

Standards of Scoring, Monitoring, and Parameter Targeting in German Neurocritical Care Units: A National Survey

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Abstract

Background Optimal management of physiological parameters in neurological/neurosurgical intensive care units (NICUs) is largely unclear as high-quality evidence is lacking. The aim of this survey was to investigate if standards exist in the use of clinical scores, systemic and cerebral monitoring and the targeting of physiology values and in what way this affects clinical management in German NICUs.

Methods National survey, on-line anonymized questionnaire. German departments stating to run a neurological,

This study was conducted for the Initiative of German NeuroIntensive Trial Engagement (IGNITE).

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neurosurgical or interdisciplinary neurological/neurosurgical intensive care unit were identified by a web-based search of all German hospitals and contacted via email.

Results Responses from 78 German NICUs were obtained. Of 19 proposed clinical/laboratory/radiological scores only 5 were used regularly by >60 %. Bedside neuromonitoring (NM) predominantly consisted of transcranial Doppler sonography (94 %), electroencephalography (92 %) and measurement of intracranial pressure (ICP) (90 %), and was installed if patients had or were threatened by elevated ICP (86 %), had specific diseases like subarachnoid hemorrhage (51 %) or were comatose (35 %). Although mean trigger values for interventions complied with guidelines or widespread customs, individual trigger values varied widely, e.g., for hyperglycemia (maximum blood glucose between 120 and 250 mg/dl) or for anemia (minimum hemoglobin values between 5 and 10 g/dl).

Conclusions Although apparently aiming for standardization in neurocritical care, German NICUs show substantial differences in NM and monitoring-associated interventions. In terms of scoring and monitoring methods, German NICUs seem to be quite conservative. These survey results suggest a need of prospective and randomized interventional trials in neurocritical care to help define standards and target values.

Keywords

Neurological/neurosurgical intensive care unit ·
Neurocritical care unit · NICU · Monitoring · Scores ·
Parameters

Abbreviations

NICU Neurological/neurosurgical intensive care unit
ICP Intracranial pressure
CPP Cerebral perfusion pressure

ICH	Intracerebral hemorrhage
IS	Ischemic stroke
SAH	Subarachnoid hemorrhage
TBI	Traumatic brain injury
SD	Standard deviation
Max	Maximum
Min	Minimum
SOPs	Standard-operating procedures
PiCCo	Pulse contour cardiac output
TEE	Transesophageal echocardiography
EEG	Electroencephalography
PbtO ₂	Partial pressure of brain tissue oxygen
regSO ₂	Regional cerebral oximetry
SjvO ₂	Jugular venous oxygen saturation
CSF	Cerebrospinal fluid

Introduction

As in any intensive care unit (ICU), it is a daily challenge in neurological/neurosurgical ICUs (NICUs) to achieve overall homeostasis and optimal levels of physiology in patients who can hardly be judged clinically due to sedation and ventilation and therefore depend on some form of monitoring. However, there does not exist a robust base of evidence for the meaning and management of most systemic or cerebral physiological parameters with regard to outcome or mortality, and thus consistent standards are lacking. Basic measures to provide adequate maintenance of vital functions and treat deranged physiological parameters include respiratory and cardiocirculatory management, regulation of hydration and electrolytes, as well as more specific brain-directed interventions such as stabilization of intracranial pressure (ICP). The various methods of assessment of physiological parameters, i.e., forms of systemic and neuro-monitoring (NM), have largely been investigated in small correlation studies and have been judged by experts to be of varying degrees of usefulness [1, 2].

In Germany, the organization of NICUs depends on the type of the hospital, the associated specialty (=the department the unit belongs to), the medically directing specialty (not necessarily the same) and the degree of interdisciplinarity. Although many NICUs are organized in societies such as the German Society for NeuroIntensive and Emergency Care (DGNI, <http://www.dgni.de>) or the German Society for Neurosurgical Care (DGNC, <http://www.dgnc.de>) that give recommendations on management, the actual monitoring practice in German NICUs is largely unknown. Two previous surveys were restricted to neurological ICUs only and focused on organizational aspects, but not on monitoring or treatment [3]. It is thus presently unclear if common practices or a consensus exist in NICU monitoring and management in a situation of poor evidence. The IGNITE group (Initiative for German NeuroIntensive Trial

Engagement, <http://dgni.de/forschung/84-ignite-initiative-of-german-neurointensive-trial-engagement.html>), is a free alliance of German neurologists and neurosurgeons working on NICUs with the aim to conduct clinical multicenter trials in neurocritical care. In 2011, IGNITE decided to organize an orienting survey to assess the up-to-date situation of German NICUs. This survey aimed to identify the monitoring strategies predominantly practiced on German NICUs and in what way therapeutic interventions are based on them. Its main purpose was to serve as a pilot-study in order to adequately plan and implement prospective trials. Here, we present the results of this survey, which is to our knowledge the largest assessment of the situation of neurocritical care in Germany to date. The parts of the survey presented are (a) the use of scores, (b) the indications and methods of monitoring, and (c) trigger values and initial interventions.

