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REVIEW ARTICLE

Multimodality Monitoring Consensus Statement: Monitoring in Emerging Economies

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Abstract The burden of disease and so the need for care is often greater at hospitals in emerging economies. This is compounded by frequent restrictions in the delivery of good quality clinical care due to resource limitations. However, there is substantial heterogeneity in this economically defined group, such that advanced brain monitoring is routinely practiced at certain centers that have an interest in neurocritical care. It also must be recognized that significant heterogeneity in the delivery of neurocritical care exists even within individual high-income countries (HICs), determined by costs and level of interest. Direct comparisons of data between HICs and the group of low- and middle-income countries (LAMICs) are made difficult by differences in patient demographics, selection for ICU admission, therapies administered, and outcome assessment. Evidence suggests that potential benefits of multimodality monitoring depend on an appropriate environment and clinical expertise. There is no evidence to suggest that patients in LAMICs where such resources exist should be treated any differently to patients from HICs. The potential for outcome benefits in LAMICs is arguably greater in absolute terms because of the large burden of disease; however, the relative cost/benefit ratio of such monitoring in this setting must be viewed in context of the overall priorities in delivering health care at individual institutions.

Keywords Neurocritical care · Multimodality monitoring · Low- and middle-income countries · Developing countries · Traumatic brain injury

Introduction

The burden of disease from conditions that require neurocritical care is often greater in emerging economies, and outcomes are generally worse. For example, it is estimated that 90 % of trauma-related deaths occur in the developing world [1], Disability-Adjusted Life Years (DALYs) losses due to injury progressively rise with decreasing income levels [2], the odds of dying due to injury are higher, and the relative proportion of TBI in injury cases is greater in low-income settings [3]. Similarly, cerebral infections and the cerebral consequences of uncontrolled hypertension may place greater demand on intensive care units (ICU). Therefore, a global community interested in developing neurocritical care arguably has some responsibility to extend expertise and resources to areas in greatest need in response to the acute brain injury version of the 10/90 gap. Also, periodically questions arise about the generalizability of study data in both directions, i.e., the extrapolation of study findings from high-income countries (HICs) to low- and middle-income countries (LAMICs) and vice versa. Therefore, clinical service and research in emerging economies present both substantial opportunities and

The Participants in the International Multidisciplinary Consensus Conference on Multimodality Monitoring are listed in "Appendix" section

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challenges. The challenges in LAMICs include how to acquire resources, train staff adequately, define how best to go about collaborative study, and determine how to generalize outcome data. The aim of this review was to examine some of these important issues in the context of neuromonitoring and multimodality monitoring (MMM). In the simplest form of MMM, if a patient undergoes serial clinical assessments (including vital signs), has repeat blood work or repeat imaging he or she is receiving MMM. Because TBI is common in LAMICs and there is a relatively greater amount of fairly homogeneous clinical data published on TBI compared with other neurocritical care disorders, we concentrated on clinical care of TBI as a measure of differences between HICs and LAMICs in demographics, outcomes, and the general use of neurocritical care monitoring.

Methods

To start, definitions of emerging economies were clarified. We used the World Bank definitions of high-, middle-, and low-income countries. The World Bank publishes the World Development Indicators which are updated on July 1st every year; the 2013 classification used here is based on the 2012 Gross National Income (GNI) per capita figures for each country, and was calculated using the World Bank Atlas Method (http://data.worldbank.org/about/country-classifications). The groups thus classified are *low income* $1,035 or less; *lower middle income*, $1,036–$4,085; *upper middle income*, $4,086–$12,615; and *high income*, $12,616 or more. A complete list can be found on the World Bank website.

Literature Search

A Medline search was conducted using the following terms: brain, monitoring, intracranial pressure, traumatic brain injury, subarachnoid hemorrhage, transcranial Doppler, brain oxygen, cerebral microdialisis, neuromonitoring, neurocritical care, neurointensive care, developing country, and emerging economy. In addition, we searched these terms with individual countries in the LAMICs group. Papers published in English, Spanish, and Portuguese were reviewed. Three databases were used, namely Scopus, Pubmed, and Scielo. We additionally hand searched articles identified from articles in the list and those known to the authors. We included adults and children because the population pyramid in developing countries tends to be broad based and because most developing world settings do not have dedicated adult and pediatric ICUs and so report mixed populations. For ease of comparison, we restricted extraction of demographic and outcome data to that of patients with severe TBI, but we considered the use of multimodality monitoring for any neurological condition. Where we were not able to extract required data for severe TBI from series with mixed grades of TBI, we did not include the result, unless the study was a direct comparison between 2 centers. We excluded outcome data from studies that reported less than 15 patients. We searched studies published from January 1990 to August 2013. Studies published before 1990 were included if thought to be of considerable relevance. The final number of papers that we reviewed was 117. The end points of this review were to answer the following questions:

- Are there differences between HICs and LAMICs in baseline characteristics for neurocritical care patients (specifically severe TBI) or selection of patients for study?
- What is the availability/penetration of various monitoring technologies/neurocritical care in emerging economies?
- Does MMM benefit patients in LAMICs and is it cost-effective?
- What are the challenges to instituting MMM in resource-constrained environments?

Results

Are There Differences Between HICs and LAMICs in Baseline Characteristics for Neurocritical Care Patients (Specifically Severe TBI) or Selection of Patients for Study?

Several studies from LAMICs were identified although few were of high quality [4–38]. Table 1 shows the results of TBI studies with regard to case mix, age, sex, and mechanism of injury. We excluded studies in which study design likely affected the demographics of the reported sample. The selection criteria for ICU admission were not clearly delineated in most studies, although it was clear that ICU bed availability is an important factor in resource-limited settings [11]. In general, both higher and lower thresholds for ICU admission likely exist in comparison with HICs: patients who are less severely injured are less likely to be admitted to the ICU, as are patients with the most severe injuries for whom a good outcome is very unlikely. Resource limitations extend beyond simple admission to the ICU, especially in low-income settings, including regular access to oxygen, water, and electricity [39].

