Perioperative Management of Traumatic Brain Injury

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Perioperative management of patients with traumatic brain injury (TBI) is guided by the imperative to avoid increasing the burden of secondary brain injury that is added to the mortality and morbidity associated with primary brain injury. Two strategies are essential in reducing secondary brain injury:

1. Promptly restore and maintain systemic cardiopulmonary stability.
2. Monitor physiologic variables that reflect potential secondary injury and promptly intervene.

Because of extensive clinical research conducted over the past two decades on patients with TBI, an extensive set of evidence-based standards, guidelines, and options has been published (1). To construct these, experts reviewed evidence and classified it as Class I (usually prospective randomized clinical trials), Class II (prospective studies of less rigorous design) and Class III (even less rigorous studies such as retrospective reviews). The evidence-based level of clinical certainty (high, moderate, and unclear) was used to construct standards, guidelines, and options, respectively. Although many standards, guidelines, and options address issues related to initial resuscitation and intensive care of TBI patients, they also contain information of interest to intraoperative management. Standards, guidelines, and options include coverage of the following topics: trauma systems, initial management, resuscitation of blood pressure and oxygenation, indications for intracranial pressure (ICP) monitoring, treatment thresholds for ICP management, ICP monitoring technology, hyperventilation, mannitol, barbiturates, glucocorticoids, treatment of intracranial hypertension, nutritional management and antiseizure prophylaxis. Those that specifically touch on perioperative management will be noted in the text.

After severe TBI, secondary brain injury contributes to adverse outcome. Secondary brain injury, assumed to be ischemic in origin, is associated with postinjury hypotension, hypoxemia, and intracranial hypertension. Contributing mechanisms include cerebral vasoconstriction (especially in the first few hours after TBI) and impaired pressure autoregulation of the cerebral circulation. Chesnut (2) reported that hypotension (systolic blood pressure <90 mm Hg) after severe TBI dramatically reduced the likelihood of favorable outcome (Table 1).

To minimize mortality and morbidity, severely head-injured patients require effective preoperative, intraoperative, and postoperative management, especially prevention and prompt treatment of hypotension (2). One option derived from evidence-based medicine (1) is that the "...first priority...is complete and rapid physiologic resuscitation." A related guideline is that oxygen saturation <90% or Pao_2 <60 torr must be avoided or corrected immediately.

Cerebral Circulatory Responses to Acute Head Injury

TBI is characterized by reduced cerebral blood flow (CBF), impaired cerebral pressure autoregulation, and increased intracranial pressure (ICP). In one-third of 106 head-injured patients injured ≤6 h previously, CBF was $<18\ mL \cdot 100g^{-1} \cdot min^{-1}$ (the threshold for cerebral ischemia) (3). The cerebral arteriovenous oxygen content difference (systemic arterial oxygen content − jugular venous bulb oxygen content) was abnormally high in the first few hours after injury and then progressively decreased (3). Hyperventilation may further reduce CBF and reduce brain oxygenation (4).

Impaired pressure autoregulation may contribute to the risk of posttraumatic cerebral ischemia. In one-third of patients after TBI, CBF passively changed as cerebral perfusion pressure (CPP) changed (5). In experimental animals after TBI, CBF was poorly maintained in response to hemorrhagic hypotension (6) but was increased by infusion of phenylephrine (7). In general, cerebral circulatory management after TBI emphasizes control of intracranial hypertension, maintenance of adequate CPP (usually considered to be >60 mm Hg), and preservation of CBF.

Preanesthetic Stabilization and Assessment

During initial stabilization of head-injured patients and transport to and from brain imaging studies and to the operating room, minimal time may be available

Table 1. Influence of Early (Admission) or Late (Intensive Care Unit) Hypotension on Outcome After Severe TBI

	Hypotension (n)	Outcome (%)	
		GR or MD	SD, PVS, or Death
None	307	64	36
Early	30	40	60
Late	117	20	80
Early and late	39	15	85

GR = good recovery; MD = moderate disability; SD = severe disability; PVS = persistent vegetative state. From (2).

for resuscitation and preanesthetic assessment. Recognition of associated injuries and hypotension strongly influence planning and resuscitation. The Glasgow Coma Scale (GCS) score provides important prognostic information. In patients with severe TBI, defined as a GCS score ≤8, overall mortality among severely injured patients has averaged approximately 33% (8).

