Intracranial pressure following aneurysmal subarachnoid hemorrhage: monitoring practices and outcome data

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Object. Elevated intracranial pressure (ICP) is an important consequence of aneurysmal subarachnoid hemorrhage (SAH) that often results in decreased cerebral perfusion and secondary clinical decline. No definitive guidelines exist regarding methods and techniques for ICP management following aneurysm rupture. The authors describe monitoring practices and outcome data in 621 patients with aneurysmal SAH admitted to their neurological intensive care unit during an 8-year period (1996–2003).

Methods. A fiberoptic catheter tip probe or external ventricular drain (EVD) was used to record ICP values. The percentage of monitored patients varied, as expected, according to admission Hunt and Hess grade ($p < 0.0001$). Intracranial pressure monitoring devices were used in 27 (10%) of 264 Grade I to II patients, 72 (38%) of 189 Grade III patients, and 134 (80%) of 168 Grade IV to V patients. There was a strong propensity to favor transduced ventricular drains over parenchymal fiberoptic bolts, with the former used in 221 (95%) of 233 cases. This tendency was particularly strong in the poor-grade cohort, in which EVDs were placed in 99% of monitored individuals. The rates of cerebrospinal fluid infection in patients in whom ICP probes (0%) and ventricular drains (12%) were placed accorded with those in the literature.

Conclusions. Following aneurysmal SAH, ICP monitoring prevalence and techniques differ with respect to admission Hunt and Hess grade and are associated with the patient's functional status at discharge.

KEY WORDS • intracranial pressure • subarachnoid hemorrhage • ventricular drain

Following aneurysmal SAH, the sudden introduction of blood into the subarachnoid space results in CSF outflow resistance.^{5,7,9} Increased ICP and a resultant decrease in cerebral perfusion play a principal role in the development of cortical damage.^{3,4,6,13,24} Persistent ICP elevations have been correlated with poor clinical condition after aneurysm rupture.^{12,21} The continuous monitoring of ICP aids in the early detection of secondary cerebral insults and guides therapeutic interventions by providing real-time, physiological feedback. Intracranial pressure control affords the opportunity for surgical treatment and postoperative intensive care to effect a favorable outcome in patients suffering from aneurysmal SAH.^{19,21}

The two predominant methods for quantifying ICP measurements include placement of EVDs and fiberoptic catheter tip transducers. No definitive guidelines exist to delineate optimal monitoring practices or techniques. Decisions must account for the clinical condition of the patient and the inherent risks associated with applying each device or strategy. This study examines a large cohort of patients with aneurysmal SAH who underwent ICP mon-

itoring with fiberoptic probe or EVD; data obtained in these patients were compared with results in a group of patients in whom ICP was not monitored. We compare patient demographics, functional outcome data, hospital LOS, and CSF infection rates across the cohorts.

CLINICAL MATERIAL AND METHODS

Patient Population

This investigation was approved by the institutional review board at Columbia University, New York Presbyterian Hospital. Six hundred twenty-one patients with ruptured intracranial aneurysms admitted to the Neurological Intensive Care Unit at Columbia Presbyterian Medical Center between 1996 and 2003 were included in this study. Hunt and Hess grade⁷ (good grade, I–II; intermediate grade, III; and poor grade, IV–V) was determined by the patient's clinical status at admission and throughout the hospital course. Intracranial pressure monitoring decisions (no invasive techniques, placement of fiberoptic probe, placement of an EVD) were made by the neurological critical care team. Length of stay and mortality rate were determined by examining hospital records. Clinical condition was determined at the time of discharge and stratified according to the GOS scores.⁸ Outcome was classified as favorable in patients with GOS scores of 1 or

Abbreviations used in this paper: ANOVA = analysis of variance; CSF = cerebrospinal fluid; EVD = external ventricular drain; GOS = Glasgow Outcome Scale; ICP = intracranial pressure; LOS = length of stay; SAH = subarachnoid hemorrhage.

2, severe disability in those with GOS scores of 3, and poor in those with GOS scores of 4 or 5. Cerebrospinal fluid infection was determined by examining blood cultures and clinical symptomatology.