In general, compared with data from HICs, patients admitted with TBI to ICUs in developing countries tended to be younger (even when only adult studies are

Table 1 Data for demographics of TBI studies

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
Resource utilization in the management of TBI—an audit from a rural setup in a developing country	Agrawal [5]	Wardha, India	Retrospective	162	Adults and children	79.0 %	36 (1–83)	RTA 67 %	Rural part of India. $N = 381$ patients all grades of TBI
Prognosis of traumatic head injury in South Tunisia: a multivariate analysis of 437 cases	Bahloul [6]	Tunisia	Retrospective	253	Adults	90.0 %	28 (15–98)	RTA 86 %	Mixed grades of TBI severity in the ICU. $N = 437$ all grades of TBI
Severe head injury among children: Prognostic factors and outcome	Bahloul [7]	Tunisia	Retrospective	222	Children	73.0 %	7.5 (0.3–15)	RTA 76 %	
Trauma admissions to the intensive care unit at a reference hospital in Northwestern Tanzania	Chalya [8]	Tanzania	Retrospective	192	Adults and children	85.0 %	4–71	RTA 71 %	Trauma admissions to the ICU. Severe TBI 192 patients (62 %). Major trauma accounted for 37 % of admissions and 95 % of emergency admissions. 312 overall trauma cases; TBI 95 % of these
Head injury mortality in two centers with different emergency medical services and intensive care	Colohan [9]	India (New Delhi); US (Charlottesville, virginia)	Prospective observational study at two centers	1373, mixed (551 New Delhi; 822 Charlottesville)	Adults	81 % (New Delhi); 69 % (Charlottesville)	25 (New Delhi); 32 (Charlottesville)	RTA 60 % both series	All grades of TBI severity. Compared demographics and outcomes at Charlottesville, Virgina and New Delhi, India Groups not completely comparable, so controlled for GCS motor score

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
Examination of the management of traumatic brain injury in the developing and developed world: focus on resource utilization, protocols, and practices that alter outcome	Harris [10]	Jamaica, US	Prospective observational study at 3 centers	269	Adults	81 % (Jamaica); 74 % (Atlanta)	34 (Jamaica); 38 (Atlanta)	RTA 66 % (Jamaica); 44 % (Jamaica); 35 % (Atlanta)	Studied two centers in Jamaica, one in Atlanta, Georgia. Mixed grades of TBI severity; $N = 1607$. Atlanta: higher percentage of severe TBI; better outcome; older patients; more ICP monitoring (13 %); median time to death a bit later. Jamaica: more assaults (approx 40 %), younger patients, higher rates of penetrating injuries. No difference in mild/moderate injury mortality, but significantly different for severe TBI
Cost effectiveness analysis of using multiple neuromodalities in treating severe traumatic brain injury in a developing country like Malaysia	Ibrahim [13]	Malaysia	Prospective, observational	62	Adults	92.0 %	33.8	RTA 85.5 %	Study comparing baseline neuromonitoring and MMM. 32 patients were managed with MMM, 30 with baseline neuromonitoring (ICP and conventional care)
Prognostic study of using different monitoring modalities in treating severe traumatic brain injury	Idris [14]	Malaysia	Prospective randomized study	52	Adults	90.0 %	35 (15–75)	RTA 86 %	Randomized to 2 different surgeons for care. MMM versus ICP only

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
Outcome of severe traumatic brain injury: comparison of three monitoring approaches	Isa [15]	Malaysia	Prospective, observational	82 total (17 MMM; 31 ICP; 34 none)	Adults and children	82–85 %	27	NR	Historical comparison of three groups: No monitoring; ICP monitoring only; MMM
Early prediction of outcome in very severe closed head injury	Jain [16]	India	Prospective, observational	102	Adults and children	91.0 %	31.7 (6–75)	RTA 44 %; railway traffic accidents in 36 %	Included only patients with a GCS of five or less. Overall mortality 76 %
Delayed traumatic intracranial hemorrhage and progressive traumatic brain injury in a a major referral center based in a developing country	Jeng [12]	Malaysia	Retrospective	16	Adults	86.0 %	33	RTA 81.5 %	Imaging study. Mixed grades of TBI severity; $N = 81$
Outcome of children with traumatic brain injury in rural Malaysia	Kumaraswamy [17]	Malaysia	Prospective	33	Children	75.0 %	6–13	RTA 100 %	Mixed grades of TBI severity
Traumatic brain injury in a rural and urban Tanzanian hospital—a comparative, retrospective analysis based on computed tomography	Maier [41]	Tanzania	Retrospective	680	Adults and children	Ratio 5.7:1 (rural); 2.1:1 (urban)	33.7 (rural); 40.5 (urban)	RTA 46.3 % (urban); rural 25.4 %. Included injuries due to wild and domestic animals	Review of imaging. More pathology encountered in the rural area, long distances to travel; unusual mechanisms of injury
Prognosis of head injury: an experience in Thailand	Ratanalert [19]	Thailand	Retrospective	300	Adults and children	87.0 %	30 (5–76)	84 % RTA (66 % motocycle accidents)	Excluded brain death presentations

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
Care of severe head injury patients in the Sarawak General Hospital: Intensive care unit versus general ward	Sim [11]	Malaysia	Prospective	35	Adults	91.0 %	37 (13–75)	RTA 80 %	65.7 % of patients were ventilated in the general ward; 34.3 % managed in the ICU. Decision made by anesthetic team based largely on availability of ICU bed. Inclusion/exclusion criteria for management not specified. Ward mortality higher; however, mean age of ward managed patients was higher than ICU patients and GCS was lower. Groups not easily comparable
Intensive care and survival analyses of traumatic brain injury	Sut [20]	Turkey	Retrospective	126	Adults	80.2 %	34.5	RTA 60 %	
Post-traumatic seizures—a prospective study from a teriary level center in a developing country	Thapa [66]	India	Prospective observational	130	Adults and children	81.0 %	28 (0.08–89)	RTA 48 %	Excluded late admissions and GCS 4 or less. All grades of TBI severity. 520 total; 25 % sTBI; overall mortality 11.5 %; severe TBI mortality not separately reported

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
Epidemiology of TBI in Eastern China 2004: a prospective large case study	Wu [21]	China	Prospective	2983	Adults and children	77.0 %	39 (0–98)	RTA 61 %	Standardized questionnaire in the region over a 1 year period. All patients admitted with a diagnosis of head injury to one of 77 hospitals in the region. All grades of TBI severity. Severe and moderate TBI each about 20 %
Continuous measurement of the cumulative amplitude and duration of hyperglycemia best predicts outcome after traumatic brain injury	Yuan [22]	China (Shanghai)	Prospective observational	56 moderate and sTBI	Adults	76.8 %	46	RTA 61 %	78 % underwent craniotomy or craniectomy; not likely a consecutive series; also higher mean age. Moderate and severe TBI
Outcome of head injuries in general surgical units with an offsite neurosurgical service	Zulu [23]	South Africa, KZN	Prospective observational	42	Adults	83.0 %	31 (12–80)	NR	Outcome of patients in general surgical ICU with offsite neurosurgery transfer. 316 total patients mixed grades of injury; 12 % had severe TBI
The relationship between intracranial pressure and brain oxygenation in children with severe traumatic brain injury	Rohlwink [43]	South Africa	Retrospective	75	Children	65.0 %	6.4 (0.3–14)	RTA 80 %	
The relationship between basal cisterns on CT and time-linked intracranial pressure in pediatric head injury	Kouvarellis [67]	South Africa	Retrospective	104	Children	63.0 %	6 (0.42–14)	RTA 82 %	