Emergent Airway Control

The intubation sequence for head-injured patients should preserve systemic oxygenation and CO_2 elimination, prevent aspiration of gastric contents, maintain systemic blood pressure, minimize increases in ICP, and avoid aggravation of cervical spine injury. Orotracheal intubation of hemodynamically stable anesthetized patients is most likely to provide such conditions if no anatomic airway abnormalities are present. Because cervical spine injury accompanies TBI in as many as 10% of severely head-injured patients, manual inline axial stabilization is advisable during laryngoscopy. Clinical series demonstrate satisfactory results with this approach (9). Blind nasal intubation provides a method for securing the airway without giving drugs but carries a small risk of intracranial placement for patients with maxillary or basilar skull fractures (10).

During intubation, cardiopulmonary stability should not be compromised in an effort to reduce CBF, cerebral blood volume (CBV), the cerebral metabolic rate for oxygen ($CMRO_2$), or ICP. Pharmacologically mediated improvements in cerebral hemodynamics may be antagonized by hypotension or by coughing, straining, hypercarbia, or hypoxemia. Both thiopental and etomidate dose-dependently reduce $CMRO_2$, CBF, and ICP, but etomidate is less likely to precipitate hypotension in hypovolemic patients. The usual induction dose of either agent should be reduced if hypovolemia is suspected. Supplementation with lidocaine IV will blunt sympathetic responses to intubation and limit associated increases in ICP. Midazolam decreases CBF, does not increase ICP, and provides satisfactory hemodynamic stability when given in small doses but may cause rigidity when used without neuromuscular blockers. Propofol reduces ICP and CBF in head-injured humans (11). However, propofol-induced hypotension may be poorly tolerated, especially in hypovolemic patients. Muscle relaxants should be chosen primarily to facilitate rapid, effective laryngeal exposure. After acute TBI, succinylcholine is appropriate despite its association with small, transient increases in ICP.

Fluid Resuscitation

Prompt restoration of systolic blood pressure and mean arterial pressure (MAP) is essential. Although restoring circulating blood volume is the mainstay of treatment, temporary use of vasopressors will improve CPP (CPP = MAP − ICP). No resuscitation fluid has proven ideal for hypotensive, head-injured patients (12). Because the intact blood-brain barrier enhances the influence on brain water of changes in serum sodium, hypotonic solutions (including lactated Ringer's solution) are more likely to increase brain water content than 0.9% saline or colloids dissolved in 0.9% saline. However, after experimental TBI, Drummond et al. (13) demonstrated that infusion of colloid solutions was associated with lower brain water accumulation than infusion of crystalloid solutions.

In experimental animals, resuscitation with hypertonic 3.0% to 7.5% saline solutions is associated with lower ICP than resuscitation with isotonic or slightly hypotonic fluids (14). Prehospital resuscitation of hypotensive head-injured patients with 7.5% saline, with or without added dextran, was associated with improved outcome when compared with conventional fluid resuscitation (Table 2) (15).

Intraoperative Management

After severe TBI, systemic monitors, including electrocardiography, arterial catheterization, pulse oximetry, bladder catheterization, and capnography should be used routinely. Pulmonary arterial catheterization may address uncertainty regarding the adequacy of intravascular volume or cardiac performance. Conventional admonitions to restrict fluids in head-injured patients appear to be archaic, unsupported by experimental or clinical evidence. Aggressive hemodynamic support, including large volumes of fluid, appears not to worsen neurologic injury (16). Studies of trauma patients in whom systemic oxygen delivery was therapeutically enhanced have yielded conflicting results: apparent improvement in one study (17) but no improvement in another (18). Early nonneurologic surgery such as fixation of unstable orthopedic injuries appears not to worsen the outcome of multiply traumatized patients with TBI (19).

Table 2. Predicted Versus Actual Survival in Patients with Glasgow Coma Scale Scores <8

	LRS	HS	HS, 6% D	HS, 12% D
GCS < 8 (n)	25	29	26	30
% predicted	14	13	16	14
% actual	12	34	27	30

LRS = lactated Ringer's solution; HS = hypertonic (7.5%) saline; D = dextran; GCS = Glasgow Coma Scale score.

