementing standardized clinical protocols and care pathways, improving access to advanced monitoring and diagnostic technologies, and fostering collaborative research and educational initiatives.

The establishment of working groups and interdisciplinary collaborations within the emerging Lombardia neurocritical care network is a critical step toward operationalizing these objectives. By aligning clinical practice through shared protocols, promoting continuing education, and fostering collaborative research, the region can significantly improve both the quality and equity of care.

Nonetheless, ensuring equitable access to specialized care and harmonizing clinical practice across institutions must remain central priorities for future healthcare policy and system-level reform.

Abbreviations

ASST	Azienda Socio-Sanitaria Territoriale: Local Health and Social Care Trust
CCA	Critical Care Area
CT	Computed tomography
CTS	Specialized Trauma Centers
CTZ-NCH	Regional Trauma Centers with Neurosurgery
CTZ	Regional Trauma Centers
DCI	Delayed Cerebral Ischemia
DSA	Digital Subtraction Angiography
ESM	Electronic Supplementary Material
ICP	Intracranial Pressure
ICU	Intensive Care Unit
IRCCS	Istituto di Ricovero e Cura a Carattere Scientifico: Scientific Institute for Research, Hospitalization and Healthcare
MRI	Magnetic Resonance Imaging
NHS	National Health System
$PbtO_2$	Brain Tissue Oxygen Tension
qEEG	Quantitative Electroencephalography
RHS	Regional Health System
SAH	Subarachnoid Haemorrhage
SIAT	Integrated Trauma Care System
UK	United Kingdom
US	United States

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s44158-025-00311-5.

Supplementary Material 1. Information about experts included in the Delphi process.

Supplementary Material 2. Survey Ti Neuro Lombarde.

Supplementary Material 3. The LINK—Lombardia NeuroIntensive care Network Working Group.

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Authors' contributions

Conceptualization and study definition: Giuseppe Citerio, Angelo Guglielmi. Funding acquisition: none. Data verification: Francesca Graziano, Angelo Guglielmi Access to raw data: Giuseppe Citerio, Angelo Guglielmi. Formal analysis, figures and tables: Francesca Graziano, Angelo Guglielmi. Project administration, Data access and verification: Giuseppe Citerio. Writing—original draft: Angelo Guglielmi, Giuseppe Citerio. Writing—review and editing: All the authors. The final responsibility for the decision to submit for publication: All the authors.

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Data availability
The data supporting the study findings are available upon reasonable request after approval of a proposal from the corresponding author (GC).

Declarations

Ethics approval and consent to participate
This study involved a survey conducted among healthcare professionals on institutional and clinical practices. No patient data were collected, and participation was voluntary. Given that no personal or sensitive data were obtained, formal written consent was not required under European General Data Protection Regulation (GDPR) guidelines.

Competing interests
The authors declare no competing interests.

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