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
The effect of increased inspired fraction of oxygen on brain tissue oxygen tension in children with severe traumatic brain injury	Figaji [26]	South Africa	Prospective, observational	28	Children	NR	5.8 (0.75–11)	NR	
Pressure autoregulation, intracranial pressure, and brain tissue oxygenation in children with severe traumatic brain injury	Figaji [44]	South Africa	Prospective, observational	24	Children	83.0 %	6.3 (1–11)	RTA 75 %	
The effect of blood transfusion on brain oxygenation in children with severe traumatic brain injury	Figaji [27]	South Africa	Retrospective	17	Children	NR	5.4 (0.75–12)	NR	
Transcranial Doppler pulsatility index is not a reliable indicator of intracranial pressure in children with severe traumatic brain injury	Figaji [45]	South Africa	Prospective, observational	34	Children	NR	6.5 (0.75–14)	NR	
Brain tissue oxygen tension monitoring in pediatric severe traumatic brain injury. Part 1: Relationship with outcome	Figaji [46]	South Africa	Prospective observational	52	Children	75.0 %	6.5 (0.75–14)	RTA 77 %	
Acute clinical grading in pediatric severe traumatic brain injury and its association with subsequent intracranial pressure, cerebral perfusion pressure, and brain oxygenation	Figaji [62]	South Africa	Retrsospective	52	Children	NR	6.5 (0.25–14)	RTA 77 %	

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
Does adherence to treatment targets in children with severe traumatic brain injury avoid brain hypoxia? A brain tissue oxygenation study	Figaji [63]	South Africa	Prospective, observational	26	Children	85.0 %	6.8 (0.75–14)	RTA 81 %	
Intracranial pressure and cerebral oxygenation changes after decompressive craniectomy in children with severe traumatic brain injury	Figaji [47]	South Africa	Retrospective	18	Children	NR	7.8 (0.25–14)	NR	
Head Trauma in China	Jiang [68]	China	Retrospective	1626	Adults and children		1–92	NR	Mixed TBI grade severity, Databank analysis of 47 hospitals over 9 months
Pediatric neurotrauma in Kathmandu, Nepal: implications for injury management and control	Mukhida [69]	Nepal	Retrospective	46	Children	65.0 %	0–18	RTA 35 %	Patients in the city region took about 8 h to get to the hospital while patients in the rural area took more than a day to get to hospital. Ventriculostomy used in 3 % of total 352 patients (46 sTBI). Delayed transfer to hospital may have selected patients. Patients who came from the rural area paradoxically had lower mortality, possibly for this reason

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
Decreased risk of acute kidney injury with intracranial pressure monitoring in patients with moderate or severe brain injury	Zeng [57]	Shanghai	Prospective, observational	47	Adults	64.3 %	43 (18–68)	NR	Prospective comparison of ICP-monitored and non-monitored moderate and severe TBI patients. Examined GOS at 6 month and acute kidney injury. Non-randomized. 168 all grades of TBI
Use of indomethacin in brain-injured patients with cerebral perfusion pressure impairment: preliminary report	Biestro [60]	Uruguay	Prospective, interventional	11	Adults	73.0 %	24	NR	Non-consecutive series. Ten TBI, one SAH
Osmotherapy for increased intracranial pressure: comparison between mannitol and glycerol	Biestro [59]	Uruguay	Prospective, interventional	16	Adults	88.0 %	37 (15–69)	NR	Both effective, mannitol better for bolus and glycerol for baseline treatment
Optimizing cerebral perfusion pressure during fiberoptic bronchoscopy in severe head injury: effect of hyperventilation	Previgliano [70]	Argentina	Prospective, interventional	34	Adults	88.0 %	39	NR	
Incidence of intracranial hypertension related to jugular bulb oxygen saturation disturbances in severe traumatic brain injury patients	Schoon [48]	Argentina	Retrospective	116	Adults	64.7 %	30.9 (16–67)	NR	
Jugular venous oxygen saturation or arteriovenous difference of lactate content and outcome in children with severe traumatic brain injury	Perez [49]	Argentina	Prospective, observational	27	Children	52.0 %	10 (1–16)	NR	

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
Influence of the respiratory physiotherapy on intracranial pressure in severe head trauma patients	Thiesen [71]	Brazil	Retrospective	35	Adults	77.0 %	25 (17–49)	NR	
Serum Hsp70 as an early predictor of fatal outcome after severe traumatic brain injury in males	da Rocha [56]	Brazil	Prospective, observational	20	Adults	N/A	34.5 (18–64)	RTA 70 %	Males only included in the series
Effects of dexmedetomidine on intracranial hemodynamics in severe head injured patient	Grille [72]	Uruguay	Prospective, interventional	12	Adults	90.0 %	33	NR	
Cerebral hemodynamic changes gaged by transcranial Doppler ultrasonography in patients with post-traumatic brain swelling treated by surgical decompression	Bor-Seng-Shu [52]	Brazil	Prospective, observational	19	Adults	68.4 %	33.3	RTA 89.5 %	
Role of serum S100B as a predictive marker of fatal outcome following isolated severe head injury or multitrauma in males	da Rocha [55]	Brazil	Prospective, observational	30	Adults	NR	34 (19–64)	RTA 78 %	S100B within 48 h post-injury has significant predictive value for mortality
Optimized hyperventilation preserves 2,3-diphosphoglycerate in severe traumatic brain injury	Torres [54]	Brazil	Prospective, observational	11	Adults	90.9 %	25.5 (15–49)	RTA 63.6 %	
Indomethacin and cerebral autoregulation in severe head injured patients: a transcranial Doppler study	Puppo [31]	Uruguay	Prospective, interventional	16	Adults	88.0 %	39	NR	