Methods

Questionnaire

After two IGNITE meetings and a test run in five NICUs an electronic questionnaire (http://www.q-set.de/Meine_Online-Umfragen/Umfrage_werbefrei_testen.php?sCode=HYYAVHFSTEWZ) was established which was arranged to be anonymously answered by directing clinicians of the respective NICU. A financial compensation was not provided. This national online survey consisted of 50 multiple-choice or open questions with these categories: features of the participating center, admission diagnoses, use of standard operating procedures (SOPs), protocols, adherence to guidelines (part 1, not subject of this article, [4]) and scores, NM modalities, target values of distinct blood/cerebrospinal fluid (CSF) parameters (part 2). Responses were received between December 2011 and March 2012.

Participants

Aiming for a number of recipients as high as possible, the authors collected a list of 326 German hospitals claiming publicly to possess a specialized neurological, neurosurgical, or interdisciplinary NICU without secondary confirmation thereof being aware that some of these might not stand up to these standards. The presence of at least five ventilator-equipped ICU beds and the connection to a neurological or neurosurgical department was assessed using the homepages of the identified hospitals. Sources for this web-based research were homepages of all German hospitals (<http://www.deutsches-krankenhaus-verzeichnis.de>), department lists of the German medical association (Deutsche Ärztekammer) and public hospital lists of German neurological/neurosurgical intensive care societies

[DGNI, DGNC and the German Interdisciplinary Association of Intensive and Emergency Medicine (DIVI)]. Anonymized on-line questionnaires were sent to the attending of the ICU or to the head of the department requesting to forward it. Reminding letters were sent within 6–8 weeks.

Data Analysis

The data were anonymously analyzed by an independent certified psychologist experienced in survey statistics using SPSS.19 (SPSS Inc., Chicago, IL, USA). Descriptive statistics were utilized to display the features of the participating hospitals, use of scores, NM modalities and goal parameters of distinct blood/CSF values by calculating frequencies, percentage quotations, arithmetic means, standard deviations, minima and maxima. Tests of differences between the admission diagnoses were carried out by the nonparametric Mann–Whitney *U* test (university hospital vs. non-university hospital) and the Kruskal–Wallis test (neurology vs. neurosurgery vs. anesthesiology as directing specialty), respectively. In the latter, the single comparisons between the specialties were analyzed by a single factor analysis of variance (ANOVA) using the Post-Hoc test Tukey HSD. Differences in the use of scores were tested by the Chi square test. As continuity correction, the Fisher's exact test was applied. For more than 2×2 fields, the asymptotic significance was determined, and the single comparisons between the specialties were analyzed by paired difference test via *Z* tests and the Bonferroni correction.

Ethical Approval

Ethical approval was obtained from Köln University Research Ethics Committee.

Results

Participants

Three hundred twenty-six of the screened hospitals were identified and contacted, 78 questionnaires from NICUs were returned (the number of participants are given in the presentation of the respective results). All data were included in the analysis. The participating hospitals were university hospitals (53 %), community hospitals (30 %), BG-Kliniken (Berufsgenossenschaftskliniken = hospitals specialized in work accidents, predominantly owned by insurances) (4 %) and others (13 %). 91 % of the respondents were ICU attendings. Regarding the specialization (=department-association) of the ICU, 32 % of the units

were neurological, 35 % neurosurgical, 17 % interdisciplinary and 16 % of other specialties. Regarding the ICU-directing profession, 37 % of the units were led by neurologists, 22 % by neurosurgeons, 28 % by anesthetists and 13 % by others. In community hospitals the units were mainly led by anesthetists, university hospitals had their own neurological or neurosurgical ICU in most cases. The mean unit size was 11 beds (SD 5, range 3–30), the mean number of clinicians in charge was 8 (SD 4, range 2–25).

Estimate the Percentage of Proposed Admission Diagnoses at Your NICU During the Last Year

The most commonly stated diagnoses were ischemic stroke (IS, 19 %), intracerebral hemorrhage (ICH, 17 %), and subarachnoid hemorrhage (SAH, 14 %), followed by brain tumor and traumatic brain injury (TBI) (Fig. 1a). The admission diagnoses differed significantly according to the diverse unit-directing specialties. IS and status epilepticus were more commonly reported by neurology-directed NICUs, SAH and tumor by neurosurgery-directed NICUs, and TBI and tumor by anesthesiology-led NICUs. The differences between the three specialties were significant except for ICH and “others” ($p \leq 0.02$, see Fig. 1b for details). When comparing university with non-university hospitals, myasthenic crisis was more often treated in university hospitals (2.8 vs. 0.9 %, $p = 0.02$), as opposed to epidural/subdural hemorrhage (6 vs. 11 %, $p = 0.004$) and TBI (7 vs. 12 %, $p = 0.024$) (data not shown).

Scores

Which of the Following Scores Do You Use Routinely and For Which Primary Purpose Are They Assessed?