Statistical Analysis

Statistical analyses were performed using the ANOVA, nonparametric Mann–Whitney, and chi-square tests. A probability value of less than 0.05 was considered statistically significant. Patient population was stratified according to the mode of ICP monitoring applied (no invasive monitoring, fiberoptic probe, or EVD) and clinical presentation at admission. A chi-square test (involving a multiple contingency table) was performed to determine if monitoring practices varied with respect to admission Hunt and Hess grade. Patient demographics (age and sex) were compared across cohorts. Clinical condition (as reflected by the GOS score) at the time of discharge was analyzed in each group. Chi-square tests (involving a multiple contingency table format) were performed to determine if monitoring varied with functional outcome for each admission Hunt and Hess grade. Within the good- and intermediate-grade cohorts, a frequency of decline to poor grade was determined (assessed by worst Hunt and Hess grade during the hospital course). A chi-square test was then performed to assess for a significant association between decline to poor grade and subsequent placement of an ICP monitoring device. The correlation between a decision to withdraw medical support and a lack of ICP monitoring in poor-grade patients was assessed by chi-square analysis. The three monitoring groups, along with their stratified subpopulations, were compared for mean hospital LOS by performing ANOVA and nonparametric Mann–Whitney tests. The CSF infection rates were determined for each of the cohorts.

Monitoring Protocol

In patients able to follow commands, ICP was not monitored (neither by EVD nor ICP probe). Patients unable to follow or those who ceased being able to follow commands underwent ICP monitoring (Fig. 1). In those in whom neuroimaging studies demonstrated radiographic evidence of hydrocephalus, an EVD was placed. In those with small ventricles, no hydrocephalus, a fiberoptic ICP probe was placed.

Fig. 1. Flow diagram depicting the decision-making process of the neurological intensive care team with regard to ICP monitoring in patients with aneurysmal SAH.

tients with small ventricles (that is, no hydrocephalus) a fiberoptic ICP probe was placed to avoid the higher infection rates associated with the EVD.

RESULTS

Intracranial Pressure Monitoring

Table 1 provides a summary of data obtained in patients with aneurysmal SAH stratified according to admission Hunt and Hess grade. Of the 621 patients, 388 (62%) did not undergo monitoring, 12 (2%) underwent monitoring via fiberoptic ICP probes, and 221 (36%) underwent monitoring via EVDs. Intracranial pressure monitoring devices were placed in 27 (10%) of the 264 good-grade patients, 72 (38%) of the 189 Grade III patients, and 134 (80%) of 168 poor-grade patients. A significant difference existed in monitoring practices (unmonitored compared with fiberoptic ICP probe or EVD) according to clinical presentation at admission ($p < 0.0001$).

Patient Demographics

Table 2 provides a summary of demographic data obtained in the entire population of patients with aneurysmal SAH stratified according to admission Hunt and Hess grade. No significant sex differences existed across monitoring groups in the total population. By contrast, a significant difference in age was demonstrated between patients in whom monitoring was not performed and those in whom probes and EVDs were placed for ICP monitoring ($p < 0.05$). Within each subgroup cohort (stratified according to admission Hunt and Hess grade) there were no age or sex differences with respect to monitoring.

Outcome After Aneurysmal SAH

Table 3 provides a summary of functional GOS score-related outcome data at discharge for all patient groups. Outcome data are presented for the entire aneurysmal population with SAH and stratified by admission Hunt and Hess grade (good, intermediate, and poor grades).

Good-Grade Subgroup. As functional outcome worsened, the prevalence of ICP monitoring increased ($p < 0.0001$). In 10% of good-grade patients status declined to poor grade during the hospital stay. A significant correlation existed between a clinical decline to poor grade and subsequent placement of an ICP monitoring device ($p < 0.0001$; no monitoring, no decline: 86%; no monitoring, decline: 6%; monitoring, no decline: 4%; and monitoring, decline: 4%).

TABLE 1
Summary of monitoring-related data in patients with aneurysmal SAH

ICP Monitoring	All Patients W/ Aneurysmal SAH	Good	Intermediate	Poor
none	388	237	117	34
ICP probe	12	6	5	1
EVD	221	21	67	133
total	621	264	189	168

TABLE 2
Summary of demographic data*

ICP Monitoring	All Patients W/ Aneurysmal SAH		Admission Hunt and Hess Grade					
			Good		Intermediate		Poor	
	Age (yrs)	M/F	Age (yrs)	M/F	Age (yrs)	M/F	Age (yrs)	M/F
none	52.3 ± 0.7	128:260	50.6 ± 0.9	82:155	54.6 ± 1.3	34:83	56.8 ± 2.7	12:22
ICP probe	45.8 ± 2.5	3:9	41.8 ± 3.9	2:4	49.4 ± 3.1	1:4	52.0 ± 0.0	0:1
EVD	55.6 ± 1.0	69:152	49.4 ± 3.6	7:14	56.3 ± 1.7	25:42	56.3 ± 1.3	37:96
total	53.4 ± 0.6	200:421	50.3 ± 0.9	91:173	55.0 ± 1.0	60:129	56.4 ± 1.2	49:119

*Age-related values are presented as means ± standard error of the means.