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
Value of repeat cranial computed tomography in pediatric patients sustaining moderate to severe traumatic brain injury	Da Silva [33]	Brazil	Retrospective	22	children	NR	6 (1–14)	RTA 46 %	Excluded patients who died in the first 24 h; moderate and severe TBI. $N = 63$ total
Cerebral CO_2 reactivity in severe head injury. A transcranial Doppler study	Puppo [29]	Uruguay	Prospective, interventional	16	Adults	85.0 %	40 (17–60)	NR	
Early prognosis of severe traumatic brain injury in an urban Argentinian trauma center	Petroni [34]	Argentina	Prospective, observational	148	Adults	81.0 %	24 (14–77)	RTA 87 %	Excluded patients who were sedated or intubated, had a penetrating head injury, were brain dead on arrival or if consent was refused. Almost 90 % mortality in those over age 50
Continuous subcutaneous apomorphine for severe disorders of consciousness after traumatic brain injury	Fridman [73]	Argentina	Prospective, interventional	8	Adults	50.0 %	22–41	NR	Non-consecutive series
Factors associated with intracranial hypertension in children and teenagers who suffered severe head injuries	Guerra [35]	Brazil	Retrospective	191	Children	NR	9.7	RTA 79.5 %	Most ICP monitors with subdural or subarachnoid Richmond screw
Non-invasive intracranial pressure estimation using support vector machine	Chacon [74]	Chile-Uruguay	Prospective, observational	8	adults	NR	25.8 (16–48)	NR	
Neuron-specific enolase, S100B, and glial fibrillary acidic protein levels as outcome predictors in patients with severe traumatic brain injury	Bohmer [75]	Brazil	Prospective, observational	20	Adults	90.0 %	29	NR	Consecutive series

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
A trial of intracranial-pressure monitoring in traumatic brain injury	Chesnut [37]	Bolivia–Ecuador	Prospective RCT	324	Adults	87.0 %	29	76 % RTA (majority motorcycles)	Multicenter study in Boliva and Ecudaor. Only 45 % came in with an ambulance. Median time to hospital 3.1 h
Delayed intracranial hypertension and cerebral edema in severe pediatric head injury: risk factor analysis	Bennett Colomer [38]	Chile	Retrospective	31	Children	58.0 %	8.9	NR	
Bedside study of cerebral critical closing pressure in patients with severe traumatic brain injury: a transcranial Doppler study	Puppo [28]	Uruguay	Prospective, observational	12	Adults	83.0 %	32	NR	
Mortality and morbidity from moderate to severe traumatic brain injury in Argentina	Rondina [40]	Argentina	Prospective, observational	169 in Argentina; 103 in Oregon	Adults	85 % (Argentina); 75 % (Oregon)	33 (Argentina); 40 (Oregon)	NR	Included moderate and severe TBI
Highlighting intracranial pressure monitoring in patients with severe acute brain trauma	Falcao [76]	Brazil	Retrospective	100	Adults	81.0 %	11–70	RTA 71 %	
Comparison between two static autoregulation methods	Puppo [77]	Uruguay	Prospective, observational	14	Adults	71.0 %	37 (16–63)	NR	
Outcomes following prehospital airway management in severe traumatic brain injury	Sobuwa [78]	South Africa	Retrospective	124	Adults	89 %	32	RTA 67 %	
prognostic factors in children with severe diffuse brain injuries: a study of 74 patients	Pillai [79]	India	Retrospective	74	Children	67.3 %	0-15	RTA 70 %	Children with severe diffuse TBI

Table 1 continued

Article title	First author	City/country	Study design	Patient numbers	Case mix	Males	Age	Mechanism of injury	Comment
Assessment of endocrine abnormalities in severe traumatic brain injury: a prospective study	Tandon [80]	India	Prospective observational	99	adults and children	87 %	32.5	NR	

sTBI severe traumatic brain injury, *N* sample size (for severe TBI unless specified), *NR* not reported, *Mechanism of injury* percentage of study patients involved in road traffic accidents (RTA), *Age* mean age (range) or only range where mean age was not reported

considered) and are more likely to be male (in some studies up to 85–91 %) [9, 40], e.g., the CRASH Trial (8927 patients in 46 countries) [32]. Patients are also more likely to be injured in road traffic accidents (RTAs), although there were sometimes substantial differences in the mechanism of injury, depending on the country or region of origin, including prominence of assaults and penetrating injuries in Jamaica [10], railway accidents in India [16], motor cycle accidents in Thailand [19], and animal attacks in Tanzania [41]. Although the burden of RTAs is greater in LAMICs, its prevalence depends on the economy and the rate of urbanization: countries with a very low GNI tend to have fewer cars on the road. There are obvious discrepancies also in prehospital care. One comparative study found that admission time to hospital was less than 1 h in 50 % of cases in Charlottesville, VA (USA) and in 7 % of cases in New Delhi, India [9]; 89 and 29 % of patients, respectively, were admitted within 3 h; 84 and 0.5 % of patients, respectively, were brought in by ambulance. In summary, there are differences in baseline characteristics in TBI patient populations admitted to the ICU in LAMICs compared with HICs. Selection for ICU admission is likely to be affected by local conditions.

What is the Availability/Penetration of Various Monitoring Technologies/Neurocritical Care in Emerging Economies?

Emerging economies are not homogenous. Even within a single country, substantial disparities exist across private/public and rural/urban divides; this is true also in HICs. There are some indications that neurocritical care is developing as a discrete specialty. In a Chinese survey, 95 % of neurointensive care units (72 of 76) had fulltime neurocritical care doctors, 79 % had neurocritical care directors, and 47 % had neurocritical care residents [42]. Only 30 % used invasive ICP monitoring, but neurological ICUs ($n = 43$) outnumbered the neurosurgical ones ($n = 27$), which may partly explain the difference. Advanced MMM is practiced in LAMICs but is concentrated where there is an interest in neurocritical care: monitoring using ICP, brain oxygenation, cerebral blood flow monitoring, continuous EEG, jugular venous saturation, and microdialysis are all described [13, 15, 27–29, 31, 35, 36, 43–60]. In some of these centers, there is little, if any, difference from what is used in centers in HICs with an interest in neurocritical care. On the whole though, organized neurocritical care appears to be uncommon in LAMICs. ICP monitoring, as an index measure for monitoring beyond basic clinical care, is not commonly employed outside of the relatively few specialist centers (Table 2). For ICP monitoring, often ventriculostomy or subdural/subarachnoid catheters are used instead of the

