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CURRENT OPINION/ARGUMENTS

Differentiate the Source and Site of Intracranial Pressure Measurements Using More Precise Nomenclature

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Abstract

Background: Intracranial pressure (ICP) monitoring is fundamental for neurocritical care patient management. For many years, ventricular and parenchymal devices have been available for this aim. The purpose of this paper is to review the published literature comparing ICP recordings via an intraventricular catheter or an intraparenchymal (brain tissue) catheter.

Methods: Literature search of Medline, CINAHL, Embase, and Scopus was performed in which manuscripts discussed both ICP monitoring via an intraventricular catheter and ICP monitoring through intraparenchymal (brain tissue) catheter. Keywords and MeSH terms used include critical care, intracranial pressure, ICP, monitoring, epidural catheter, intracranial hypertension, ventriculostomy, ventricular drain, external ventricular drain, and physiologic monitoring.

Results: Eleven articles met inclusion criteria. The published literature shows differences in simultaneously recorded ICP between the intraventricular and intraparenchymal sites.

Conclusions: We propose two new terms that more accurately identify the anatomical site of recording for the referenced ICP: intracranial pressure ventricular (ICP-v) and intracranial pressure brain tissue (ICP-bt). Further delineation of the conventional term "ICP" into these two new terms will clarify the difference between ICP-v and ICP-bt and their respective measurement locations.

Keywords: Intracranial pressure, Brain injuries, Neurophysiological monitoring, Neurocritical care

Background

Decades of advances in intracranial pressure (ICP) monitoring have resulted in a variety of invasive devices capable of monitoring ICP from different sites within the skull. Historically, epidural, subdural, intraparenchymal, and intraventricular sites have been used to record ICP. Currently, in most institutions, only intraparenchymal and intraventricular sites are used. Modern external ventricular drains (EVDs) have origins in intraventricular ICP monitoring first performed in 1866 using hollow catheters with the tip placed intraventricularly close to the Foramen of Monroe and connected to an external transducer via a continuous fluid column [1]. Intraparenchymal monitors (IPMs), developed nearly 120 years later, rely upon fiberoptic or pneumatic transducers placed directly into the brain parenchyma [2, 3]. Thus, ICP from an EVD reflects a referred intraventricular pressure, whereas ICP from IPM reflects direct intraparenchymal pressure. Given that there is no conventional distinction to differentiate ICP by anatomical location, the purpose of this paper is to propose two new terms to more accurately identify the anatomical structure for the referenced ICP.

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Despite efforts to confirm inter-device agreement, most studies describe both statistically and clinically significant differences measuring ICP via IPM versus EVD source [4–6]. Altman and Bland [7] demonstrate clearly that two different methods of measuring two different variables are unlikely to be perfectly correlated. Rather than continuing to seek a universal measure of ICP, we propose that terminology be incorporated to help differentiate ICP measures. We propose that ICP-v (ICP ventricular) should be used to describe pressures obtained wherein the referenced ICP is derived from the ventricular system (e.g., EVD). We also propose that ICP-bt (ICP brain tissue) should be used to describe pressure wherein the transducer or a referred component is measuring the pressure within brain tissue or parenchyma.

Methods

A comprehensive literature search was performed by a medical librarian to include references from Medline, CINAHL, Embase, and Scopus in which manuscripts discussed both ICP monitoring via an EVD and IPM. Keywords and MeSH terms used include critical care, intracranial pressure, ICP, monitoring, epidural catheter, intracranial hypertension, ventriculostomy, ventricular drain, external ventricular drain, and physiologic monitoring. The following limits were placed on the search: English, full text, adult human subjects. The following were excluded: dissertations, case reports, abstracts, conference proceedings, books, and reviews. This search resulted in 47 articles. Thirty-seven articles from Medline (see Supplementary 1), additional 2 articles from CINAHL (see Supplementary 2), 2 articles from Embase (see Supplementary 3), and 6 articles from Scopus (see Supplementary 4) were also included.

Each of the 47 articles was reviewed for title and abstract by 5 authors (DO, CR, JS, MM, and VA) to determine whether they met full eligibility criteria. On first pass, 16 articles were unanimously excluded as review articles with no original data (7), pediatric only (3), not including ICP data (3), case study (2), and no human subjects (1). The remaining 31 articles were then subjected for full read, and this resulted in 20 exclusions for not comparing ICP values for ICP-v and ICP-bt measures (17), not including human subjects (2), or review/case study (3). During peer review, 1 additional study from 1992 was found in a secondary search (reference list) [8]. These 10 articles are summarized in Table 1 [3, 5, 6, 9–14].