Intermediate-Grade Subgroup. As functional outcome worsened, the prevalence of ICP monitoring increased ($p < 0.001$). In 35% of intermediate-grade patients status declined to poor grade during the hospital stay. A significant correlation existed between a clinical decline to poor Grade and subsequent placement of an ICP monitoring device ($p < 0.0001$; no monitoring, no decline: 50%; no monitoring, decline: 12%; monitoring, no decline: 15%; and monitoring, decline: 23%).

Poor-Grade Subgroup. As functional outcome worsened, the prevalence of ICP monitoring tended to decrease (not statistically significant). Lack of monitoring was highly correlated with a decision to withdraw care ($p = 0.02$; no monitoring, care withdrawn: 10%; no monitoring, care continued: 6%; monitoring, care withdrawn: 25%; and monitoring, care continued: 59%).

Hospital LOS. Table 4 provides data related to LOS in all patient groups. Length of stay data are expressed for the total population with aneurysmal SAH and stratified according to admission Hunt and Hess grade. Within the total population, LOS was significantly different (ANOVA, $p < 0.0001$). Specifically, in the unmonitored cohort LOS was shorter than in EVD-monitored patients ($p < 0.05$). This correlation remained significant within the intermediate- and poor-grade Hunt and Hess classification subgroups ($p < 0.05$) and trended in the same direction for the good-grade subgroup.

Risk of CSF Infection

In four (1%) of 387 unmonitored patients a CSF infection was demonstrated. We calculated a 12% rate of meningitis/ventriculitis among the 220 patients in whom EVDs were placed. No patient who underwent catheter tip ICP monitoring suffered a CSF infection.

DISCUSSION

It is recognized that intracranial hypertension and diminished cerebral perfusion pressure account for the initial neurological deficit in a considerable portion of patients who have suffered an aneurysmal SAH.⁹ Furthermore, surgical treatment of ruptured intracranial aneurysms is far more difficult in the presence of hydrocephalus and significant cerebral edema.^{1,17} By altering intracranial hemodynamics, timely ICP management can effectively protect against secondary cortical damage, improve functional status, and facilitate operative exposure

during aneurysm surgery.^{4,12,20,21,23} Elevated ICP, however, is also thought to play an important role in the arrest of bleeding from ruptured aneurysms.^{6,17,18} These competing factors must be balanced when attempting to evaluate quantitatively or control ICP. Although ICP monitoring and CSF drainage are common practice in the management of patients in whom intracranial aneurysms have ruptured, no large scale trials have been designed to evaluate these protocols.

In this study we have examined the prevalence of and techniques for ICP monitoring in a large consecutively treated series of patients with ruptured intracranial aneurysms admitted to the Neurological Intensive Care Unit at New York Presbyterian Hospital. Of the 621 patients admitted, 62% did not undergo monitoring, 2% underwent placement of fiberoptic ICP probes, and 36% underwent

TABLE 3
Summary of outcome data in all patients and stratified by admission grade*

ICP Monitoring Group	Outcome (GOS Score)		
	Favorable (1 & 2)	Severe Disability (3)	Poor (4 & 5)
all patients			
no monitoring	203	134	27
ICP probe	0	7	5
EVD	31	99	82
total	234	240	114
good H & H grade			
no monitoring	153	66	3
ICP probe	0	5	1
EVD	7	10	2
total	160	81	6
no. monitored (%)	7 (4)	15 (19)	3 (50)
intermediate H & H grade			
no monitoring	49	56	5
ICP probe	0	1	4
EVD	17	40	10
total	66	97	19
no. monitored (%)	17 (26)	41 (42)	14 (74)
poor H & H grade			
no monitoring	1	12	19
ICP probe	0	1	0
EVD	7	49	70
total	8	62	89
no monitored (%)	7 (88)	50 (81)	70 (79)

* H & H = Hunt and Hess.

TABLE 4
Summary of LOS in all patients*

ICP Monitoring	All Patients W/ Aneurysmal SAH		Admission Hunt and Hess Grade					
			Good		Intermediate		Poor	
	No.	LOS	No.	LOS	No.	LOS	No.	LOS
none	385	13.9 ± 0.6	238	14.5 ± 1.0	111	12.9 ± 0.8	36	13.7 ± 1.4
ICP probe	11	21.5 ± 3.5	4	20.8 ± 5.4	7	22.0 ± 4.9	0	
EVD	219	23.3 ± 1.4	21	19.0 ± 2.7	67	26.5 ± 2.6	131	22.4 ± 1.8
total	615	17.4 ± 0.6	263	14.9 ± 0.9	185	18.2 ± 1.2	167	20.5 ± 1.4

* The LOS values are presented in days as the means ± standard error of the means.

insertion of EVDs for ICP monitoring. The percentage of monitored patients varied as expected according to admission Hunt and Hess grade (Table 1; $p < 0.0001$). Intracranial pressure monitoring devices were applied in 10% of Grade I to II, 38% of Grade III, and 80% of Grade IV to V cases. There was a strong propensity to favor transduced ventricular drains over parenchymal fiberoptic bolts, especially in poor-grade patients (99% of poor-grade, 93% of intermediate-grade, and 98% of good-grade patients in whom ICP was monitored received EVDs).

