Neurocrit Care
https://doi.org/10.1007/s12028-020-01176-y

NEUROCRITICAL CARE SOCIETY

ORIGINAL WORK

Development of Neurological Emergency Simulations for Assessment: Content Evidence and Response Process

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Abstract

Objective: To document two sources of validity evidence for simulation-based assessment in neurological emergencies.

Background: A critical aspect of education is development of evaluation techniques that assess learner's performance in settings that reflect actual clinical practice. Simulation-based evaluation affords the opportunity to standardize evaluations but requires validation.

Methods: We identified topics from the Neurocritical Care Society's Emergency Neurological Life Support (ENLS) training, cross-referenced with the American Academy of Neurology's core clerkship curriculum. We used a modified Delphi method to develop simulations for assessment in neurocritical care. We constructed checklists of action items and communication skills, merging ENLS checklists with relevant clinical guidelines. We also utilized global rating scales, rated one (novice) through five (expert) for each case. Participants included neurology sub-interns, neurology residents, neurosurgery interns, non-neurology critical care fellows, neurocritical care fellows, and neurology attending physicians.

Results: Ten evaluative simulation cases were developed. To date, 64 participants have taken part in 274 evaluative simulation scenarios. The participants were very satisfied with the cases (Likert scale 1–7, not at all satisfied—very satisfied, median 7, interquartile range (IQR) 7–7), found them to be very realistic (Likert scale 1–7, not at all realistic—very realistic, median 6, IQR 6–7), and appropriately difficult (Likert scale 1–7, much too easy—much too difficult, median 4, IQR 4–5). Interrater reliability was acceptable for both checklist action items (kappa = 0.64) and global rating scales (Pearson correlation $r = .70$).

Conclusions: We demonstrated two sources of validity in ten simulation cases for assessment in neurological emergencies.

Keywords: All cerebrovascular disease/stroke, All education, Methods of education, Critical care, Status epilepticus

Introduction

The American Academy of Neurology's (AAN) resident core curriculum includes among its learning objectives the recognition and management of neurological disorders in critically ill patients [1]. It is paramount then to assess whether or not residents accomplish these objectives. A lack of exposure to a representative sampling of

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cases and the potential for patient harm limit trainees' ability to demonstrate competence in real-life neurological emergencies. Traditional clinical observational ratings are subject to multiple sources of bias unless conducted with careful rater training and calibration—processes generally absent from clinical evaluations. Alternatively, performance on pencil-and-paper examinations may not accurately reflect clinical performance. Simulation technology enables educators to develop feasible and valid assessments of learner performance in the care of critically ill patients [2, 3].

Simulation has been underutilized in neurological disorders due to skepticism regarding its validity among neurologists [4]. While other fields have demonstrated validity of simulation-based assessment in critically ill patients [2, 3, 5, 6], neurocritical care simulations have not received such rigorous treatment. Prior work in simulated cases of brain death, status epilepticus, myasthenia gravis, stroke, and cerebral vasospasm established feasibility but did not explicitly focus on validity concerns [7–10]. In this project, we apply Messick's framework of validity evidence to develop evaluative simulations for neurological emergencies [11]. Within this framework, there are five distinct sources of validity evidence: content evidence, response process, internal structure, relationship to other variables, and consequences [12]. For the purposes of this paper, we review content evidence and response process as sources of validity evidence as these are integral to simulation development.

Methods

Content Evidence: Case Development

We developed the evaluative simulation cases through a standardized, multistage process. Initially, we identified topics through the protocols developed for the Neurocritical Care Society's Emergency Neurological Life Support (ENLS) course [13]. ENLS is a series of protocols suggesting practical checklists, decision points, and communication to use during management in the first hour of a neurological emergency. ENLS was created through the collaborative efforts of members of the Neurocritical Care Society and leaders from the field of Emergency Medicine. We cross-referenced ENLS topics with the AAN's Critical Care and Emergency Neurology Section Resident Core Curriculum as well as the AAN Clerkship Core Curriculum guidelines (Table 1) [1, 14]. We then built ten simulation cases to incorporate each ENLS topic in at least two cases so that in the future we could evaluate educational interventions for a given topic with a pre- and post-intervention test case. Each case incorporated multiple ENLS topics (Table 2).

