Lack of Standardization in Determination of Intracranial Pressure

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Background: *Intracranial pressure (ICP) values guide treatment and diagnosis in the ICU. Lack of agreement on ICP determination reduces the validity of ICP as a predictor variable in research and clinical practice. This study explores international perspectives of interpreting an ICP tracing to document an ICP value across varying lengths of time.* ***Methods:*** *This was a prospective anonymous online survey study of clinician practice of ICP measurement using patient data showing an ICP trend. Participants were shown one of three scenarios at 1-minute, 3-minute, and 5-minute ICP trends. It wasn't possible to randomized participants, however multiple reading improves precision. Paired t-test was used to explore for differences within each scenario and between each epoch.* ***Results:*** *There were a total of 332 international responses which came from 247 nurses, 43 attending physicians, 29 nurse practitioners, and 12 physicians in training. Estimates of ICP were significantly different for two of the three scenarios ($p < .0001$). The range of ICP values was largest during the 3-minute epoch (from 5 to 40 mmHg).* ***Conclusions:*** *There is a wide and inconsistent variation in the determination of ICP with significant difference between for two of the three scenarios. Without a standardized amount of time to provide to clinicians, variability in ICP reporting will continue.*

Keywords: intracranial pressure, nursing research, multimodal monitoring, critical care, measurement, accuracy

INTRODUCTION

Intracranial pressure (ICP) monitoring is an essential element of modern practice in the intensive care unit (ICU) setting (Le Roux, 2016). The reliability of ICP monitoring across various hospitals has not yet been established. Elevated ICP is a risk factor for secondary brain injury and critical care nurses are most often delegated the task of monitoring and documenting ICP (Liu et al., 2020; Olson & Ortega-Perez, 2018; Ortega-Perez & Amaya-Rey, 2018). Observational studies have shown that ICP directed therapy has the potential to improve outcomes after acquired brain injury, but improving practice is only possible if the ICP is accurately and reliably documented (Klein & Depreitere, 2018). The purpose of this study was to explore the reliability of ICP documentation by multiple clinicians given up to 5 minutes of

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ICP trend data (Mahdavi et al., 2016, Olson et al., 2019).

BACKGROUND

Indications for ICP monitoring include any clinical condition in which elevated pressure is likely or may result in secondary injury (e.g., hydrocephalus, traumatic brain injury, or stroke). An external ventricular drain (EVD) catheter is placed into the ventricular system of the brain to monitor ICP. The EVD may also be used to drain cerebrospinal fluid (CSF). An external strain gauge transducer can be attached to an EVD catheter to produce an ICP waveform. The transduced waveform, trend, and minute-to-minute values can easily be displayed (e.g., bedside monitor) at the bedside (Berlin, 2016).

There are a number of known variations in clinical practice with respect to ICP monitoring. The anatomical landmark used as a reference for leveling a transducer when using an EVD is not standardized (Mcnett et al., 2017; Olson et al., 2014). The unit of measure is not universal. ICP can be measured in millimeters of mercury (mmHg), centimeters of water (cmH_2O), or centimeters of water (cmH_2O). There is wide institutional variation in the practice of assigning a number to reflect the ICP value with some institutions using mmHg, some using cmH_2O, and some using both (Olson et al., 2014; Samudra et al., 2018). There is no standardization on the frequency of documenting ICP values in clinical practice nor in research; options range from once every 6 seconds to once per day (Olson et al., 2019). There is no standardization by which to determine how and when the ICP waveform should be interpreted as meaningful (Hickey et al., 2009; Kim et al., 2016). There is no standardization by which to compare the two most common sites (EVD and intraparenchymal) for invasive ICP monitoring (Mahdavi et al., 2016). In general, the accuracy and precision of ICP measurements is poorly defined and this lack of standardization contributes to a global inability to provide high-quality recommendations for treatment thresholds and mechanisms by which to reduce ICP in the setting of secondary brain injury.