For score abbreviations and references, see also the “[Score Glossary](#)” section at the end of the article. The scores most frequently stated for daily routine use were Hunt/Hess and Glasgow Coma Scale (GCS) with more than 80 % routine application, followed by the stroke scores National Institute of Health Stroke Scale (NIHSS) and modified Rankin Scale (mRS), and the radiological Fisher scale for SAH with >60 % application. Of the 19 scores offered in total, the majority was stated to be used routinely by an extent <40 % (Fig. 2a). Figure 2a shows the frequency of application of internationally published scores, and Fig. 2b shows the primarily intended purpose of the most important scores stated as used at least “frequently” by the respondents.

When comparing the directing specialties, we found that in neurologically in contrast to neurosurgically and anesthesiologically directed units NIHSS (100 % vs. 39 % vs. 38 %, $p = 0.000$) and the mRS (86 % vs. 50 % (trend)

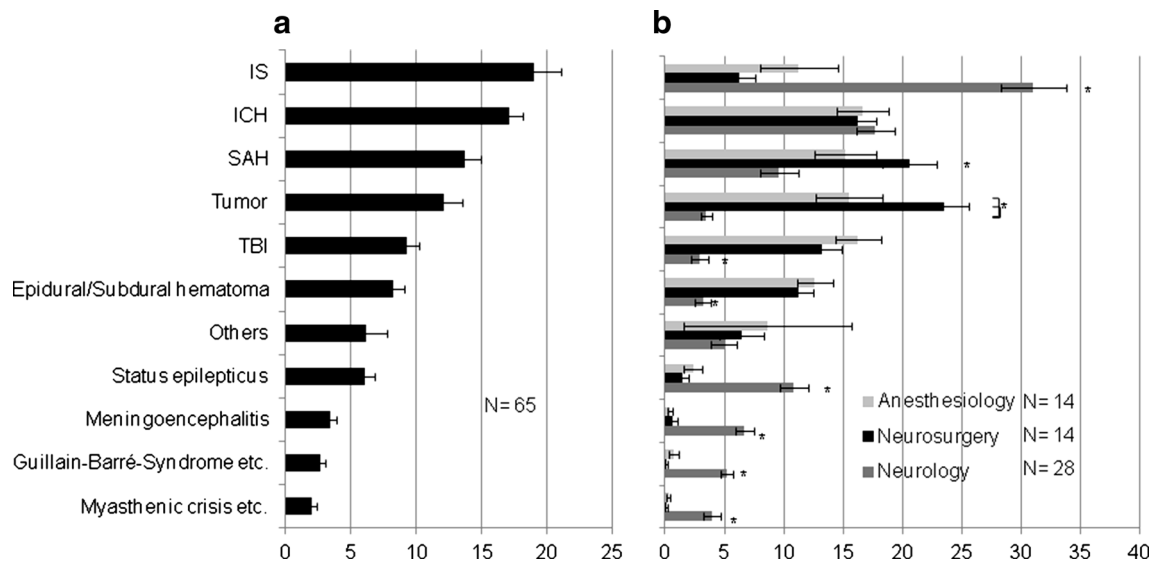


Fig. 1 a Admission diagnoses over the last 12 months (total). **b** Admission diagnoses over the last 12 months according to specialties. Data are displayed as percentage of survey participants answering this

question. *N* number of respondents, *IS* ischemic stroke, *ICH* intracerebral hemorrhage, *SAH* subarachnoid hemorrhage, *TBI* traumatic brain injury