Table 2 Data for clinical outcome after severe TBI and utilization of monitoring

Article title	Author	City, country	Study design	Overall sTBI mortality	Post-discharge and outcome reporting
Resource utilization in the management of TBI—rural setup	Agrawal [5]	Wardha, India	Retrospective	38.0 %	NR
Prognosis of traumatic head injury in South Tunisia: a multivariate analysis of 437 cases	Bahloul [6]	Tunisia	Retrospective	38.0 %	NR
Severe head injury among children: Prognostic factors and outcome	Bahloul [7]	Tunisia	Retrospective	24.3 %	GOS; mean 8 months, minimum 6 months; 52 % good recovery
Delayed intracranial hypertension and cerebral edema in severe pediatric head injury: risk factor analysis	Bennett Colomer [38]	Chile	Retrospective	35.4 %	NR
Osmotherapy for increased intracranial pressure: comparison between mannitol and glycerol	Biestro [59]	Uruguay	Prospective, inteventional	56.0 %	NR
Neuron-specific enolase, S100B, and glial fibrillary acidic protein levels as outcome predictors in patients with severe traumatic brain injury	Bohmer [75]	Brazil	Prospective, observational	25.0 %	NR
A trial of intracranial-pressure monitoring in traumatic brain injury	Chesnut [37]	Bolivia-Ecuador	Prospective, RCT	40 % (39 % ICP group vs. 41 %)	6 month GOS-E; GOAT; DRS; neuropsychological tests
Head injury mortality in two centers with different emergency medical services and intensive care	Colohan [9]	India (New Delhi); US (Charlottesville, virginia)	Prospective observational study at two centers	GCS motor score 5: 12. % (ND); 4.8 % (CV). Motor score 2-4: 56.2 % (ND); 40.9 % (CV)	NR
Serum Hsp70 as an early predictor of fatal outcome after severe traumatic brain injury in males	da Rocha [56]	Brazil	Prospective, observational	50.0 %	GOS at discharge only
Role of serum S100B as a predictive marker of fatal outcome following isolated severe head injury or multitrauma in males	da Rocha [55]	Brazil	Prospective, observational	48.0 %	NR
Highlighting intracranial pressure monitoring in patients with severe acute brain trauma	Falcao [76]	Brazil	Retrospective	38.0 %	NR

Table 2 continued

Article title	Author	City, country	Study design	Overall sTBI mortality	Post-discharge and outcome reporting
Brain tissue oxygen tension monitoring in pediatric severe traumatic brain injury. Part 1: Relationship with outcome	Figaji [46]	South Africa	Prospective, observational	9.6 %	GOS, Pediatric Cerebral Performance Category Score. Good outcome 77 %
Effects of dexmedetomidine on intracranial hemodynamics in severe head injured patient	Grille [72]	Uruguay	Prospective, interventional	10.0 %	NR
Factors associated with intracranial hypertension in children and teenagers who suffered severe head injuries	Guerra [35]	Brazil	Retrospective	51.5 %	NR
Examination of the management of traumatic brain injury in the developing and developed world: focus on resource utilization, protocols, and practices that alter outcome	Harris [10]	Jamaica, US	Prospective, Observational	56.8 % (Ja.); 53.8 % Ja.); 32.3 % (AG)	GOS, FIM
Cost effectiveness analysis of using multiple neuromodalities in treating severe traumatic brain injury in a developing country like Malaysia	Ibrahim [13]	Malaysia	Prospective, observational	NR	Barthel index at 6 months: 46.83 (conventional); 63.75 (MMM)
Prognostic study of using different monitoring modalities in treating severe traumatic brain injury	Idris [14]	Malaysia	Prospective randomized study	28.8 %—ICU mortality	Barthel index; 6 months; 38 % independent
Outcome of severe traumatic brain injury: comparison of three monitoring approaches	Isa [15]	Malaysia	Prospective, observational	0 % (MMM); 25.8 % (ICP only); 26.4 (no monitoring)	DRS at 3, 6, and 12
Head Trauma in China	Jiang [68]	China	Retrospective	21.8 %	GOS post-discharge; 50.1 % favorable outcome
Head injuries in Papua New Guinea	Liko [81]	Papua New Guinea	Retrospective and prospective	55.6 %	NR
Pediatric neurotrauma in Kathmandu, Nepal: implications for injury management and control	Mukhida [69]	Nepal	Retrospective	28 % (ICU mortality only)	GOS, time not specified (66 % of total)
Jugular venous oxygen saturation or arteriovenous difference of lactate content and outcome in children with severe traumatic brain injury	Perez [49]	Argentina	Prospective, observational	15.0 %	3 months Pediatric Cerebral Performance Category; 81 % favorable

Table 2 continued

Article title	Author	City, country	Study design	Overall sTBI mortality	Post-discharge and outcome reporting
Early prognosis of severe traumatic brain injury in an urban Argentinian trauma center	Petroni [34]	Argentina	Prospective, observational	58.8 % (33.8 % within the first 24 h, 5.4 % post-acute care)	GOS-E 6 month
Prognostic factors in children	Pillai [79]	India	Retrospective	56.8 %	GOS at discharge only; 20 % had a 'good outcome'
Head injury in a sub Saharan Africa urban population	Qureshi [18]	Malawi	Prospective, observational	66.7 %	NR
Prognosis of head injury: an experience in Thailand	Ratanalert [19]	Thailand	Retrospective	46.0 %	GOS 6 months; good outcome 42 %
Secondary injury in traumatic brain injury - a prospective study	Reed [82]	South Africa	Prospective, observational	47.5 %	GOS at discharge or at follow-up clinic: 46 % favorable outcome
Mortality and morbidity from moderate to severe traumatic brain injury in Argentina	Rondina [40]	Argentina	Prospective, observational	24.8 % (Argentina); 6.8 % (Oregon) - of consented patients (selected)	Yes, but mortality only
Care of severe head injury patients in the Sarawak General Hospital: Intensive care unit versus general ward	Sim [11]	Malaysia	Prospective	25.7 % (16.7 % in ICU; 30.4 % in the ward)	GOS on discharge only—Good recovery 40 %
Outcomes in critical care delivery at Jimma University Specialised Hospital, Ethiopia	Smith [83]	Ethiopia	Retrospective	52 % (of all head injured ICU admissions)	NR
Outcomes following prehospital airway management in severe traumatic brain injury	Sobuwa [78]	South Africa	Retrospective	38.7 %	GOS at discharge only; 59.7 % 'good outcome'
Intensive care and survival analyses of traumatic brain injury	Sut [20]	Turkey	Retrospective	50 % (27 % in the first 48 h). ICU mortality only	NR
Assessment of endocrine abnormalities in severe traumatic brain injury: a prospective study	Tandon [80]	India	Prospective, observational	50.5 %	GOS 6 months
Epidemiology of TBI in Eastern China 2004: a prospective large case study	Wu [21]	China	Prospective	33.0 %	NR
Outcome of head injuries in general surgical units with an offsite neurosurgical service	Zulu [23]	South Africa, KZN	Prospective observational	67.0 %	NR