The vast majority of individuals who presented to the hospital in good clinical condition did not undergo ICP monitoring (90% unmonitored, 2% probe monitored, and 8% EVD monitored). Because mental status change or radiographic evidence of enlarged ventricles on admission was not demonstrated in this subgroup of patients, ICP monitoring—with its inherent risks—was largely thought to be avoidable. The incidence of fiberoptic probe or EVD placement was directly related to poor functional outcome (Table 3; $p < 0.0001$). Multiple factors, including clinical symptomatology and the presence of hydrocephalus, influenced the decision of whether to monitor ICP and place a drain in Hunt and Hess Grade III patients (Fig. 1). In 62% of the patients no ICP monitoring was performed, whereas in 3% fiberoptic ICP probes were placed and in 35% EVDs were inserted. In this subpopulation, as was the case in patients with Hunt and Hess Grade I to II, monitoring was correlated with poor functional outcome (Table 3; $p < 0.001$). In both the good- and intermediate-grade cohorts, the patients who underwent either EVD- or ICP-probe monitoring placed were those who suffered clinical deterioration during the course of their hospital stay, explaining the increased prevalence of monitoring in the group with poor status at discharge.

Most of the poor-grade patients were treated with EVD (20% unmonitored, 1% fiberoptic probe, and 79% EVD). Within this cohort, the prevalence of invasive ICP monitoring was inversely related to poor functional outcome (Table 3; not significant). Largely, these individuals presented in a stuporous state or deep coma and with neuroimaging evidence of hydrocephalus, warranting continuous ICP monitoring and CSF drainage. Patients within this population who did not undergo ICP monitoring can be divided into two groups: 1) those immediately brought to the operating room, who experienced vast clinical improvement as a result of lumbar drainage and/or evacuation of clot and 2) those in whom conservative management was undertaken. Lack of intervention among poor-

grade patients was highly correlated with a decision to withdraw care ($p = 0.02$), as 65% of the unmonitored individuals had elected (by proxy) to have their medical support terminated.

Examination of the neurotrauma literature suggests that ICP monitoring results in a decreased mortality rate and reduced hospital LOS following closed-head injury.^{2,14} It is intuitive that the same would hold true for patients with aneurysmal SAH, but substantial well-scrutinized evidence is lacking. Our findings demonstrate that LOS in ICP-monitored patients was significantly greater than in those who did not undergo monitoring. When the total patient cohort was divided according to admission Hunt and Hess grade, a similar trend was evident. Confounding variables, however, were present in each of the groups. In both the good- and intermediate-grade cohorts, monitoring was performed more often in patients in whom functional status deteriorated to a poor Hunt and Hess grade ($p < 0.0001$). The increased number of patients in whom clinical decline occurred effectively prolonged the mean LOS for the ICP probe- and EVD-monitored groups. In the poor-grade cohort, a decision to withdraw care was highly correlated with a lack of invasive monitoring ($p = 0.02$); therefore, a higher mortality rate (directly related to termination of care and conservative management) decreased the mean LOS in the subgroup of patients in whom no monitoring was performed.

Risk of meningitis and ventriculitis must be compared when evaluating ICP monitoring techniques. The CSF infection rates after EVD placement have been reported to be between 1 and 22%.¹⁵ Specifically, a 10% infection rate has been cited following SAH.¹⁵ Our data concur with reported results; we found a 12% rate of meningitis/ventriculitis in cases in which EVDs were placed. Investigations of patients with traumatic brain injury have demonstrated an infection rate lower than 5% in cases involving placement of an intraparenchymal probe.^{10,11,16} In our small cohort of patients with aneurysmal SAH in whom fiberoptic catheter tip ICP monitoring probes were placed, the CSF infection rate was 0%.

To date, there are insufficient data to support a treatment standard for ICP monitoring after aneurysm rupture. In this study we present our experience with ICP monitoring in a large cohort of patients with aneurysmal SAH. We examined the different monitoring techniques and described functional outcome measures in a range of patient subpopulations. Because appropriate management decisions rely on a clear understanding of intracranial hemo-

dynamics, ICP monitoring and drainage are invaluable to the care of critically ill patients. Large-scale studies are needed to determine the optimal timing and patient selection criteria for the clinical use of available ICP monitoring devices in the treatment of aneurysmal SAH.

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