We developed the cases utilizing a modified Delphi method. Three members of the research team that are certified in neurocritical care by the United Council for Neurologic Subspecialties (UCNS) with additional training and board certification in neurology, emergency medicine, and internal medicine and critical care developed cases independently and then distributed the cases to the others for review. Two of the three case developers had previously completed the Comprehensive Instructor Workshop at the Center for Medical Simulation (Boston, MA). Finally, we sent the cases to a board-certified neurocritical care physician with experience in simulation at a separate institution, for final review and editing.

Content Evidence: Checklist Development

As part of case development, each board-certified team member developed a checklist of action items expected to be performed by examinees. We based the checklists on those provided by ENLS for each of its

Table 1 Neurological emergency topics

Neurocritical Care Society's Emergency Neurological Life Support protocols	American Academy of Neurology's core clerkship curriculum guidelines: potential emergencies
Intracranial hypertension and herniation	Increased intracranial pressure
Coma	Toxic-metabolic encephalopathy
Subarachnoid hemorrhage	Subarachnoid hemorrhage
Meningitis and encephalitis	Meningitis/encephalitis
Status epilepticus	Status epilepticus
Acute non-traumatic weakness/acute ischemic Stroke/intracerebral hemorrhage	Acute stroke (ischemic or hemorrhagic)
Spinal cord compression/traumatic spine injury	Spinal cord or cauda equina compression
Traumatic brain injury	Head trauma
Airway, ventilation, and sedation	Acute respiratory distress due to neuromuscular disease
Acute non-traumatic weakness	Temporal arteritis
Resuscitation following cardiac arrest	
Pharmacotherapy	

Table 2 Simulations for assessment in neurological emergencies and corresponding emergency neurological life support (ENLS) topics covered

Simulation scenario	ENLS protocols addressed
1. 68-year-old man presents with acute right-sided weakness. Receives intravenous tPA complicated by hemorrhagic conversion, cerebral edema/herniation leading to an alteration in mental status and need for intubation	Acute non-traumatic weakness, acute Stroke, acute ischemic Stroke, intracerebral hemorrhage, intracranial hypertension and herniation, airway and ventilation and sedation, pharmacotherapy
2. 54-year-old woman presents with unresponsiveness and fever due to HSV encephalitis with course complicated by status epilepticus	Coma, meningitis/encephalitis, status epilepticus, airway and ventilation and sedation, pharmacotherapy
3. 57-year-old man brought into trauma bay after a fall from ladder with lower extremity weakness. Initially lucid, but rapidly declines due to expanding epidural hematoma	Traumatic spine injury, spinal cord compression, traumatic brain injury, airway and ventilation and sedation, intracranial hypertension and herniation, pharmacotherapy
4. 49-year-old woman on anticoagulation for DVT presents with worst headache of life. Initial imaging is negative for subarachnoid hemorrhage but then she becomes unresponsive with fixed dilated pupils	Subarachnoid hemorrhage, coma, airway and ventilation and sedation, intracranial hypertension and herniation, pharmacotherapy
5. 24-year-old man found down without a pulse. Following return of circulation develops non-convulsive status epilepticus	Resuscitation following cardiac arrest, airway and ventilation and sedation, status epilepticus
6. 76-year-old man presents with a fall and traumatic cervical spinal cord injury complicated by bilateral vertebral artery injuries that cause a TIA	Acute stroke, acute ischemic stroke, traumatic spine injury, airway and ventilation and sedation
7. 71-year-old woman with atrial fibrillation on anticoagulation presents with hemiplegia and aphasia after losing control of her car. Found to have subdural hematoma as well as left MCA strokes	Acute non-traumatic weakness, traumatic brain injury, acute stroke, acute ischemic stroke, pharmacotherapy
8. 45-year-old woman presents with seizure and altered mental status. Found to have subarachnoid hemorrhage. Course complicated by cardiac arrest in setting of rebleed	Status epilepticus, coma, subarachnoid hemorrhage, airway and ventilation and sedation, resuscitation following cardiac arrest
9. 78-year-old man with a history of lung cancer who presents with weakness	Acute non-traumatic weakness, spinal cord compression
10. 20-year-old woman presents with fever and altered mental status	Coma, meningitis/encephalitis