Table 2 continued

Article title	ICP	Other monitoring	N	Case mix	Comment
Resource utilization in the management of TBI—rural setup	No	No	162	Adults and children	Rural part of India. No ICP monitoring available. 70 % of severe TBI deaths in the first 24 h, the rest within 2 week period
Prognosis of traumatic head injury in South Tunisia: a multivariate analysis of 437 cases	NR	NR	253	Adults	Mixed grades of TBI severity in the ICU. Only 1 % died after day 5; 78 % died within the first 48 h
Severe head injury among children: Prognostic factors and outcome	No	No	222	Children	16 % died after day 7
Delayed intracranial hypertension and cerebral edema in severe pediatric head injury: risk factor analysis	80 %	NR	31	Children	Children
Osmotherapy for increased intracranial pressure: comparison between mannitol and glycerol	100 % (selected)	No	16	Adults	Prospective study to compare mannitol and glycerol in sTBI
Neuron-specific enolase, S100B, and glial fibrillary acidic protein levels as outcome predictors in patients with severe traumatic brain injury	NR—EVD	NR	20	Adults	
A trial of intracranial-pressure monitoring in traumatic brain injury	50 %	NR	324	Adults	Multicenter RCT in Boliva and Ecudaor. Excluded patients who had a GCS of 3/15 with fixed, dilated pupils or who were deemed to have an unsurvivable injury. Only 45 % came in with an ambulance. Median time to hospital 3.1 h. Good recovery in 31 % of ICP group and 26 % of standard group. Mortality at 2 weeks 21 % and 30 %; at 6 months 39 % and 41 %
Head injury mortality in two centers with different emergency medical services and intensive care	Of total: 15 % CV (87 % for GCS 5 or less); 0 % ND	No	Mixed	patients:1373 (551 ND; 822 CV).	Adults
All grades of TBI severity. Compared demographics and outcomes at Charlottesville, Virginia (CV) and New Delhi (ND), India. Groups were not completely comparable, so they controlled for GCS motor score					

Table 2 continued

Article title	ICP	Other monitoring	N	Case mix	Comment
Serum Hsp70 as an early predictor of fatal outcome after severe traumatic brain injury in males	NR	NR	20	Adults	
Role of serum S100B as a predictive marker of fatal outcome following isolated severe head injury or multitrauma in males	NR	NR	30	Adults	
Highlighting intracranial pressure monitoring in patients with severe acute brain trauma	100 % (Selected)	NR	100	Adults	
Brain tissue oxygen tension monitoring in pediatric severe traumatic brain injury. Part 1: Relationship with outcome	100 %	Brain oxygen, TCD, ICMPlus	52	Children	Non-consecutive series - only patients who received ICP and brain oxygen monitoring
Effects of dexmedetomidine on intracranial hemodynamics in severe head injured patient	100 % (selected)	SJVO2	12	Adults 9/1	Non-consecutive; selected for intracranial monitoring
Factors associated with intracranial hypertension in children and teenagers who suffered severe head injuries	69 %	NR	191	Children	
Examination of the management of traumatic brain injury in the developing and developed world: focus on resource utilization, protocols, and practices that alter outcome	13.5 % (AG); 0.1 (Ja.); 4.5 % (Ja.) - of all grades of severity	No	269	Adults	Study at 2 centers in Jamaica (Ja.), one in Atlanta, Georgia (AG). All grades of severity included; N = 1607. Significant patient characteristic differences. No difference in mortality for mild/moderate TBI, but significantly different for severe TBI. CT scans were obtained in 95 % (AG); 20.3 % (Ja.); 68 % (Ja.)
Cost effectiveness analysis of using multiple neuromodalities in treating severe traumatic brain injury in a developing country like Malaysia	100 %	Licox, TCD, SJVO2, EEG	62	Adults	Study comparing baseline neuromonitoring and MMM. 32 patients were managed with MMM, 30 with baseline neuromonitoring (ICP and conventional care). Followed up to one year post admissioin. Statistically significant better functional outcome with MMM. Higher costs of MMM—suggest that this is compensated by better patient outcomes

Table 2 continued

Article title	ICP	Other monitoring	N	Case mix	Comment
Prognostic study of using different monitoring modalities in treating severe traumatic brain injury	100 %	MMM: TCD, Licox, regional CBF (Saber 2000), SJVO2, EEG	52	Adults	Randomized to 2 different surgeons for care—MMM versus ICP only. Several exclusions due to severity; attempted to focus on patients who were salvageable. No statistically significant difference between groups, but functional independence higher in MMM group (21.2 vs. 17.3 %). Some differences between groups at randomization; not completely equal
Outcome of severe traumatic brain injury: comparison of three monitoring approaches	Yes—different across the 3 groups	ICP, Saber 2100 CBF Sensor, Licox and TCD, NIRS, Laser Doppler, Microdialysis, SJVO2	82 total (17 MMM; 31 ICP; 34 none)	Adults and children	Historical comparison of 3 groups: No monitoring; ICP monitoring only; MMM. Excluded patients with bilaterally fixed pupils. Groups not easily comparable. GCS score 3-5: 53 % (MMM); 55 % (ICP only); 79 % (no monitoring). Abnormal pupils 70.6 % (MMM); 54.8 % (ICP only); 41 % (no monitoring)
Head Trauma in China	24.50 %	NR	1626	Adults and children	Mixed TBI grade severity, Databank analysis. $N = 7145$
Head injuries in Papua New Guinea	No	No	45	Adults and children	Study data included 3 prospective and retrospective results from 1984–1993

Table 2 continued

Article title	ICP	Other monitoring	N	Case mix	Comment
Pediatric neurotrauma in Kathmandu, Nepal: implications for injury management and control	22 %	No	46	Children	Patients in the city region took about 8 h to get to the hospital while patients in the rural area took more than a day to get to hospital. Ventriculostomy used in 3 % of total 352 patients (46 sTBI). Delayed transfer to hospital may have selected patients. Patients who came from the rural area paradoxically had lower mortality, possibly for this reason
Jugular venous oxygen saturation or arteriovenous difference of lactate content and outcome in children with severe traumatic brain injury	100 %(selected)	SJVO2 and AVDL	27	Children 52 %/48 %	Uncertain if this was a consecutive series
Early prognosis of severe traumatic brain injury in an urban Argentinian trauma center	NR	NR	148	Adults	Excluded patients who were sedated or intubated, had a penetrating head injury, were brain dead on arrival or if consent was refused. Almost 90 % mortality in those over age 50
Prognostic factors in children	NR	NR		Children	
Head injury in a sub Saharan Africa urban population	No	No	15		Study over 3 months. Mixed grades of TBI severity. Mortality calculated from percentages tabled. Overall mortality for all grades of injury of inpatient TBI was 12.4 %. There was no prehospital care
Prognosis of head injury: an experience in Thailand	13 %	No	300	Adults and children	Excluded brain death presentations

