Concussions affect the normal functioning of the autonomic nervous system and glucose metabolism, impair cerebral autoregulation to $\text{Pa}_2$, and produce abnormal variances in myogenic and vagal tone. Because anesthesia also has an impact on these same processes, it is vital to delineate the best practice in the perianesthesia period to minimize additional damage to the concussed brain. There are currently no practice guidelines surrounding perianesthesia management of patients with concussion to guide practice. To answer 4 clinically pertinent questions for nurse anesthesia practice, the authors completed a literature review. Articles obtained from the search that were identified as randomized controlled trials, systematic reviews, or integrative reviews were evaluated for relevance to clinical practice. Many of the literature recommendations emphasize the prevention of secondary neurologic injury. Optimal outcomes are believed to best align with careful attention to mean arterial pressures and $\text{Pa}_2$ to prevent global hypoperfusion. The impact of particular anesthetic agents on concussion injuries is unknown. Major advances in neuroimaging, biomarker identification, and technology have occurred. However, further research is needed to identify evidence-based interventions for managing patients after concussion requiring anesthesia.

Keywords: Concussion, mild traumatic brain injury, neurometabolic cascade, secondary neurologic injury.
Identifying At-Risk Patients.

Concussion

“*A concussion is a type of traumatic brain injury—or TBI—caused by a bump, blow, or jolt to the head or by a hit to the body that causes the head and brain to move rapidly back and forth.**”

“*Traumatic brain injury (TBI), a form of acquired brain injury, occurs when a sudden trauma causes damage to the brain. TBI can result when the head suddenly and violently hits an object, or when an object pierces the skull and enters brain tissue. Symptoms of a TBI can be mild, moderate, or severe, depending on the extent of the damage to the brain. A person with a mild TBI may remain conscious or may experience a loss of consciousness for a few seconds or minutes. Other symptoms of mild TBI include headache, confusion, lightheadedness, dizziness, blurred vision or tired eyes, ringing in the ears, bad taste in the mouth, fatigue or lethargy, a change in sleep patterns, behavioral or mood changes, and trouble with memory, concentration, attention, or thinking. A person with a moderate or severe TBI may show these same symptoms but may also have a headache that gets worse or does not go away, repeated vomiting or nausea, convulsions or seizures, an inability to awaken from sleep, dilation of one or both pupils of the eyes, slurred speech, weakness or numbness in the extremities, loss of coordination, and increased confusion, restlessness, or agitation.”

**Mild TBI**

“A patient with mild traumatic brain injury is a person who has had a traumatically induced physiological disruption of brain function, as manifested by at least one of the following: 1. any period of loss of consciousness; 2. any loss of memory for events immediately before or after the accident; 3. any alteration in mental state at the time of the accident (e.g., feeling dazed, disoriented, or confused); and 4. focal neurological deficit(s) that may or may not be transient; but where the severity of the injury does not exceed the following: • loss of consciousness of approximately 30 minutes or less; • after 30 minutes, an initial Glasgow Coma Scale (GCS) of 13-15; and • posttraumatic amnesia (PTA) not greater than 24 hours.”

**Table 1. Definitions Related to Concussion**

<table>
<thead>
<tr>
<th>Source</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centers for Disease Control and Prevention</td>
<td>Uses the same definition for both traumatic brain injury (TBI) and concussion</td>
</tr>
<tr>
<td>National Institutes of Health</td>
<td>Uses this definition for TBI, which can also be descriptive of concussion</td>
</tr>
<tr>
<td>American Congress of Rehabilitation Medicine</td>
<td>Uses this definition to distinguish severity of TBI that could also be descriptive of concussion</td>
</tr>
<tr>
<td>Concussion</td>
<td>“A concussion is a type of traumatic brain injury—or TBI—caused by a bump, blow, or jolt to the head or by a hit to the body that causes the head and brain to move rapidly back and forth.”</td>
</tr>
<tr>
<td>Mild TBI</td>
<td>“A patient with mild traumatic brain injury is a person who has had a traumatically induced physiological disruption of brain function, as manifested by at least one of the following: 1. any period of loss of consciousness; 2. any loss of memory for events immediately before or after the accident; 3. any alteration in mental state at the time of the accident (e.g., feeling dazed, disoriented, or confused); and 4. focal neurological deficit(s) that may or may not be transient; but where the severity of the injury does not exceed the following: • loss of consciousness of approximately 30 minutes or less; • after 30 minutes, an initial Glasgow Coma Scale (GCS) of 13-15; and • posttraumatic amnesia (PTA) not greater than 24 hours.”</td>
</tr>
</tbody>
</table>

PubMed, and the results are detailed in Table 2. After these articles were sorted, it was determined that searching brain injuries AND anesthesia or concussion AND anesthesia yielded results most relevant to the topic. A detailed flow diagram depicts the results of this search, as well as the article selection process, in Figure 1. References were limited to full-text English articles written within the last 5 years and key articles published before 2012. Reference lists of selected articles were screened for additional studies of interest. The CDC database was also searched. An evidence grid was used to categorize study designs, data, settings, variables, instruments, interventions, comparisons, results, levels of evidence, implications, and limitations.