protocols. The ENLS protocol checklists include key steps in managing a patient with a potential neurological emergency, as well as a catalog of critical features to communicate in hand-off each emergency. We cross-referenced the checklists against relevant guidelines from the American Heart Association [15–20], the American Academy of Neurosurgeons/Congress of Neurological Surgeons [21], the Brain Trauma Foundation [22], the Epilepsy Foundation/American Epilepsy Society [23], the Infectious Disease Society of America [24, 25], and the Neurocritical Care Society [26, 27]. Like clinical management assessment, we assessed communication by developing a communication checklist using the relevant ENLS protocols. We gave each action item equal weight and anchored them dichotomously as either completed correctly or not.

We circulated the checklists among the three case developers, as well as content experts in epilepsy and vascular neurology, and together we reviewed them for completeness and accuracy. Finally, a board-certified neurocritical care attending at a separate institution reviewed the checklists. The final checklists were a consensus among the authors (Tables 3, 4).

Case Implementation

All cases took place in the Shock Trauma Simulation Center at the University of Maryland Medical Center/R Adams Cowley Shock Trauma Center. As we intended to assess individuals' performance in neurological emergencies, trainees participated in cases on an individual basis, aided by a confederate nurse. We utilized SimMan 3G (Laerdal; Wappinger Falls, NY) for all cases. SimMan 3G is an advanced patient simulator capable of displaying real-time neurological signs such as pupillary constriction in response to light, abnormal breathing patterns, and seizures. Facilitators can actively manipulate the physical exam findings and monitor displays (including telemetry, oxygen saturation, end-tidal carbon dioxide, arterial blood pressure). SimMan 3G is not capable of reproducing multiple facets of the neurological exam such as eye movements, the motor exam, or reflexes. In order to obtain this pertinent information, we instructed participants to ask the simulated patient if they were capable of performing such tasks as part of a pre-briefing (e.g., "Can you look to the right?", "Can you hold your arms out in front of you with your palms up?", "What happens as I strike your Achilles tendon with this

Table 3 Critical action checklist—case 1: acute ischemic Stroke with hemorrhagic conversion

Critical action	Completed?
Obtain last known normal time	
Perform NIHSS completely	
Localize lesion to left MCA	
Rule out contraindications to intravenous tPA as able	
Determine ASPECTS score correctly (8 ± 1)	
Lower blood pressure to < 185/110 with labetalol or nicardipine/clevidipine prior to IV tPA	
Administer IV tPA (dosed correctly)	
Alert interventional neuroradiology to likely large vessel occlusion	
Order CT angiogram head and neck	
Recognize neurological deterioration	
Stop IV tPA infusion immediately upon recognition of deterioration	
Order STAT coagulation studies including fibrinogen	
Repeat head CT	
Reverse IV tPA with cryoprecipitate ± antifibrinolytic	
Consult neurosurgery service	
Pre-oxygenate for intubation	
Intubate (or have consultant intubate) at appropriate time	
Confirm endotracheal tube placement	
Elevate the head of the bed	
Hyperventilate	
Administer hyperosmolar therapy (hypertonic saline and/or mannitol at appropriate dose)	

Table 4 Communication checklist—case 1: acute ischemic Stroke with hemorrhagic conversion

Communication	Completed?
HPI (including age, prior coumadin use, VS)	
Time of onset	
NIHSS	
Imaging findings	
Time IV tPA started	
Time/cause of complication	
How IV tPA reversed	
How herniation treated	
Mental status and neurological examination immediately prior to intubation	
Vitals, hemodynamics, and gas exchange pre- and post-intubation	
Ease of intubation and Endotracheal tube position confirmation	
Ventilation targets and ETCO2	
Analgesia and sedation strategy	