Results

The 10 articles reviewed included comparative ($n=6$) [5, 6, 8, 11, 12, 14], observational ($n=3$) [3, 9, 13], and cross-sectional ($n=1$) studies [10]. All ten articles included both EVD and IPM devices for ICP, and one article

Table 1 Summary of evidence for retained articles

References	Study design	Population	Sample size	Comparison
Gambardella et al. [9]	Retrospective	SAH, ICH, TBI, HCP, tumor	209	Compare absolute values from the ICP-v and ICP-bt. The correlation coefficient for each study ranged from 0.586 to 0.996. The overall correlation coefficient was 0.946
Schickner and Young [8]	Prospective	TBI, ICH	10	Student *t* test and Wilcoxon signed rank found mean ICP fiberoptic (36.6 mmHg) and mean EVD (27.4 mmHg) differences ($p<0.01$)
Shapiro et al. [10]	Retrospective	SAH, ICH, TBI, edema, AVM, tumor	244	There was a very strong correlation between the ICP-bt and ICP-v in the first measure taken ($r=0.97$)
Chambers et al. [11]	Prospective	Not state	11	The mean difference was less than 0.1 mm Hg (EVD–Spiegelberg) with an SD of 4.9 mm Hg
Slavin and Misra [12]	Retrospective	ICH, AVM, tumor	5	The difference between the infratentorial (IPM) and supratentorial ICP (EVD) readings ranging from 2 to 8 mmHg
Koskinen (2005)	Prospective	Multiple diseases	128	Mean ICP-v = 18.30 ± 3 mm Hg, mean ICP-bt = 19.0 ± 0.2 mm Hg; $r=0.79$, $p=0.0001$
Vender Olivecrona [13]	Prospective	TBI	11	ICP-bt and ICP-v showed no significant mean difference in open $p=0.2162$ or closed 0.3776 positions
Lescot et al. [14]	Retrospective	SAH, TBI, AVM, tumor	30	ICP-bt approximated the ICP-v pressures by ± 7 mmHg
Berlin et al. [6]	Prospective	SAH, TBI, ICH	35	Paired observation with difference of ± 3 mm Hg = 93%; 4–8 mm Hg = 7%; ≥ 9 mm Hg ≤ 1%
Mahdavi et al. [3]	Retrospective	TBI	37	Paired t tests found significantly different (p 0.001) ICP values recorded by EVD and IPM. ICP-v/ICP-bt correlation was weaker ($r=0.3576$) in lower values (< 20 mm Hg)

AVM arteriovenous malformation, *EVD* external ventricular drain, *HCP* hydrocephalus, *ICH* intracerebral hemorrhage, *ICP* intracranial pressure, *ICP-bt* intracranial pressure brain tissue, *ICP-v* intracranial pressure ventricular, *IPM* intraparenchymal monitor, *SAH* subarachnoid hemorrhage, *TBI* traumatic brain injury

compared ICP between supratentorial and infratentorial sites.

Gambardella et al. [9] included 209 patients with SAH, ICH, TBI, hydrocephaly, and cerebral neoplasms and examined absolute ICP values from both the ICP-v (averaged 17.71 ± 4.86 mm Hg) and the ICP-bt (averaged 15.81 ± 4.93 mm Hg). Correlation coefficients (r^2) ranged from 0.586 to 0.996, with correlations for the complete data set $r^2 = 0.946$ across all values. Data were gathered for three days, as accuracy of readings after this time period for fiberoptic devices was questionable. Similarly, Shapiro et al. [10] conducted a retrospective study to evaluate reliability of IPM and reported a correlation coefficient of 0.99. However, this calculation was based on a nonzero intercept and the data show consistently higher values for ICP-v compared with ICP-bt. Schickner and Young [8] studied 10 patients with fiberoptic and EVD and ICP tracings. In this sample, 21% of the fiberoptic ICP values were lower and 66% were higher than EVD-derived ICP values.

Chambers et al. [11] compared the Spiegelberg® brain pressure catheter with an EVD and demonstrated an inverse relationship between the degree of difference between ICP-bt and ICP-v values. Specifically, increases in ICP values resulted in smaller differences between ICP-bt and ICP-v values ($r = -0.355$, $p < 0.01$). Overall, the mean difference between paired readings was less than 0.1 mmHg (EVD–Spiegelberg®), indicating good overall agreement between devices.

Slavin and Misra [12] in a retrospective study found clinically relevant differences between the infratentorial and supratentorial ICP readings. When using EVD and IPM, the pressure gradients between the two intracranial compartments vary, and the difference in values changes over time sometimes reaching equilibrium.

Koskinen and Olivercrona [13] compared pressure of ICP-bt (via Codman® MicroSensor) with ICP-v and reported mean differences in ICP based on device (mean ICP-v = 18.3 ± 0.3 mmHg, mean ICP-bt = 19.0 ± 0.2 mmHg). Overall, measurements were highly correlated ($r = 0.79$, $p < 0.0001$); however, ICP-v measurements < 15 mm Hg tended to be systematically higher than ICP-bt readings. Thus, though there are strong correlations between readings, there is significant disagreement between ICP-v and ICP-bt values.

Vender et al. [5] provided comparisons for three types of ICP monitoring (EVD, IPM, and fluid-coupled and each type in both open and closed drainage positions). In the discussion, they report poor reliability demonstrated by intraclass correlation coefficient for open (0.38) and closed (0.54) drainage states for all ICP monitor variants. They also describe poor correlations between parenchymal and ventricular pressure measurements (open $r = 0.0067$, $p = 0.9854$, closed $r = 0.2345$, $p = 0.5144$) and note discrepancies in ICP readings when the EVD is opened to divert cerebrospinal fluid (CSF). Despite these discrepancies, paired t tests of ICP-bt values with ICP-v with drain state open yielded $t\ (9) = -1.33$, $p = 0.2162$ and with ICP-v drainage closed $t\ (9) = -0.93$, $p = 0.3776$. The small sample size of this study is worth noting ($n = 11$).