**Results**

**Identifying At-Risk Patients.** Concussions affect Americans of all ages. Children 0 to 4 years old, adolescents and young adults 15 to 19 years, and adults older than 75 years are the most likely age groups to visit the ED with traumatic brain injury.9 Those older than 75 years have the highest rates of related hospitalizations and deaths.9 The rate of concussions is highest in males.10 The leading cause of nonfatal TBI is falls (35%), followed by motor vehicle crashes (17%) and objects striking the head (17%).9

Abcejo et al10 were the first to publish a study describing the use of anesthesia for postconcussion patients in the most relevant literature. This retrospective cohort study illustrated characteristics of 1,038 concussed patients within 1 year of diagnosis, who underwent 1,820 diagnostic and surgical procedures at the Mayo Clinic requiring anesthesia. A reflective review of medical charts revealed that 67% of concussions were diagnosed on the day of injury. This represents delayed diagnosis for one-third of all patients. This is important because most patients included in the study underwent anesthesia within 1 week of diagnosis. Males represented 59% of all patients. The mean age (SD) was 39 (23) years. These demographic characteristics are similar to a study by Algarra et al,11 in which most patients were male (68%) and the median age was 41 years. In the Mayo Clinic study, most concussions were related to motor vehicle crashes. These patients required the highest number of procedures in which anesthesia was used. The most common type of procedures requiring anesthesia were orthopedic and general surgery (57%).10 The authors noted that these procedures occurred during a critical period, in which “the brain may be most vulnerable to secondary injury.”10 Neurologic outcome was not measured, however.10

Yue et al12 described patients presenting with mTBI and sport-related concussions throughout the United States in a retrospective cohort study. Of 3,046 pediatric patients identified in the National Trauma Data Bank from 2003 to 2012, falls or interpersonal contact were found to be the most common mechanism of brain injury (47.4%). Mean hospital stay (SD) was 2.68 (0.07) days.
but was prolonged for moderate and severe head injuries, as well as injuries related to roller sports. The rate of medical morbidity was 2.1%, the most common complication being pneumonia. Although the mortality rate was 0.8%, it can be presumed to be much higher globally. This study only encompassed Level I and II Trauma Centers. Many mTBIs are not reported or are treated at smaller facilities.\textsuperscript{12} Anesthesia providers are commonly unaware of an underlying concussion in the preoperative period. This may be due to lack of awareness, lack of diagnosis, or delay in patients seeking care for persistent symptoms.

In the United States, sport-related concussions occur in an estimated 1.6 to 3.8 million people annually\textsuperscript{7}, accounting for 20% of all mTBIs.\textsuperscript{1,13} Many tools, such as the Sport Concussion Assessment Tool (SCAT), have been devised to assess injury on the sidelines. The utility of such tools decreases after the immediate injury subsides, however.\textsuperscript{13} Balance and cognitive deficits are customary in the first 24 to 72 hours, although they typically improve in the first 1 to 2 weeks. Most athletes return to the field of play within 10 days, but this interval has increased over the past 10 years. Severity of initial symptoms directly correlates with duration of recovery. Preexisting conditions such as mental health problems or migraines are predictors of persistent concussion symptoms.\textsuperscript{13} A definitive timeline for recovery cannot be made based on the current state of the literature and our realm of our medical knowledge. For now, this must be evaluated on an individual basis.\textsuperscript{1} Concerning for the nurse anesthetist should be a patient who presents with persistent (> 10-14 days in adults and > 4 weeks in children) and/or severe symptoms because this represents the most obvious delay in healing.\textsuperscript{13}

- **Confirming Concussion Diagnosis.** Concussion diagnosis is often elusive because symptoms are underreported and data are typically vague or subjective. In the realm of sports, athletes may not immediately report symptoms. Athletic trainers or healthcare personnel may not be readily available. Even if present, these providers rely on a variety of tools that have not been scientifically validated, plus there is lack of standardization in diagnosis. In tertiary care centers, providers continue to rely on computed tomography and magnetic resonance imaging (MRI) despite virtually no diagnostic value in cases of mTBI, or concussion.\textsuperscript{7} Because the neurometabolic cascade\textsuperscript{2} of concussion is dynamic, diagnostics should also be dynamic. Successful standardization of concussion diagnosis lies in the development of technology and laboratory testing that compliments astute clinician evaluation and assessment.