Table 2 continued

Article title	ICP	Other monitoring	N	Case mix	Comment
Secondary injury in traumatic brain injury - a prospective study	NR	No	61	Adults	No patient with an acute SDH had surgery within 4 h of injury. The mean time between injury and assessment by a neurosurgeon was 6 h. Outcome data only available for 77 % of patients
Mortality and morbidity from moderate to severe traumatic brain injury in Argentina	NR	NR	169 in Argentina, 103 in Oregon	Adults	Prospective, observational study of outcomes from TBI in Argentinian hospitals that had adopted the acute care guidelines comparison with Oregon. Mortality is reported for screened and consented patients (272 of 661). The mortality rate for screened but not consented patients with severe TBI patients is not clear because the numbers of all patients screened and not consented is not reported separately for Argentina/Oregon, only the number of deaths. Mortality for all screened patients consented and not consented was 32 % (combined). Excluded patients who died within the first 24 h—60 and 80 % of deaths occurred in the first 24 h in Argentina and Oregon respectively and were not included in the analysis. A greater proportion of Oregon deaths (60 % of the studied sample) occured late (at home or 'other')

Table 2 continued

Article title	ICP	Other monitoring	N	Case mix	Comment
Care of severe head injury patients in the Sarawak General Hospital: Intensive care unit versus general ward	NR	NR	35	Adults	65.7 % of patients were ventilated in the general ward; 34.3 % managed in the ICU. Decisions made by anesthetic team were based largely on availability of ICU bed. Inclusion/exclusion criteria for management not specified. Ward mortality higher; however, mean age of ward managed patients was higher than ICU patients and GCS was lower. Groups not easily comparable
Outcomes in critical care delivery at Jimma University Specialised Hospital, Ethiopia	NR	NR	370 (total)		Review of outcomes in general critical care over 12 months. Overall mortality rate for all admissions to ICU was 50 %; surgical admissions 43 %. Identified delayed presentation as a key factor; inadequate staffing, diagnostic and interventional limitations
Outcomes following prehospital airway management in severe traumatic brain injury	NR	NR	124	Adults	
Intensive care and survival analyses of traumatic brain injury	NR	NR	126	Adults	ICU mortality for severe TBI only + cost analysis. Mean stay costs were 4846 USD and daily cost 575 USD. Costs per life saved 9533 USD; costs per life-year saved 313.6 USD
Assessment of endocrine abnormalities in severe traumatic brain injury: a prospective study	NR	NR	99	Adults and children	Ten percent of patients died after hospital discharge

Table 2 continued

Article title	ICP	Other monitoring	N	Case mix	Comment
Epidemiology of TBI in Eastern China 2004: a prospective large case study	NR	NR	2983	Children and adults	Standardized questionnaire in the region over a 1 year period. All patients admitted with a diagnosis of head injury to one of 77 hospitals in the region. All grades of TBI severity. Severe and moderate TBI each about 20 %; mortality overall 11 %
Outcome of head injuries in general surgical units with an offsite neurosurgical service	No	No	42	Adults	Outcome of patients in general surgical ICU with offsite neurosurgery transfer. 316 total patients mixed grades of injury; 12 % had severe TBI

sTBI severe traumatic brain injury, *ICP* utilization of ICP monitors, *Other monitoring* utilization of other MMM, *N* sample size (for severe TBI unless specified), *NR* not reported

more expensive parenchymal devices, although this is not consistent, given the increased concern about ventriculostomy-related sepsis [9]. However, the type of ICP monitor used can affect interpretation of comparative studies. Apart from ICP monitoring, it appears that the most commonly employed monitor, especially in Latin America, is transcranial Doppler. There are many more reports of MMM in subarachnoid hemorrhage, meningitis, and stroke, but the TBI-related studies are shown here for ease of reference. For some of the papers, the samples are non-consecutive and reflect monitoring as part of the study's objectives, rather than an unselected series of severe TBI. Presumably, familiarity with various monitoring technologies and clinical expertise also vary. This is important because a monitoring modality on its own will not benefit patients outside of the clinical expertise of the user. There are no data to quantify the latter in our literature review.

In a comparative study, ICP monitoring was used in 4.5 % of TBI cases (all grades of TBI severity) in Atlanta, Georgia and only 0.1 % of cases in Jamaica [10]. Although more patients were admitted to ICU in Atlanta (65.6 %) compared with the 2 Jamaican centers (3.3 and 13 %), the median length of stay was shorter in Atlanta. Head CT scans were used for 95 % of cases in Atlanta but only 68 and 20.3 % at the Jamaican centers. ICP monitors were used for 15 % of the total number of cases in Charlottesville, Virginia (and 87 % for those with a GCS of 5 or less) and for none of the cases in New Delhi [9].

In the BEST TRIP trial in Bolivia and Ecuador (discussed below), ICP monitors were introduced into an environment where they had not been used previously [37]. Outcome was similar using a management strategy based on ICP monitoring or not, in these centers. This has raised questions about the value of ICP monitoring in this environment, especially amidst the other priorities of healthcare, and the role of experience with ICP monitoring.

Does Multimodality Monitoring Benefit Patients in LAMICs and is It Cost-Effective?

There is little evidence of the direct benefit of MMM in LAMICs, in large part because it is understudied. However, evidence is accumulating that describes a role of MMM in LAMICs. Recently, a multicenter randomized controlled trial (BEST TRIP), funded by the National Institutes of Health in the United States, examined 2 treatment regimens at hospitals in Bolivia and Ecuador [37]. A total of 324 adult patients were randomized to treatment based on a clinical- and imaging-based protocol or an ICP monitoring protocol which used an ICP threshold of 20 mmHg to initiate treatment. Their primary outcome, a composite of 21 measures of functional and cognitive status, was similar in the two groups. The treating clinicians at the various hospitals underwent training, but ICP monitoring was not a standard at any of these hospitals before the trial and their familiarity and expertise with ICP monitors are unclear. Mortality was relatively high, but in keeping with the environment. The 2-week mortality was 21 % in the ICP group and 30 % in the imaging-clinical examination group. The 6-month mortality rates were 39 and 41 %, respectively; good recovery (upper and lower) on the GOS-E scale were 31 and 26 %, respectively. The median length of stay in the ICU was similar. There were significantly more brain-specific treatments administered in the imaging-clinical examination group. None of the patients received rehabilitation therapies, and 35 % of deaths occurred >14 days post-injury. Although internally valid, the external validity is debated, and hence the results are not generalizable. Several questions remain whether results would be different (1) in a different environment, (2) if better prehospital and post-acute care were administered, (3) if a different ICP threshold was targeted, (4) if different ICP-lowering therapies were used, (5) if ICP monitoring were combined with more information (MMM), and (6) whether training in ICP care yields similar results to cumulative clinical expertise among others.