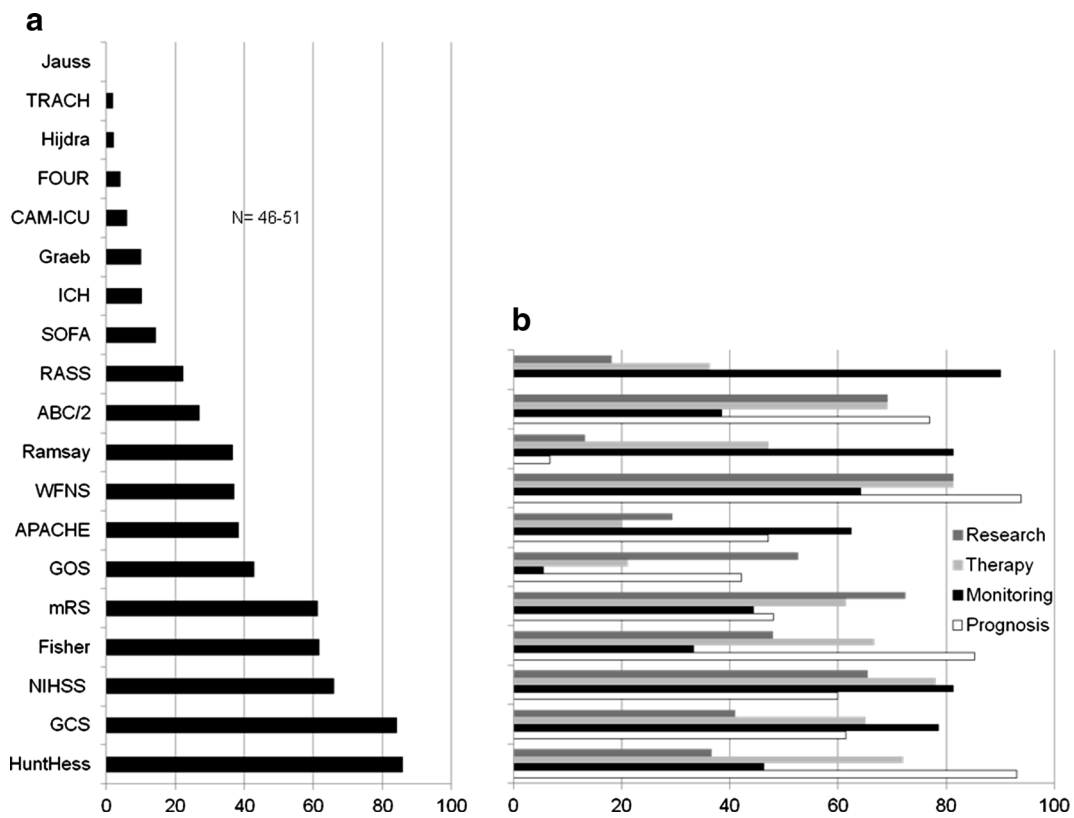


Fig. 2 a Routine use of clinical and radiological scores. **b** Primary purpose of scores (selected scores used routinely by more than 20 % participants). Data are displayed as percentage of survey participants

answering this question. *N* number of respondents; for Score abbreviations see “Score Glossary” section at the end of the manuscript

vs. 13 %, $p = 0.001$) were used more as opposed to the Glasgow Outcome Scale (GOS) (5 % vs. 77 % vs. 50 %, $p = 0.000$) and the GCS (68 % vs. 100 % vs. 100 %, $p = 0.018$). In neurosurgically led units the SAH scores World Federation of Neurosurgeons Scale (WFNS) (67 % vs. 15 % vs. 29 % (trend), $p = 0.011$) and the Fisher scale (90 % vs. 43 % vs. 63 % (trend), $p = 0.043$) were more commonly reported compared to neurologically and anesthesiologically led units (data not shown).

Significant differences between university and non-university hospitals existed in the use of the GCS (72 vs. 100 %, $p = 0.007$), NIHSS (79 vs. 48 %, $p = 0.033$) and mRS (76 vs. 40 %, $p = 0.017$). There were no further differences between the two types of hospitals (data not shown).

Monitoring and Target Parameters

In What Situation Do You Add Advanced Hemodynamic Monitoring to Your Basal Monitoring Parameters (such as ECG, Heart Rate, Blood Pressure, Temperature)?

Most respondents stated to extend their basal monitoring in septic (88 %) and cardiocirculatorily instable (86 %)

patients, <60 % applied hemodynamic monitoring in HHH (hypertension, hypervolemia, hemodilution)-therapy in SAH, increased ICP and hypothermia. Only 4 % stated to use it “always” or “never” (Fig. 3a).

What Methods Do You Employ for Advanced Hemodynamic Monitoring?

Most frequently, the volumetric “PiCCo” (Pulse Contour Cardiac Output, Pulsion medical systems) was stated (94 %, followed by TEE (transesophageal echocardiography) (52 %), pulmonary artery catheter (27 %) and others (6 %) (Data not shown). “Others” included “CEVOX” (central venous oxygen saturation, Pulsion medical systems), FlowTrac (Edwards Lifesciences) and Vigileo (Edwards Lifesciences) (stated by only one respondent each).

“In what situation do you perform neuromonitoring?”

The most commonly stated situations were increased ICP (86 %) and special diseases (51 %), 35 % used it in comatose patients (Fig. 3b). Almost nobody stated to apply it “always” or “never”. Regarding the special diseases in