reflex hammer?"). The simulated patient would respond with answers in agreement with their scripted exam through the speaker system inside SimMan 3G ("Yes, I can look to the right.", "When I hold out my arms in front of me my right arm drifts down to the bed.", "My foot bounces up and down several times after you strike me with the reflex hammer."). In this way, the entire neurological exam was obtained in a manner similar to the sensory exam. In instances when the patient was unable to respond (aphasic, comatose, etc.), a nurse confederate responded to questions regarding the exam as instructed through an earpiece microphone by the simulation operator. We provided pertinent laboratory values and imaging (Computerized Tomography, Magnetic Resonance Imaging) upon request on a high-definition screen within the simulated environment. When imaging was requested, participants were required to leave the simulation bay while the patient was "transported" to simulate the loss of patient contact during imaging studies and potential for deterioration. Participants placed orders for diagnostics and therapeutics verbally. Consultants, when available, were available by phone and simulated by the simulation operator.

Response Process

Response process is defined as evidence of data integrity such that all sources of error associated with the test administration are controlled or eliminated to the maximum extent possible [12]. Acknowledging the disadvantages of a checklist-based assessment, we also incorporated rating scales of each topic within the case (i.e., intracerebral hemorrhage, airway/ventilation/sedation, intracranial hypertension/cerebral herniation, etc.) and a global rating scale for each entire case. The scales ranged from one (novice) to five (expert). We further ensured data integrity prior to implementation of cases through a pre-briefing, simulator operator training, rater training, and rater calibration.

Response Process: Pre-briefing

We pre-briefed all participants. The pre-briefing included an orientation to the simulation bay and SimMan 3G (as described above). As part of the pre-briefing, we informed all participants that the simulated cases were part of a research study to validate the use of simulation as a test of proficiency in the assessment and management of patients with neurological emergencies. We informed them that we would videotape and rate their performance and that we expected them to perform to the best of their abilities. There were no direct consequences to the participants based on their performance. We informed participants that their results would be confidential, not shared with their program leaders, and shared anonymously in intended publications. Participation was voluntary.

Response Process: Operator Training

Two neurocritical care attending members of the research team experienced in simulations operations ran simulation cases using Laerdal Learning Application (LLEAP, Laerdal; Wappinger Falls, NY) software. We preprogrammed initial frames for all simulation cases but allowed the operators freedom to respond appropriately to participant maneuvers. The operators piloted the cases first, then executed the cases together several times. One operator intermittently viewed videos of cases to ensure consistency between operators. We instructed the operators to remain faithful to case scripts as much as possible while maintaining realistic consistency with participant driven actions. A nurse confederate was present at all times and maintained one-way communication with the operator through an earpiece. The operator utilized the nurse confederate as needed to clarify orders, prompt differential diagnoses, and generally ensure that participants verbalized thought processes for assessment.

Response Process: Rater Training and Calibration

All rating was completed via video review in Learning Space™ software (CAE Healthcare, Sarasota, FL) by two neuro-intensivists. Prior to rating, we reviewed each critical action on the checklists to ensure mutual understanding during a single 90-min meeting. Following rating of the first two cases of each scenario, the raters met again to evaluate for discrepancies in rating and ensure consistent application of critical action checklists. For areas of significant discrepancy, we re-watched the scenarios on video with discussion until a final agreement could be reached. The global rating scales did not include pre-specified anchors as the action checklists were thought of as prompts to important aspects of patient management. Interrater reliability for checklist items was determined by percentage agreement and the Cohen's kappa statistic. Interrater reliability for the ordinal rating scales was determined by Pearson's correlation.

Standard Protocol Approvals and Participant Consent

The local Institutional Review Board approved the protocol and approved a waiver of documentation of consent.

Data Availability Policy

Individual de-identified participant data will be shared on request to the corresponding author.