More advanced and meaningful scientific improvements have been made in otherwise routine neuroimaging technology. Assessment of neurologic function after concussion has evolved with functional MRI, carbon dioxide (CO\textsubscript{2}) stress testing, and blood oxygen level-dependent MRI.\textsuperscript{14} Use of the blood oxygen level-dependent MRI allows for observation of cerebral blood flow patterns, glucose metabolism, and energy expenditure, as well as other neuronal activity in real time.\textsuperscript{13} Innovations such as these may be useful preoperatively to screen patients and assess vulnerability. Concerns are cost, availability, and the time it takes to complete these tests. An inexpensive, efficient, and validated tool for measuring

### Table 2. PubMed Search Results

<table>
<thead>
<tr>
<th>Search terms</th>
<th>References</th>
<th>Reviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>brain injuries</td>
<td>81,500</td>
<td>11,071</td>
</tr>
<tr>
<td>brain injuries AND anesthesia</td>
<td>1,760</td>
<td>288</td>
</tr>
<tr>
<td>brain injuries AND general surgery</td>
<td>976</td>
<td>127</td>
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<tr>
<td>brain injuries AND anesthesia AND general surgery</td>
<td>163</td>
<td>22</td>
</tr>
<tr>
<td>concussion AND anesthesia</td>
<td>79</td>
<td>10</td>
</tr>
</tbody>
</table>

**Figure 1. Flow Diagram of Search Strategy and Study Selection**

Abbreviation: CDC, Centers for Disease Control and Prevention.

(Graphic design by Roger Yoder)
Autonomic function is essential to understanding this disease state. One has yet to be developed.

In a case-control pilot study by Mutch et al., brain MRI was used to study responsiveness of cerebral vasculature to CO₂ partial pressure (PaCO₂) changes. It is well known that cerebral blood flow is strongly dependent on and responsive to changes in PaCO₂. Demographics, medical history, and additional pertinent details were obtained for 5 control subjects, 8 symptomatically concussed patients, and 4 patients with a history of concussion but no symptoms. Cerebrovascular responses to periods of hypercapnia and hypocapnia were measured under MRI as reactive voxel counts. Patients with concussions demonstrated a quantifiably abnormal cerebrovascular response. This should concern anesthesia providers who routinely modify ventilatory patterns and alter blood pressure based on known physiologic mechanisms, with the goal being optimal cerebral perfusion. The findings by Mutch et al demonstrates deviance from routine physiology in concussed patients. Furthermore, it establishes the need for a neuroimaging tool for measuring autonomic function in concussed patients. Anesthesia providers should anticipate altered hemodynamics due to disturbances in ANS integrity, as well as impaired or delayed physiologic responses to surgical stressors in concussed patients. This may be observed as alterations in heart rate, pulse pressure variation in arterial line waveforms, and pupillometry among others.

• Cellular Pathophysiology. Although concussed patients may exhibit obvious external symptoms such as dizziness, memory problems, confusion, ataxia, and headaches, much of what occurs after a concussion is still being discovered on a microscopic level. Results of studies have clearly demonstrated that concussion precedes cellular changes in the nervous system. This includes damage to cell membranes in which ions essential for depolarization (sodium, potassium, and calcium) passively diffuse in unconventional directions. Thus, routine cellular communication and activity is interrupted. In an attempt to restore cell integrity, increased energy demand is seen in altered cerebral blood flow, leading to altered delivery. In animal studies, glucose metabolism after brain injury was found to be impaired for 7 to 10 days in adults and 3 days in younger subjects. Damage to critical axons has also been well documented and includes "mechanoporation, stretching and beading of individual axons, disruption of axonal transport and axonal blebbing, as well as disconnection." Some of these changes are temporary, whereas others are more permanent. Correlations between cellular disruption and overt physical symptoms are only beginning to be made. As documented by Giza and Hovda, it is uncertain how long it might take for damaged neurons to heal effectively. Early studies suggest that younger, myelinated cells seem to be more
Practitioner recommendations

Consider delay of elective surgery/procedures requiring anesthesia until concussive symptoms resolve. If surgery/procedures cannot be delayed due to emergent nature, the following goals should be considered:

- Systolic blood pressure > 90 mm Hg
- Intracranial pressure < 20 mm Hg
- Cerebral perfusion pressure > 50 mm Hg
- PaCO₂ 30-40 mm Hg in absence of intracranial hypertension
- Avoid hyperthermia (> 38°C)
- Avoid hyperglycemia (> 200 mg/dL)

Table 3. Recommendations to Prevent Secondary Insults in Patients With Concussion

<table>
<thead>
<tr>
<th>Numeric parameters adapted from Algarra et al.11</th>
</tr>
</thead>
</table>

- Cerebral perfusion pressure > 50 mm Hg
- Intracranial pressure < 20 mm Hg
- Systolic blood pressure > 90 mm Hg
- Paco₂ 30-40 mm Hg in absence of intracranial hypertension
- Avoid hyperthermia (> 38°C)
- Avoid hyperglycemia (> 200 mg/dL)

- Monitoring Response to Anesthesia Interventions.