More recent studies compared simultaneous monitoring devices. Lescot et al. [14] compared ICP-v readings with ICP-bt readings obtained from two systems Codman® (range −6 to 40 mmHg) and the Pressio® (range −6 to 62 mmHg). Although there was no statistically significant difference between readings from the parenchymal monitors, the ICP-bt approximated the ICP-v pressures by ±7 mmHg. Similarly, Berlin et al. [6] compared the readings of a multi-parametric device ICP (The Hummingbird Synergy Ventricular System®). This single device measures both ventricular ICP and parenchymal ICP. The authors found congruence within ±3 mmHg in 93% of their observations for ICP-v and ICP-bt. However, 167 readings (7%) revealed ventricular and parenchymal differences between 4 and 8 mmHg. Interestingly, the authors note that these differences required correctional interventions.

Mahdavi et al. [3] conducted a retrospective observational study to compare ICP-v and ICP-bt specifically at different ranges of values. Findings indicate a strong correlation between ICP-v and ICP-bt values when all time-indexed data points are considered ($r = 0.6955$) and when ICP values are beyond normal range ($r = 0.6113$ when ICP ≥ 20 mm Hg and $r = 0.5654$ when ICP ≥ 25 mmHg in either EVD or IPM). However, this correlation weakened ($r = 0.4232$) when ICP was < 25 mmHg in either EVD or IPM and became questionable ($r = 0.3576$) when ICP was < 20 mm Hg in either EVD or IPM.

Discussion

There are both precedent and need to define ICP as either ICP-v or ICP-bt. Numerous other physiologic variables are defined and differentiated by source or location: oral versus core temperature, invasive versus cuff blood pressure, and heart rate versus pulse rate [15–17]. The historical foundations often cited when validating ICP as single representative value describing pressure throughout the skull have long been questioned [18]. Monro [19] described the passage between the lateral and third cavities of the brain and argued that the volume of the blood in the cranial vault must be nearly constant and therefore continuous venous blood outflow is required to make room for continuous incoming arterial blood [19]. Kellie [20] presented support for this hypothesis. Neither author mentions CSF as contributing to pressure [19, 20].

Kellie, in fact, hypothesized that any water in the ventricles and brain could not be present in normal premorbid conditions. In the mid-nineteenth century CSF was introduced into the Monro–Kellie hypothesis by George Burrows and Harvey Cushing [19–21]. There are scientific and clinical benefits to defining ICP as either ICP-v or ICP-bt which are founded the evolution of the fundamental concept of ICP.

Given the summary of results from published studies, there is little evidence to support that a computational constant could be derived to convert values. Five of the 10 studies reported directional data; ICP-bt was lower than ICP-v [6], higher than ICP-v [11], and bidirectionally different than ICP-v [3, 8, 9]. This is potentially explained by pathology of the disease. For example, ipsilateral ICP-bt monitoring provides point of measure proximal to mass effect and would be expected to have higher pressure values than those observed in the contralateral ventricle (ICP-v). Similarly, the patient with intraventricular hemorrhage would be expected to have higher ICP-v compared to a distally located contralateral reference point.

With the exception that EVD monitoring was established prior to IPM monitoring, there is no sound scientific evidence to support an assumption that EVD is the "gold standard" for ICP monitoring. Nor is there convincing evidence that one measurement method results in clinically superior outcomes. The evidence does demonstrate that both IPM pressure monitoring and EVD pressure monitoring have advantages and disadvantages. Drift or zero loss (zero drift) has been discussed primarily for IPM; however, the most recent summary of the literature supports that mean drift is less than 1 mmHg [22]. Similarly, recent articles find that measurement techniques and anatomical reference points are not standardized and may contribute to measurement variability [16, 17, 23]. The importance of delineating between measurement techniques is a critical first step toward identifying the optimal measurement approach. Subsequent research is then needed to examine linkages between specific measurement approaches, management decisions, and clinical outcomes.

Conclusion

Despite several studies having argued that there are significant differences in ICP measured via EVD versus ICP measured via IPM, the values are often reported in clinical and research settings as interchangeable when in fact they are not. This current opinion article offers a logical solution that will help move the science of ICP monitoring forward. The time has come to report ICP-v and ICP-bt as distinctly different measures. Delineation of measurement type must occur to accurately identify impact on physiologic parameters and patient outcomes.

Electronic supplementary material
The online version of this article (https://doi.org/10.1007/s12028-018-0613-x) contains supplementary material, which is available to authorized users.

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Author's Contributions
DO, MM, JS, CR, and VA conceived the review idea, designed the search strategy, and participated in screening and data extraction with review by SO and JR. All authors participated in the creation of the manuscript and read and approved the manuscript.

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The authors declare that they have no conflict of interest.

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