Results

We developed ten simulation scenarios with ten corresponding action item checklists (Table 2). To date, we have assessed 64 participants including nine neurology sub-interns, 26 neurology residents, four neurosurgery interns, eight neurocritical care fellows, 13 non-neurology critical care fellow, two vascular neurology fellows, one vascular neurology attending, and one neurocritical care attending. The 64 participants have engaged in 274 scenarios. Forty-two participants completed post-simulation evaluations (8 did not complete evaluations, 14 have not completed the curriculum). Overall, participants were very satisfied with the scenarios (Likert scale 1–7, not at all satisfied—very satisfied, median 7, interquartile range (IQR) 6–7). They considered the scenarios to be very realistic (Likert scale 1–7, not at all realistic—very realistic, median 6, IQR 6–7) and the difficulty to be appropriate (Likert scale 1–7, much too easy—much too difficult, median 4, IQR 4–5). Participants strongly agreed that the simulations increased their experience (Likert scale 1–5, strongly disagree—strongly agree, median 5, IQR 5–5), proficiency (Likert scale 1–5, strongly disagree—strongly agree, median 5, IQR 5–5), and confidence (Likert scale 1–5, strongly disagree—strongly agree, median 5, IQR 4–5), in taking care of neurological emergencies. They strongly agreed that their education and clinical practice would benefit from more simulation of neurological emergencies (Likert scale 1–5, strongly disagree—strongly agree, median 5, IQR 5–5), and they agreed that they preferred simulation to didactic lectures for learning about neurological emergencies (Likert scale 1–5, strongly disagree—strongly agree, median 4, IQR 3.25–5).

Response Process: Interrater Reliability

Fifty cases were randomly chosen and assessed for interrater reliability. For the 1073 independent checklist action item ratings, there was 82% agreement between the raters. The kappa statistic was 0.64, indicating substantial agreement. The raters completed 263 rating scales ranking performance from one (novice) to five (expert), including one scale for performance in each topic within each case and one scale for the overall performance in the case. The raters' scale ratings were strongly correlated (Pearson correlation $r = 0.70$).

Discussion

The goal of this study was to document evidence of validity for the *development* of simulation scenarios as assessment tools in neurological emergencies. We focused on content evidence and the response process. We demonstrated that a collaboration of educators, leveraging interdisciplinary expertise, can develop simulation-based assessments for neurological emergencies that participants view as highly satisfactory, very realistic, and appropriately difficult with acceptable interrater reliability. Future work will focus on the additional sources of Messick's framework including the internal structure and relationship to other variables.

The Accreditation Council for Graduate Medical Education and the American Board of Psychiatry and Neurology place the identification and independent management of neurological emergencies as key performance targets among the milestones which provide a framework for assessment for neurology residents [28]. It is uncertain how such assessments are taking place in neurological emergencies. According to a 2010 AAN survey, only 64% of neurology residency programs affiliate with a hospital with a dedicated neurocritical care unit and only 56% of residents had a dedicated rotation in a neurocritical care unit [29]. While those percentages have likely increased, a 2016 survey of residents from the Neurocritical Care Society found serious ongoing concerns regarding educational exposure [30]. The neurocritical care unit is not the only venue for emergency neurology training, but other locales do not similarly guarantee neurology resident involvement. For instance, at the author's residency training center, the neurosurgical service managed all patients with subarachnoid hemorrhage without any involvement of neurology residents, even in the emergency department.

Other fields of medicine have better described deficiencies in resident exposure to emergencies [31–33]. Amidst work hour restrictions and increasing calls for direct attending involvement to ensure patient safety, it is reasonable to expect opportunities for assessment of resident performance in emergencies to decrease [34]. Even when residents do gain experience in managing emergencies, they are infrequently supervised by faculty and rarely receive constructive feedback [35, 36]. It is pivotal then that we develop valid assessments in neurological emergencies that we can administer in a standardized fashion. An institution's clinical volume, designation (as a trauma center or comprehensive stroke center, for instance), or division of labor should not limit opportunities for residents to demonstrate competence. Simulation affords an opportunity to standardize the assessment process [2, 3, 5].

Critics argue that simulation falls short in neurological emergencies because the nature of the problem is less obvious and because simulation is unlikely to add value to a strategy of talking it through (i.e., if your patient is still seizing, what would you do next?) [4]. We would argue that much of emergency neurology is not so opaque. For instance, most cases of convulsive status epilepticus do not escape attention, while current clinical management, guided by traditional didactic methods and assessments, continues to fall short of guideline algorithms [37]. Debriefing following simulation allows learners to understand and correct these shortcomings [38].