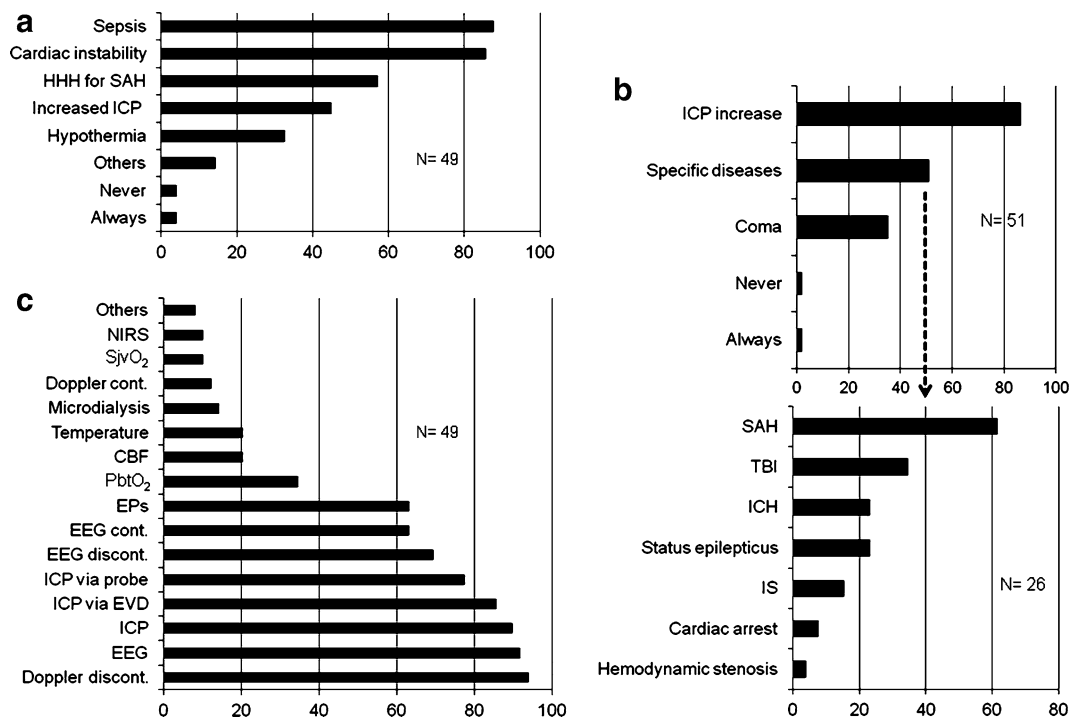


Fig. 3 a Situations triggering enhanced hemodynamic monitoring. b Situations triggering neuromonitoring. c Preferred methods of neuromonitoring. Data are displayed as percentage of survey participants answering this question. N number of respondents; HHH hypervolemia, hemodilution, hypertension; SAH subarachnoid hemorrhage; ICP intracranial pressure; TBI traumatic brain injury; ICH intracerebral hemorrhage; IS ischemic stroke; NIRS near infrared spectroscopy;

SjvO₂ jugular venous oxygen saturation; Doppler cont. prolonged TCD by temporal device; (dis)cont. (dis)continuously; CBF cerebral blood flow; PbtO₂ cerebral oxygen partial pressure; EP evoked potentials; EEG electroencephalography; ICP intracranial pressure; BIS Bispectral Index; LD Laser Doppler; “Others” were BIS, LD, Electrocorticography, serum S 100

which NM was routinely performed, the most common were SAH and TBI.

What Types of Neuromonitoring are Employed in your NICU?

Neuromonitoring was predominantly stated to consist of transcranial Doppler sonography (94 %), electroencephalography (EEG, 92 %), ICP-measuring (90 %), and evoked potentials (Fig. 3c). Rarely applied modalities were continuous Doppler, near infrared spectroscopy (NIRS), jugular venous oxygen saturation (SjvO₂) measurement and microdialysis (<20 %), (Fig. 3c). The preferred purpose of NM was the recognition of stable conditions (stated by 88 % participants), therapeutic decisions (51 %), and research (32 %).

Triggers for Intervention (Neuromonitoring Parameters, Blood/CSF Values)

What Value Do You Regard as Trigger for Intervention? What is Your Initial Measure to Correct it?

Some of the NM parameters were very rarely applied, for microdialysis parameters, for instance, none of the respondents specified trigger values. Trigger values for intervention are displayed in Fig. 4a, some of which varied considerably. For ICP, 62 % respondents stated 20 mmHg to be a trigger value for intervention, 35 % stated 25 mmHg. Osmotherapy (34 %) and augmenting sedation (21 %) were the most common initial measures for lowering ICP. For cerebral perfusion pressure (CPP), the majority stated 60 mmHg as a trigger, but as much as 26 % stated 55 mmHg or less, the preferred initial measure of intervention was an increase of the blood pressure (70 %). Regarding Doppler mean flow velocities of the middle cerebral artery (vMCA) to detect SAH vasospasm the majority (56 %) regarded velocities between 120 and 200 cm/s as a trigger for intervention, while 28 % regarded velocities >200 cm/s as a trigger.

Figure 4b displays trigger values and their respectively preferred initial interventions for blood values, differentiated according to cerebrovascular diseases and other neurological diseases. However, these management differences between vascular and non-vascular diseases were not significant for any offered parameter. In some instances laboratory trigger values varied widely, as for hyperglycemia: maximum blood glucose between 120 and 250 mg/dl, the mean value being stated as 163/170 (vascular/non-vascular, respectively). First choice measure in most cases was intravenous insulin (>70 %). Likewise, for hyponatremia the range was between 120 and 135 mmol/l (mean 129), most participants (62 %) stated application of isotonic sodium chloride (NaCl) infusion as a first measure. A mean

Fig. 4 a Neuromonitoring trigger values and interventions across all diseases. Participants chose between discontinuous values. Data are displayed as percentage of survey participants answering this question. *ICP* intracranial pressure, *CPP* cerebral perfusion pressure, *PbtO₂* cerebral oxygen partial pressure, *vMCA* maximum flow velocity in middle cerebral artery, *SAH* subarachnoid hemorrhage. **b** Systemic trigger values and interventions for vascular versus non-vascular diseases. Participants specified continuous values. Data are displayed as mean/min/max values. *Min* minimum, *Max* maximum, *s.c.* subcutaneous, *i.v.* intravenous, *mg* milligram, *dl* deciliter, *mmol* millimole, *l* liter, *NaCl* sodium chloride, *PaO₂* arterial partial pressure of oxygen, *PaCO₂* arterial partial pressure of carbon dioxide, *Hb* hemoglobin, *FiO₂* fraction of inspired oxygen, *CPAP* Continuous Positive Airway Pressure, *PEEP* positive end-expiratory pressure, *NIV* non-invasive ventilation, *RBCC* red blood cell concentrate. *N* number of participants answering this question