A measure with high precision is one in which all values measured under the same condition will be *nearly* identical (Streiner & Norman, 2006). If the ICP threshold reaches above 20–25 mmHg, the clinical team is generally notified as there may be concerns for increasing cerebral edema, lesions, intracranial blood volume, or increased CSF (Bazil & Olson, 2019). Assessing and improving the precision (similarity) of ICP measures is, therefore, a reasonable approach to improving the science of ICP monitoring. There are multiple external factors known to impact ICP precision including the level of the transducer relative to the ventricular system, patient position, medications, or possible clinical interventions occurring at the time of reading (e.g., suctioning). Once the ICP monitor (e.g., EVD) is placed, daily management of the EVD and recording ICP values is generally conducted by the nurse (Altun Ugras et al., 2018; Olson et al., 2013a; Olson et al., 2013b).

There is a growing body of literature supporting that documentation of ICP values may vary depending on: the device used, the duration of observation, and the institution's norms of practice (Liu et al., 2020; Mcnett et al., 2017; Olson et al., 2014; O'Phelan et al., 2016; Rogers et al., 2017). Although there is consensus that common data elements are important, there has been little research on how to be consistent with ICP management. Standardizing practice would improve reliability and validity of ICP data, but change will only come about if the current paradigm is thoroughly examined (Damani et al., 2019).

METHODS

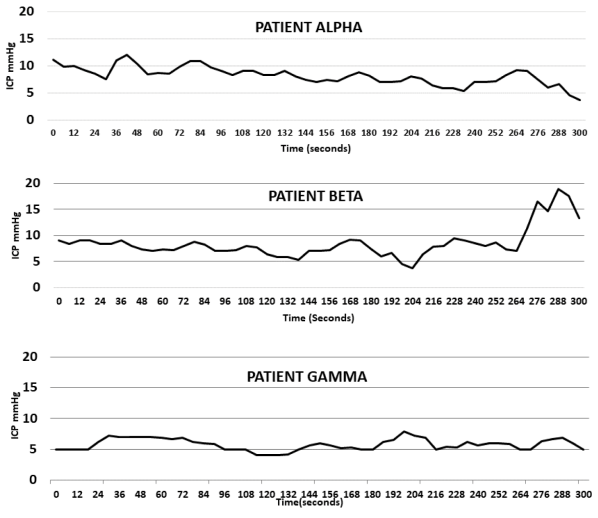
To explore ICP documentation, a two-phase study was used. In phase 1, the survey was developed using real-life data. In phase 2, the electronic survey was disseminated to clinicians across the globe. All study procedures were approved by the Institutional Review Board prior to initiation of the study and were performed in accordance with

the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

In phase 1, continuous ICP recordings were obtained from three patients (Alpha, Beta, and Gamma [pseudonyms]) who had ICP monitoring in place. After consent, patients were placed supine with 30° head of bed elevation. For each patient, 5 minutes of ICP data were sampled with a strain gauge transducer maintained at the level of the tragus (to approximate the level of the foramen of Monro), and connected to an EVD that was closed to avoid CSF diversion (Liu et al., 2020). ICP data were acquired via the Component Neuromonitoring System (CNS, Moberg Industries) at a sampling rate of 100 Hz with ICP values recorded in mmHg. From each set of patient data, three scenarios were created to represent the first minute of ICP data, the first 3 minutes of ICP data, and the full 5 minutes of ICP data. This resulted in a total of nine scenarios from the three patients (Figure 1).

The survey was then developed and pilot tested prior to being distributed electronically. Initially, a draft version of the survey was constructed in RedCap (Vanderbilt). The first few questions addressed eligibility to confirm that persons completing the survey were familiar with ICP monitoring. Next, a randomization procedure was programmed into RedCap so that participants would be randomly assigned to one of three sets of questions in which they were asked to score (assign a value) ICP. The data for this section is from the nine scenarios described above. In this manner, each subject was asked to score three scenarios. Finally, the survey was pilot tested with physicians and nurses (n = 10) for face validity.