In head-injured patients undergoing nonneurosurgical procedures, ICP monitoring may permit more precise anesthetic management. Several guidelines and recommendations have been developed regarding ICP monitoring in TBI patients (1). These include the following: 1) ICP monitoring is indicated in patients with severe TBI (GCS ≤8) and abnormal CT scans; 2) monitoring is indicated in patients with severe TBI and normal CT scans if they exceed 40 yr of age or have had a systolic blood pressure <90 mm Hg; 3) ICP monitoring is not indicated in mild or moderate TBI although physician judgment may occasionally prompt monitoring; and 4) the most accurate, cost-effective and reliable method of ICP monitoring consists of a ventricular catheter and an external strain gauge.

Jugular venous bulb catheterization samples "mixed" cerebral venous blood that may reflect cerebral ischemia. During intensive care after TBI, even one episode of jugular venous desaturation was associated with worse neurologic outcome (20). Direct monitoring of brain tissue Po_2 provides evidence of ischemia that also correlates with neurologic outcome and promptly reflects changes in CPP and $Paco_2$ (21). Unfortunately, either jugular venous saturation or brain tissue Po_2 monitoring is only approximately 50% sensitive in detecting episodes of cerebral ischemia detected by the other monitor (22). As an option, brain oxygenation monitoring may help to identify cerebral ischemia if hyperventilation ($Paco_2$ <30 torr) is considered to be necessary (1).

Acute intracranial hypertension demands immediate pharmacologic or surgical management. Acute hyperventilation remains the most rapidly effective, if temporary, means of reducing life-threatening intracranial hypertension. Although hyperventilation has been used in the past as prophylaxis against increased ICP as well as for acute reduction of severe intracranial hypertension, the associated reduction in CBF may be harmful. A recommended standard is that prophylactic hyperventilation should be avoided, especially in the first 24 h after TBI (1). Diuretics such as mannitol or furosemide (or a combination of the two) may be required to acutely reduce ICP.

Agents used for maintenance of anesthesia variably influence CBF, CBV, $CMRO_2$, pressure autoregulation, and responsiveness to $Paco_2$. Anesthesia is commonly maintained with various combinations of barbiturates, benzodiazepines, narcotics, N_2O, and sub-MAC concentrations of volatile anesthetics. Barbiturates, benzodiazepines, narcotics, and hypocapnia appear to limit N_2O-induced increases in CBF and ICP. N_2O should be avoided in the presence of pneumocephalus or pneumothorax. Fentanyl appears to be well tolerated. Both sufentanil and alfentanil may increase ICP in humans (23,24). Low (<0.5 MAC) concentrations of a volatile agent, such as isoflurane or sevoflurane, may be used to supplement narcotics and benzodiazepines.

Important adjuvant drugs include nondepolarizing muscle relaxants and those that diminish hypertension and tachycardia (e.g., β-blockers, lidocaine). Neuromuscular blockade alone does not reduce CBF or ICP. Ideally, a neuromuscular blocker used in head-injured patients should not reduce blood pressure or increase CBF and ICP. Administration of vecuronium or rocuronium produces few side effects.

Because hypoxemia increases CBF, Pao_2 should at least be maintained >60 mm Hg. An ideal target Pao_2 has not been identified. Because an increase in Pao_2 from a range of 100–150 mm Hg to 200–250 mm Hg improved cerebral venous oxygenation in patients after TBI, (4) mild hyperoxia could improve cerebral oxygenation during correction of systemic hypotension, intracranial hypertension, or therapeutic hyperventilation. In patients with respiratory compromise, necessary mechanical ventilatory interventions should be used without undue concern for intracranial hemodynamics.

Treatment of systemic hypertension with nitroprusside, hydralazine, or nitroglycerin may induce unacceptable cerebral vasodilation in patients who have decreased intracranial compliance. Barbiturates, narcotics, or benzodiazepines may reduce MAP with less risk. Labetalol, a combined α- and β-blocker, will reduce both MAP and ICP. Emergent management of hypotension may require short-term infusion of vasoconstrictors to maintain CPP until hypovolemia can be corrected. Once the dura is opened, ICP abruptly declines to zero; hypertension at that time should be controlled promptly because a sudden increase in CPP may abruptly increase CBF.

After emergency brain surgery, most patients are neither awakened nor extubated unless preoperative consciousness had been normal (e.g., surgical elevation of a depressed skull fracture) or if preoperative consciousness had rapidly declined (e.g., because of an expanding intracranial hematoma). Therefore, as inhalational agents are discontinued, many clinicians administer additional narcotics, benzodiazepines, neuromuscular blockers, or antihypertensives. Profound paralysis reduces changes in ICP associated with stimulation during transfer from the surgical suite to the intensive care unit (ICU). Blood pressure monitoring, pulse oximetry, and capnometry are continued during transport. If equipment is available,

continuation of ICP monitoring or brain oxygenation during transport also is desirable.