of 81/77 mmHg (range 60–100) arterial oxygen partial pressure (PaO₂) led respondents to primarily increase inspiratory fraction of inspired oxygen (FiO₂, 69/74 %). An arterial partial pressure of carbon dioxide (PaCO₂) value of 46/48 mmHg (range 30–55/30–70) was regarded as a trigger, the mostly chosen initial measure was an increase of the respiratory rate (64/60 %). In anemic patients a hemoglobin value of 8 g/dl was the mean trigger for intervention, but the individual values varied widely between 5 and 10 g/dl. Most people stated to give two erythrocyte concentrates as a first intervention (56/51 %).

Discussion

This is the largest survey to provide data on monitoring practices and associated interventions in German NICUs, so far. To our knowledge, it is the largest national survey on neurocritical care monitoring in general.

The average interventions derived from the NM seem to be in line with general customs and guidelines, but individual interventions can vary considerably both with regard to their triggers and their specific types. Our survey adds new insights to previous surveys in 1992/1993 and 1996/1997 [3], as these were focused on organizational and structural aspects of NICUs only and confined to neurological ICUs with neurological guidance. In the second survey in 1996/1997, 62 ICUs were documented, 30 of these with full ventilation facilities, 16 intermediate care units, and 16 interdisciplinary wards. The first part of our survey was recently completed and focused on structural aspects and guideline/protocol adherence of the centers [4]. This revealed a general interest in and a need for guidance in neurological critical care medicine in Germany. A guideline adherence of 75 % was stated by 41 % of the NICUs. Applications of standard procedures was reported to be achieved by more than 80 % for several ICU management aspects, significantly differing according to hospital status or leading specialty.

a

ICP in mmHg	Answers in %
15	3
20	62
25	35
N=29 Preferred initial interventions: osmotherapy (34%), increase sedation (21%)	
CPP in mmHg	%
50	15
55	11
60	52
65	7
70	15
N=27 Preferred initial interventions: raise blood pressure (70%), osmotherapy (13%)	
PbtO ₂ in mmHg	%
5	10
10	20
15	20
20	50
N= 10 Preferred initial interventions: raise blood pressure (57%), change ventilator settings (29%)	
SAH-vMCA in cm/s	%
< 120	4
>120<200	56
>200	28
Increase of vMCA>50% in 24hrs	8
Lindegaard-Index > 3	4
N=25 Preferred initial interventions: raise blood pressure (33%)	

b

	vascular disease	non-vascular disease
Hyperglycemia - Glucose in mg/dl		
Min	120	120
Mean	183	170
Max	250	250
Preferred initial Interventions	N= 29 Insulin i.v. (74%), Insulin s.c. (26%)	N= 27 Insulin i.v. (72%), Insulin s.c. (28%)
Hyponatremia in mmol/l		
Min	125	120
Mean	130	130
Max	135	135
Preferred initial Interventions	N= 31 isotonic NaCl-Infusion (62%), Individual (16%)	N= 31 isotonic NaCl-Infusion (58%), Individual (19%)
Hypernatremia in mmol/l		
Min	145	145
Mean	152	152
Max	170	170
Preferred initial Interventions	N= 29 Fluids (37%), 5% Glucose (23%)	N= 29 Fluids (39%), 5% Glucose (24%)
PaO₂ in mmHg		
Min	60	60
Mean	81	77
Max	100	100
Preferred initial Interventions	N= 24 Raise FiO ₂ (69%), raise PEEP (14%)	N= 23 Raise FiO ₂ (74%), raise PEEP (9%)
PaCO₂ in mmHg		
Min	30	30
Mean	46	48
Max	55	70
Preferred initial Interventions	N= 18 Raise respiratory frequency (64%), CPAP/NIV (11%)	N= 18 Raise respiratory frequency (60%), CPAP/NIV (10%)
Hb in g/dl		
Min	5	5
Mean	8	8
Max	10	10
Preferred initial Interventions	N= 17 2 RBCC (56%), 1 RBCC (19%)	N= 15 2 RBCC (51%), 1 RBCC (23%)

Regarding the admission diagnoses, it is interesting that IS was stated as the most frequent admission diagnosis (20 %) among all NICUs. This could mean that in many German centers neurological intensive care is a part of comprehensive stroke care beyond the stroke unit. It probably also reflects the increasing rate of invasive therapies in stroke patients, such as endovascular recanalization involving mechanical ventilation or decompressive surgery in space-occupying ischemic hemispheric or cerebellar stroke.

In the section about general and neurological/neurosurgical ICU-Scores, our results show that the use in German NICUs is confined to a small number of traditional ones. For example, the classical SAH-score Hunt/Hess is more frequently used than the more modern WFNS score although the latter is advocated considerably by German neurosurgical societies and although the HH is reported to have a lower interrater reliability [5, 6]. However, both scores are equally recommended in current guidelines [7, www.dgn.org (German guideline)], including a guideline of the American Heart Association, and the predictive value of the Hunt/Hess score was still found high in some studies [8–10].