Figure 1. Showing 5 minutes (300 seconds) of ICP data used for patient scenarios.



Snowball recruitment (initial dissemination group is noted in acknowledgments) was used and participants were encouraged to access a hyperlink and anonymously complete the seven-question survey. Data were de-identified prior to developing the survey. Participants were eligible for the study if they met the following criteria: 18 years or older, registered nurses, nurse practitioners, physician assistants, or physicians that regularly care for patients with ICP monitoring and understand written English. Participants were excluded if they did not have background or training in managing patients with ICP monitors.

The first four questions were the same for all participants. These questions assessed demographic information: general location of practice, years of practice, role with ICP monitoring, and frequency of ICP monitoring. For questions 5–7, participants were randomized to see only three of the nine scenarios (ICP trends). For each ICP trend, participants were instructed to provide one value (score) that best represented the ICP for that epoch (Figures 1–3). For the purpose of this study an epoch is defined as the ICP waveform time period (1, 3, 5 minutes). The last three questions of the survey were randomized, such that, participants saw only one portion of the ICP trend from each patient; (e.g., one set of trends included 1 minute of ICP data from patient Alpha, 3 minutes from patient Beta, and 5 minutes from patient Gamma).

Survey data was exported from Redcap to an Excel (Microsoft) spreadsheet. SAS v9.4 (SAS

institute) was used for all analyses. Appropriate descriptive statistics were computed for continuous data (including mean and standard deviation [*SD*]), and ordinal/nominal data (frequency and percent [%]). Histograms were constructed to visualize the frequency and distribution of the ICP values for the 1-, 3-, and 5-minute epochs. Paired *t*-tests were performed to compare mean ICP values within each epoch and scenario. We then performed an omnibus test to compare ICP values at 1, 3, and 5 minutes within a scenario to test the null hypothesis. Bonferroni correction was applied such that a *p*-value of < .0056 was required to reject the null.

RESULTS

There were 332 respondents between July and October of 2019. As shown in Table 1, survey respondents included attending physicians (43), physicians in training (12), advanced practice providers (e.g., nurse practitioners, physicians' assistants) (29) nurses (247), and 1 not declared. Although 279 (84.8%) of respondents were from North America, other respondents were from Africa (1), Asia (12) Australia (12), Europe (3), South America (22), and 3 not declared. There was a fairly even distribution for the number of days each month when respondents worked with patients who had ICP monitoring: 1–10 days/-month (153), 11–20 days/month (137), >20 days/-month (38), and 4 not declared.

Individual ICP values were significantly different both within each epoch and between epochs for each patient (Table 2). For patient Alpha, individual ICP values ranged from 2 to 20 mmHg; and mean (*SD*) ranged from 8.2(0.8) to 8.7(1.2). For patient Beta, individual ICP values ranged from 2 to 20 mmHg; and mean (*SD*) ranged from 4.8(1.2) to 6.5(2.3). For patient Gamma, individual ICP values ranged from 1 to 40 mmHg; and mean (*SD*) ranged from 11.1(3.4) to 15.1(3.3).

Paired *t*-test was used to examine ICP values comparing adjudicated for each time interval. ANOVA for all three epochs within subjects using an omnibus test was statistically significant for patient Beta and patient Gamma ($p < .0001$), but not significant for patient Alpha ($p = .0589$). As shown in Table 3, there was a statistically significant difference in ICP values for patient Alpha comparing 1 and 3 minutes ($p < .0001$), but not comparing 3 and 5 minutes ($p = .1123$), nor 1 and 5 minutes ($p = .9394$). There was a statistically significant difference in ICP values for patient Beta comparing both 1 and 3 minutes, and 1 and 5 minutes ($p < .0001$), but not comparing 3 and 5 minutes ($p = .0822$). Similarly, there was a statistically significant difference in ICP values for patient Gamma comparing both 1 and 3 minutes, and 1 and 5 minutes ($p < .0001$), but not comparing 3 and 5 minutes ($p =. 0232$; [*Bonferroni requires < 0.0056*]).