In Malaysia, several studies compared various monitoring approaches [11, 13, 15]. One compared severe TBI in 3 non-random treatment groups [15]: no monitoring, ICP alone, and ICP with MMM (which included jugular venous saturation, TCD, CBF [Saber sensor], brain oxygen, and continuous EEG). Patient baseline characteristics showed some differences, and the overall numbers were small ($n = 82$). In the ICP and no monitoring group, mortality was 26 % versus no deaths in the multimodal group; however, the proportion of bad outcome survivors at 12 months after injury was higher in the multimodal group. The same group later randomly assigned 52 TBI patients to the care of one of two surgeons: one who monitored ICP only and one who used MMM [14]. The early outcome figures were similar, but there was a small increase in the number of functionally independent patients in the multimodal group at 6 months (21.2 vs. 17.3 %). At 1 year, functional outcome in 62 patients was significantly better for the multimodal group [13]. In South Africa, MMM including ICP, brain oxygen, and transcranial Doppler has been used in pediatrics; mortality was low (9.6 %) in a series of 52 severe TBI patients [45, 46, 61]. MMM was used to assess clinical grading, conventional ICP-based management, blood transfusions, oxygen reactivity, autoregulation, decompressive craniectomy, and brain death [25–27, 43, 44, 47, 62, 63].

A recent study in China found lower mortality, better functional outcome, and less acute kidney injury when ICP was monitored [57]; however, the decision to perform ICP monitoring was non-random, the groups were likely not similar enough, and not enough data were presented. Whitmore et al. [64] created a decision-analytical model to compare three strategies for treating severe TBI patients, namely an ‘aggressive care’ approach (using ICP monitoring and decompressive craniectomy), ‘routine care’ (in which the Brain Trauma Foundation Guidelines were not followed), and ‘comfort care’ (in which a single day in ICU was followed by ward care). Probabilities for treatment resulting in various GOS categories were calculated from published outcomes studies, and the resulting GOS scores were converted to quality-adjusted life years. They found that aggressive care delivered a greater amount of quality-adjusted life years for all age categories, although the difference was greatest in younger patients and diminished with age. Aggressive care also was more cost effective for each age group up until age 80.

The associated costs of neurocritical care or MMM are not widely reported. In the Malaysian study referenced above, the authors included a calculation of costs in the 2 groups (MMM vs. conventional treatment). The cost of MMM patients was significantly higher, but the authors contended that this was justified by the better functional outcomes [13]. Sut et al. [20] examined the costs of treating severe TBI patients at a hospital in Turkey: mean stay costs were $4846 (US) and daily cost $575. Costs per life saved were $9533; costs per life-year saved were $313.60. The authors contrasted these with mean ICU costs in New Zealand of $10725 and the hospital cost of TBI in the US of $28428, although the latter likely included in-hospital rehabilitation costs. The authors suggest that costs at their institution are substantially lower but that these have to be interpreted against the backdrop of each country’s GNI per capita. In Eastern China, the median hospital costs for severe TBI in young to middle-aged adults ranged from US$2600 to 2800 (in 2004 figures) [65], compared with costs in Spain (5622 Euros), Sweden (8951 Euros), and Germany (7620 Euros). However, the average annual income in Eastern China in 2004 was US$1230 per person compared with US$43570 in the United States. Costs for patients with severe disability (US$5894) were just over double that of patients who made a good recovery (US$2530). Of interest, neurointensive care costs were higher, but not substantially so, than general ward care costs.

Finally, it is worth noting that it is not infrequent that authors of studies in LAMICs are from HICs. Sometimes, this arises from collaborations where authors in HICs have research relationships with centers in LAMICs and so offer support, advice, and research capacity. On other occasions, the studies may be performed in LAMICs centers, but the funding, design, and execution are primarily by the HICs authors. Several ethical issues have to be considered in detail before embarking on these studies, especially when there is potential generalization of the study’s findings.

That said, these collaborations represent opportunities for patient benefit and advancement of science. These research collaborations, settings in which they occur, and the findings require greater definition, especially given the spectrum of capacity and skills across the range of countries in this group. However, there is no current evidence that patients in LAMICs should be treated differently to patients in HICs given the wide range in expertise and resources not only within the LAMICs group but also within individual HICs.

What are the Challenges to Instituting MMM in Resource-Constrained Environments?

There are several challenges to instituting MMM and advanced critical care in LAIMCs that are difficult to quantify, especially given the spectrum across the range of LAMICs. These challenges are best described in a qualitative manner and include a higher burden of disease, poor prehospital care, delays in transfer, lack of ICU/neurocritical care equipment and consumables, shortage of ICU beds, lack of staff training and specialization, and less rehabilitative capacity. The size of the need and the priority areas likely vary with the economic status of the nation. The series of articles from Malaysia referenced above demonstrated potential benefits of MMM, but it was clear that functional outcome had to be improved to justify the costs [11, 13–15]. Clearly, careful cost analyses would be essential to motivate at individual institutions. Arguably, the potential benefits of improved neurocritical care in LAMICs are greater in absolute terms given the greater burden of trauma and the higher DALYs losses; the relative benefits would have to be weighed up against competing priorities in health care in each individual setting. It must also be remembered that substantial differences occur even within a single country.

Conclusion

It is challenging to adequately describe the current status and future role of neurocritical care in general, and MMM specifically, within the diversity that exists in the LAMICs group. MMM *is* used, at an advanced level, but in few centers. In these centers, good outcomes similar to that achieved in HIC are possible. This is promising because larger numbers of patients treated within a sophisticated infrastructure have value both for clinical service delivery and research potential. Several opportunities and challenges exist to develop capacity in these countries. At this time, direct comparison of data from individual studies and generalization of study findings across the HIC/LAMIC divide face several obstacles and so require greater scrutiny.

Conflict of interest Anthony Figaji and Corinna Puppo have declared no conflicts of interest.

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