The relevance of traditional scores like this one is reflected by the respondents stating to use them for therapeutic decisions to a considerable degree. It is quite remarkable that general ICU scores like APACHE, Ramsay, and SOFA that have a fairly solid base of evidence in general critical care are stated to be used by <40 % of participants. This may be explained by the majority of NICUs being directed by neurologists or neurosurgeons less aware of or less interested in these more general ICU scoring tools. Remarkably few recently published scores in internationally recognized (N)ICU journals are applied in German NICUs. Apparently, there is not much interest in or knowledge of these modern scores. Alternatively, the facts that most of these scores were not established in Germany or that ICU attendings are not exchanged that often in Germany while residents are, may prevent implementation of new scoring tools.

Fifty one percent stated to apply NM in specific brain diseases, the top two of which were SAH and TBI. This might be similar in US NICUs, is at least in line with US guidelines, where jugular venous saturation, brain tissue oxygen monitoring and ICP monitors are recommended in severe TBI [11]. In US guidelines on SAH, EEG, PbtO₂ monitoring, and CMD are proposed for the detection of delayed cerebral ischemia (DCI), albeit as “low quality evidence—weak recommendation” [12]. Indeed, with five more recent monitoring studies in TBI [13–17] and four in SAH [18–21], these two entities seem to be the most actively studied NICU diagnoses in countries outside Germany as well.

This might be explained by the fact that most data on NM derives from these two entities and that both often

require surgery with the simultaneous option to place invasive monitoring devices. Coma in general accounted for <40 % as an indication for NM, possibly because coma on NICUs can be attributable to numerous causes not related to brain injuries like drug effects or systemic metabolic disturbances.

Regarding the methods of NM, it was not surprising that non-invasive techniques are more often applied, with the exception of ICP measurement. Doppler and electrophysiological monitoring are the most frequently applied methods, although their short-comings outside very specific situations have been demonstrated. These methods have a strong tradition in Germany in general neurology, which might account for their frequent use in the NICUs. On the contrary, only few centers use advanced NM beyond ICP (e.g., PbtO₂ < 40 %, CBF/microdialysis/NIRS (near infrared spectroscopy)/SjvO₂ (jugular venous oxygen saturation) etc., < 20 %), probably because the understanding of these methods is still not widespread, their use is quite sophisticated, expensive, time- and manpower-consuming, and no benefit from larger studies regarding the outcome has been shown yet [1]. In the brain trauma foundation guidelines, cerebral microdialysis, thermal diffusion probes, transcranial Doppler, and near infrared spectroscopy are mentioned, but not generally recommended due to a lack of evidence [11]. Furthermore, there are hardly any accepted trigger values for therapeutic interventions for the specific parameters of advanced NM beyond ICP, so far as it is rarely applied. PbtO₂ is somewhat more frequently used compared to other invasive methods, possibly because it is minimally invasive, fairly robust and can be combined with ICP probes [22]. There are also data regarding correlations with the outcome, e.g., in patients with SAH [2, 23, 24]. Microdialysis has been used in neurocritical care for ~20 years, demonstrating its prognostic potential in brain diseases such as malignant IS [25], ICH [26] and SAH [23]. The fact that only a minority of the German survey participants seems to use microdialysis at all and if so, mainly for research purposes, is probably explained by the requirement of a special recording and analysis system and the time- and manpower-demand associated with this method [1]. Monocentric series in Australia or in the USA demonstrate an international interest in establishing microdialysis as an additional diagnostic tool of NM [18, 27], the problems of practicability, however, have been acknowledged in a recent international conference [1]. Study results on these more modern methods as well as CBF, brain temperature, NIRS or SjvO₂ will thus not have a relevant impact on monitoring and management of patients in German NICUs. In other words, multimodal NM does not seem to be a widespread reality in German NICUs yet.

Most mean values that were found to trigger interventions were close to what has been recommended by societies or consensus papers including US guidelines [11], such as ICP values 20 or 25 mmHg. However, individual trigger values

varied widely in some cases, e.g., CPP values between 50 and 70 mmHg. The variance here might be explained by the fact that there exist different recommendations for different diseases. For instance, in IS, it is recommended to maintain a CPP > 70 mmHg according to German neurological guidelines while recommendations vary between 50 and 70 mmHg for TBI (www.braintrauma.org/coma-guidelines).

Another striking variance was that found for Doppler values triggering interventions in SAH-related vasospasm. Although a vMCA > 200 cm/s is recommended as a trigger value in current guidelines [12], most respondents stated to interfere at a vMCA between 120 and 200 mmHg. The Lindegaard index, proposed to provide more certainty to the Doppler assessment on true intracranial spasms (as opposed to overall increase of cerebral perfusion), does not seem to play a relevant role as intervention trigger.