TABLE 1. DescriptiveStatistics of the Variables

Variable	*N* (%)
Role	
Attending Physician	43 (12.9%)
Physician in Training (Resident, Fellow)	12 (3.6%)
Advanced Practice Provider	29 (8.8%)
Nurse	247 (74.6%)
Years of ICP monitoring experience	
1–5 years	152 (46.1%)
6–10 years	84 (25.5%)
11–15 years	34 (10.3%)
16–21 years	22 (6.7%)
>21 years	38 (11.5%)
Location	
Africa	1 (0.3%)
Asia	12 (3.7%)
Australia	12 (3.7%)
Europe	3 (0.9%)
North America	279 (84.8%)
South America	22 (6.7%)
Days per month spent monitoring ICP	
1–10 days	153 (46.7%)
11–20 days	137 (41.8%)
21–31 days	38 (11.6%)

TABLE 2. Survey Responses Assigning ICP Values[a] for Each Scenario

Patient	Time	*N*	Mean (*SD*)	Median	Range
Alpha	1 minute	106	8.2 (0.8)	8.0	4–9
	3 minutes	117	8.7 (1.2)	9.0	2–12
	5 minutes	106	8.2 (2.6)	8.0	2–20
Beta	1 minute	116	4.8 (1.2)	5.0	1–10
	3 minutes	108	6.5 (2.3)	6.0	5–20
	5 minutes	104	6.1 (0.9)	6.0	5–8
Gamma	1 minute	108	15.1 (3.3)	14.0	7–20
	3 minutes	104	12.5 (5.3)	12.0	5–40
	5 minutes	117	11.1 (3.4)	10.0	3–20

Note. [a]Values are measured in mmHg.

TABLE 3. Paired *t*-Tests to Compare Mean ICP Values Within Epoch and Scenario

Patient	Comparison	Test Statistic	*p* value
Alpha	1 and 3 minutes	–3.97	< .0001
	3 and 5 minutes	1.60	.1123
	1 and 5 minutes	–0.08	.9394
Beta	1 and 3 minutes	–6.98	< .0001
	3 and 5 minutes	1.76	.0822
	1 and 5 minutes	–8.37	< .0001
Gamma	1 and 3 minutes	4.20	< .0001
	3 and 5 minutes	2.30	.0232
	1 and 5 minutes	9.35	< .0001

DISCUSSION

The findings provide additional evidence that the documented ICP values are unlikely to be accurate and unlikely to provide an accurate picture of intracranial dynamics (Liu et al., 2020). Our results are unique in that they provide a global perspective that confirms and extends early findings that there is poor agreement on almost every aspect of ICP management day (Chung et al., 2017; Chung et al., 2019; Mcnett et al., 2017; Mcnett et al., 2018; Olson et al., 2014; Olson et al., 2015a; Olson et al., 2019). Nomenclature is the process by which we name things and helps improve understanding (e.g., "heart attack" elicits a different response than "myocardial infarction"). Previous work has found that hospitals generally have high intra- and interinstitutional variance, (Olson et al., 2014; O'Phelan et al., 2016; Samudra et al., 2018). This lead to a call for improved consistency in performance and the use of nomenclature (Olson et al., 2019; Suarez et al., 2019). Furthermore, the statistically significant difference in ICP values based varying times allotted for observation of the ICP supports the need for a recommendation that addresses how long a nurse should observe ICP prior to documenting that value. Promoting efforts to standardize nomenclature may help, but still does not fully

address the implications of how the ICP value is documented (Damani et al., 2019; Olson et al., 2019).