Intraoperative Brain Protection

Many pharmacologic and physiologic approaches have been used to preserve traumatized brain tissue. Routine use of barbiturates, glucocorticoids, calcium entry blockers, free radical scavengers, glutamate antagonists, and hyperventilation has been ineffective in clinical trials (25–31). As a standard, glucocorticoids are not recommended in patients with TBI (1). However, high-dose pentobarbital improved ICP control when added to conventional therapy in patients with refractory intracranial hypertension (32) and was associated with substantial reductions in brain extracellular lactate and the excitotoxic amino acids glutamate and aspartate (33). As a guideline, barbiturates may be considered in refractory intracranial hypertension (1).

Passive or active cooling will reduce $CMRO_2$ and lower ICP. Although phase II clinical trials suggested that mild hypothermia (approximately 34°C) during intensive care improved outcome after severe TBI, (34,35) a subsequent multicenter trial failed to identify any benefit (Table 3) (36). Because rewarming of spontaneously hypothermic TBI patients has been associated with worse outcome, special care should be taken to slowly rewarm head-injured patients (36). At this time, intraoperative hypothermia cannot be recommended in head-injured patients. However, hyperthermia should be scrupulously recognized and treated because of experimental evidence that small elevations in temperature increase release of excitotoxic amino acids during ischemic episodes.

One of the most theoretically appealing strategies for improving outcome after TBI is to maintain CPP above a target level with the hope that better CBF will be assured. Rosner et al. (37) reported an uncontrolled trial in which a central strategy of maintaining CPP >70 mm Hg was associated with excellent overall outcomes. Although increasing MAP theoretically could increase ICP, therapeutically increasing MAP using vasopressors is associated in the majority of patients with either no change or a reduction in ICP (38). Robertson et al. (39) compared a CBF-targeted strategy of maintaining CPP >70 mm Hg with an ICP-targeted strategy and found no difference in outcome (Table 4). However, jugular venous saturation was monitored in both groups, and desaturation to <50% was aggressively treated. Of particular note is the observation that the incidence of jugular venous desaturation was nearly twice as high (50.6% vs 30%) in the ICP-targeted group. One possible implication of this study is that monitoring cerebral oxygenation and intervening in episodes of desaturation or hypoxia are more effective in preventing secondary ischemic injury than correcting systemic variables (e.g., hypotension) that are associated with cerebral ischemia but are not equivalent.

Table 3. Poor Outcome* and Death 6 Months After Severe Traumatic Brain Injury

	Hypothermia	Normothermia
Total number of patients (n)	190	178
Six-month scores		
SD/PVS	55 (29%)	54 (30%)
Dead	53 (28%)	48 (27%)

SD = severe disability; PVS = persistent vegetative state. *Poor outcome defined as SD, PVS, or death, adjusted for age and admission Glasgow Coma Scale score. From (36).

Table 4. Glasgow Outcome Scores with CBF- and ICP-Targeted Strategies

	All Patients		
	CBF-Targeted (%)	ICP-Targeted (%)	*P* value
3-mo. scores			.554
GR/MD	29 (31.9)	30 (37.0)	
SD	28 (30.8)	27 (33.3)	
PVS/Dead	34 (37.4)	24 (29.6)	
6-mo. scores			.491
GR/MD	33 (39.8)	35 (49.3)	
SD	20 (24.1)	14 (19.7)	
PVS/Dead	30 (36.1)	22 (31.0)	

GR = good recovery; MD = moderate disability; SD = severe disability; PVS = persistent vegetative state. From (39).

Transfer of Patients to the Intensive Care Unit

During transfer of the head-injured patient from the operating room to the ICU, ventilation, oxygenation, and CPP must be carefully maintained. During this interval, continuous blood pressure monitoring, capnography, and pulse oximetry may be useful. If possible, ICP and cerebral circulatory monitoring should be continued during transport to the ICU. If emergence from anesthesia results in an increase in blood pressure and ICP, additional sedatives, narcotics, or labetalol may be required. Alveolar ventilation must be carefully supported and monitored during the transition from mechanical to manual ventilation (or to a transport ventilator) and finally to a second mechanical ventilator in the ICU.

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