Regarding glycemic control, there was a wide range of stated trigger values as well (maximum blood glucose between 120 and 250 mg/dl). This variability is probably due to the conflicting data from the few randomized controlled trials regarding the optimal serum glucose range and the subsequent uncertainty of best therapy. Recent recommendations based on the largest meta-analysis suggest intermediate glycemic goals to be most appropriate as a range for neurocritical care patients in general [28, 29]. However, the upper glucose goal of 250 mg/dl was not supported by randomized controlled trials because very loose glycemic control with a target of > 180 mg/dl (10 mmol/l) appeared to be associated with poor outcome. It might still be the practice in some NICUs because of previous guidelines suggesting a trigger value for glucose of 300 mg in IS [30]. To date, the optimal range of serum glucose for neurocritical care patients and more over for the various specific neurocritical diseases is unknown and awaits further trials.

Finally, a wide ranges of individual answers related to accepted oxygenation parameters and hemoglobin values, probably again due to a lack of consistent recommendations for goal parameters [31]. With regard to hemoglobin, common practice from general ICU care is to tolerate anemia up to levels of 7–8 g/dl. In NICU patients, however, there is evidence from several studies in SAH, TBI, ICH, and IS that low hemoglobin values are associated with worse outcome [32]. While no prospective trials exist that demonstrate benefits of a more aggressive transfusion strategy in these patients, the lower trigger value of 5 g/dl given by some respondents is still surprising.

Our study has several limitations. First, there were just a few criteria for the selection of participating centers, as our aim was to reach as many eligible participants as possible. Certainly, not all of the selected hospitals truly had specialized NICUs as indicated on their homepages. Therefore, the response rate of 78/326 is definitely falsely low and makes it difficult to judge how representative our findings

are. However, 78 ICUs which clearly qualified themselves as specialized NICUs by their structures and equipment constitute the largest cohort for assessment, so far. The uniqueness of this survey is also its weakness, as the results can hardly be compared and rather have to be displayed descriptively than to be interpreted to a greater extent. Any survey depends on the completeness and correctness of answers given by the consulting physician, and measures to support this were only guaranteed anonymity and lack of financial compensation. There might have been a selection bias because the ICU-leading physicians who took part might also have been the ones especially motivated to implement ICU standards. Finally, not all the questionnaires were answered completely so that in some parts the statistical validity might have been reduced. These missing data and a lower response rate than could have been obtained might have been the result of a questionnaire volume of 50 questions that possibly was too burdensome. We had agreed upon this, after a satisfactory test run among ICUs of the IGNITE group and to yield much information.

An official assessment with rigorously defined criteria for the participating centers would certainly be ideal, with involvement of spectrum of respondents (ICU attending, resident, nurse) and control instruments such as data monitoring systems and registries. Our survey might serve as a base for such an official assessment as well as for the planning of future trials to provide evidence for lacking standards.

Conclusions

Daily practice in German NICUs seems to be characterized by the use of traditional scores and traditional monitoring methods, such as Doppler, EEG, EP, and ICP-measurement. Modern scores or advanced methods of NM seem to play a minor role. While an interest in achieving standardized physiological and laboratory parameters is recognizable, striking differences with regard to goal parameters and intervention triggers are found in individual centers. The reason might be the low level of evidence for most parameters, emphasizing the need for prospective and randomized interventional studies for neurological/neurosurgical diseases to define standards and target values. German NICUs might benefit from networks, high-quality multicenter trials, and a guideline committee.

Conflict of interest The authors declare that they have no conflicts of interest.

Score Glossary

Jauss Score CT-based score to evaluate space-occupying effects in cerebellar infarctions [33]

TRACH Score	Clinical/radiological prediction score for tracheostomy in ICH [34]
Hijdra Score	CT-based score to predict vasospasm in SAH by distribution of blood [35]
FOUR Score	(Full outline of unresponsiveness) clinical score to determine depth of coma [36]
CAM-ICU	Confusion assessment method for the ICU [37]
Graeb Score	CT-based score for volumetry in intraventricular bleeding [38]
ICH Score	[Intracerebral Hemorrhage (Score)] clinical/radiological score for the prognosis in ICH [39]
SOFA	Sepsis-related organ failure assessment [40]
RASS	Richmond agitation sedation scale [40]
ABC/2	CT-based volumetry in ICH [41]
Ramsay	Score to assess depth of sedation [42]
WFNS	(World Federation of Neurological Surgeons Grading System for Subarachnoid Hemorrhage) clinical prognostic score in SAH [9]
APACHE	(Acute Physiology And Chronic Health Evaluation) ICU-score based on laboratory parameters and vital signs to determine disease severity and survival [40]
GOS	(Glasgow outcome scale) Score for grading recovery after brain lesion [43]
mRS	(Modified Rankin Scale) Score to assess functional recovery after ischemic stroke [44]
Fisher	Radiological score for the extent of bleeding and prediction of vasospasm in SAH [45]
NIHSS	(National Institute of Health Stroke Scale) clinical score to determine symptoms and severity in stroke [46]
GCS	(Glasgow Coma Scale) score to grade level of consciousness [36]
Hunt and Hess	Clinical severity score in SAH [5]

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