The findings have the potential for both statistical and clinical significance. Because the most recent guidelines for treating ICP after traumatic brain injury recommend a treatment threshold of 22, it must be assumed that if a practitioner documents the value as 21 mmHg the patient will not be treated for intracranial hypertension (Marehbian et al., 2017). However, our results indicate that a different practitioner taking care of the same patient might document the value as 23 mmHg and therefore the patient would be treated for intracranial hypertension. This same example holds true for treatment thresholds used for CSF drainage after subarachnoid hemorrhage, and mannitol or hypertonic saline administration treatment thresholds for vasogenic cerebral edema (Chung et al., 2019). Precisely because ICP is tightly controlled, a difference in reading of only 1 or 2 mmHg may have profound clinical implications.

The broad variation in ICP values is not surprising. One study found that although clinicians reported that they observed an ICP trend for 5 minutes, the median time spent observing ICP was 1 minute (Olson et al., 2015b). Liu et al. (2020) found that median time for closure of an EVD stopcock (required to determine the ICP value) was only 25 seconds. The statistically significant differences in ICP comparing the 1-minute and 3-minute observation periods suggests that inconsistencies in how ICP is document may be higher than previously reported (Olson et al., 2020; Olson et al., 2015b; Rogers et al., 2017).

The temptation to accept the similarity of mean values should be approached with caution. Beyond simple mean (averaged) there are at least three relevant values that cannot be obtained by determination of mean ICP: the number of episodes > 20 mmHg; time spent with ICP > 20 mmHg; and the highest daily ICP value (Jha et al., 2018). There are a variety of interventions that have been described to impact the quality and reliability of ICP readings (Olson et al., 2020; Samudra et al., 2018). The head of bed position relative to the transducer (Altun Ugras et al., 2018; Mcnett et al., 2018). CSF drainage causes errors and missed readings (Howells et al., 2017; Liu et al., 2020; Rogers et al., 2017). Moreover, a variety of nursing care interventions have been linked to ICP variability (Olson et al., 2017). The type of monitoring device also influences the ICP value (Mahdavi et al., 2016; Zhang et al., 2017). Given the plethora of known influential variables, the ability to agree upon a minimum length of time that ICP should be observed prior to documenting a value should be a high priority.

ICP is dynamic and known to have temporal variation. These ICP variations can be noted across both short (seconds) and long (days) epochs. The dynamic state of ICP is exacerbated during neurological injury and is a potential signal of clinical deterioration (Adams et al., 2017; Eide et al., 2012). Changes in pulsatile blood flow and respiration result in short-term influence on the ICP waveform and ICP value (Hickey et al., 2009; Unnerback et al., 2018; Unnerback et al., 2019). Injury and edema that develop as secondary brain injury may result in steadily rising ICP trends seen over several days (Jha et al., 2018). Even so, a collective recommendation of time to observe ICP would lessen variances in reporting of ICP.

LIMITATIONS

The primary limitations associated with this study are similar to those seen with other surveys. Although the surveys were sent out internationally, the survey was developed in North America. Therefore, language and cultural barriers may exist in the survey and responses that limit the external validity of results. A future survey would consider a way of standardizing responses globally. Anecdotal reports (email) were received that indicate confusion on the part of some practitioners regarding how to read the ICP graphs (trended data). While this is a limitation of the ability to interpret some responses, it also highlights the lack of global standardization. Despite

our sample is from a diverse population, another limitation of the study is that, we did not have enough sample to divide the data into a training and validation dataset for analysis. Another potential limitation is selection bias due to self-selection of potential respondents. Finally, the use of survey does not capture the range of variables staff observe when adjudicating ICP (e.g., coughing or body position). It is unknown if the responses would have varied this much had the observations been made in real time at the bedside.

CONCLUSION

There is wide and inconsistent variation in the practice by which ICP values are assigned. The sampling epoch by which ICP is assigned impacts ICP values. Without standardizing the amount of time for which clinicians take to interpret ICP trend data, variability in ICP reporting will continue. These results further highlight the growing need to standardize the methods of measuring and reporting ICP as a clinical variable.

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