We believe our study to be novel in its approach to demonstrate the evidence of the development process of simulations for assessment in emergency neurology. However, the validation process requires ongoing data collection from multiple sources of evidence to support or refute meaningful score interpretation [12]. Beyond content evidence and response process, more work remains to examine internal structure, relationship to other variables, and consequences for the developed evaluative simulations. Measures of individual action item difficulty and discrimination, as well as measures of convergent validity (the degree to which two measures of constructs that should theoretically be related are, in fact, related) and of divergent validity (the degree to which two measure of constructs that should not be related are, in fact, not related) will be assessed in the future as measures of internal structure. The relationship of performance to level of training and prior clinical evaluations will likewise be examined.

As validity evidence builds, we plan to use our simulations to assess performance. As we have developed at least two simulations for each topic, we can use the simulations as pre- and post-tests for other educational initiatives. High-fidelity simulation is certainly resource intensive; it may be better suited for certain educational endeavors as an assessment as opposed to the primary intervention. Of note, the interrater reliability for checklist scoring in our study supports its use as an assessment tool to evaluate the effect of an educational intervention, but is likely too low for high stakes examination [39].

There are several limitations to the current study. First, case and checklist development took place at a single institution, which may limit generalizability. However, experts from multiple disciplines including neurocritical care, vascular neurology, epilepsy, and emergency medicine oversaw this process in accordance with relevant clinical guidelines. In addition, an expert from an outside institution reviewed all cases and checklists. Second, we did not completely automate case implementation as we allowed some degree of spontaneity in response to participant driven actions. This may limit the generalizability and validity of the response process, but we felt it necessary in order to maintain realism. Third, we intended to assess individual performance within the simulations. We recognize that in most emergency neurology environments, interprofessional teams provide care to patients. Taking an individual out of a team for assessment may limit realism. Fourth, due to time constraints, we could not develop cases to represent every kind of neurological emergency. We will need to create simulations for other important diagnoses such as myasthenic crisis in future projects. Fifth, there were no consequences to participant performance, so we cannot be sure that they were properly motivated to try their best. Conversely, we cannot rule out a substantial Hawthorne effect whereby participants performed differently because they were aware that they were participating in a research study of performance assessment and being videotaped. Finally, SimMan 3G is extremely limited in its neurological repertoire. New technology promises to improve the experience. For instance, eye movements including object tracking and nystagmus are now available on Pediatric Hal®, a pediatric patient simulator (Gaumard Scientific, Miami, Florida). We plan to incorporate these technologies as they become available.

Conclusion

Through rigorous process, we developed ten simulations for assessment in neurological emergencies that participants found highly satisfactory, very realistic, and appropriately difficult. We documented evidence of validity for the development of simulation scenarios as assessment tools for participant performance in neurological emergencies. Simulation may be of benefit for evaluating trainee's performance during response to a neurologic emergency.

Supplementary Information

The online version of this article (https://doi.org/10.1007/s12028-020-01176-y) contains supplementary material, which is available to authorized users.

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Acknowledgements

The authors would like to thank Dr. S. Barry Issenberg, MD (Professor of Medicine and Medical Education, Director of Gordon Center for Research in Medical Education, Senior Associate Dean for Research in Medical Education, Department of Medicine, University of Miami Miller School of Medicine) for his general guidance and review of the manuscript.

Authors' contributions

NAM, WTC, AT, CAG, MSP, DPL, and SAT conceived and designed the study. NAM, WTC, and OJB acquired the data. NAM analyzed and interpreted the data. NAM drafted the manuscript. NAM, WTC, AT, CAG, MSP, DPL, OJB, and SAT revised the manuscript for important intellectual content. All authors gave final approval of the version to be published.

Source of support

This study was funded by the Faculty Innovation in Education Award from the American Board of Psychiatry and Neurology (Dr. Morris).

Ethical Approval

We adhered to ethical guidelines and this study was reviewed and approved by our Institutional Review Board who waived the requirement for participant consent.

Conflicts of interest

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

Publisher's Note

Received: 17 September 2020 Accepted: 4 December 2020
Published online: 21 January 2021

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