According to Giza and Hovda,2 there are fluxes in cerebral ions and altered cerebral blood flow for an indeterminate period after a concussion. These researchers have also noted disruption in key receptors, such as γ-aminobutyric acid (GABA), N-methyl-D-aspartate (NMDA), and N-acetylaspartate subunits.2 These receptors play key roles in excitatory and inhibitory neurotransmission, as well as transmission of pain signals. Alterations in GABA after TBI have been linked to the development of anxiety disorders.24 The NMDA receptor is a well-known target for anesthetic drugs, such as ketamine. The clinical significance of reduced N-acetylaspartate levels after concussion is not yet understood.2

The primary inciting event of a concussion places the brain in a vulnerable state. Beyond the cellular level, secondary brain injuries may occur during the perioperative period and should be prevented at all costs. Algarra et al11 conducted a retrospective cohort study at Harborview Medical Center in Seattle, Washington, examining 78 adult patients who underwent orthopedic surgery within 2 weeks of TBI. Inciting events for secondary brain injury included intraoperative hypotension (systolic blood pressure < 90 mm Hg, cerebral perfusion pressure < 50 mm Hg), intracranial hypertension (> 20 mm Hg), abnormally capnography results, hyperthermia, and abnormal glucose values. The placement of invasive intracranial and arterial pressure monitors, allowing for continuous readings and immediate laboratory draws, was of tremendous benefit. Abnormal values, specifically systemic hypotension, were found to be common during surgery. This led to degraded postoperative neuroimaging results, diminished Glasgow Coma Scale scores, and the need to extend and advance patient care.11 In brain-injured patients, hypotension at presentation to the ED is detrimental to successful hospital discharge. Hypotension can be devastating for brain-injured patients.12

Surgery insults the human body such that anesthesia becomes necessary to mediate its discomforts. Anesthesia involves disruption of neurologic activity. Discovering how this disruption might be harmful and/or beneficial after concussion is of paramount importance. Currently, anesthetic interventions for concussed patients should be based entirely on evidence-based data (Table 3). Hypotension (systolic blood pressure < 90 mm Hg), hyperglycemia (blood glucose level > 200 mg/dL), and hypocarbia, commonly encountered in the perioperative setting, are known mechanisms for secondary neurologic insult and should be prevented.11 Additionally, surgery, pain, and general anesthesia all affect ANS responses. These have variable effects on cerebral vascular resistance and CO₂ levels. Preliminarily, research suggests impairment of the vascular myogenic mechanism as well as vagus nerve activity within 3 days of a concussion.17,22

The ANS may be impaired within 7 days.31,22 Anesthesia providers should anticipate altered hemodynamic responses to stress and surgical stimulation within this period. The primary goal of anesthesia providers caring for these patients should be to maximize cerebral oxygen delivery while minimizing metabolic demand.

**Discussion**

- **Recommendations for Future Study.** Although researchers have observed that anesthesia for surgery and other procedures is quite common after concussion, large knowledge gaps exist in the preoperative diagnosis of concussion as well as determining how long to delay procedures in light of possible postoperative symptoms. Future studies should seek to establish guidelines for delaying or proceeding with elective surgical cases. For urgent or emergent cases in which delay is not possible, specific evidence-based guidelines should establish safety parameters and interventions that notably improve the chances for positive patient outcomes.

There are limiting factors in drawing correlations across existing studies. These include retrospective designs, possibly inaccurate medical documentation, lack of consistency in type of monitoring used, anesthetic type, and small sample size. The potential for subjective bias in making an actual concussion diagnosis exists, as well as deeming a surgical procedure elective, urgent, or emergent. Patients are often cleared for surgery at the provider’s discretion based on comfort level with a particular procedure.

Long-term neurologic outcomes are not often mea-
sured. Thus, strategies to minimize secondary injury during the surgical period have not been published for concussed patients. Providers need evidence-based guidelines to minimize the risk of secondary brain injury. For more definitive conclusions, future studies should be designed with specific measurement intervals included, in larger sample sizes. Neuroimaging technology methods should be validated. For screening purposes, accessibility to expensive equipment remains a barrier. For example, MRI may not be feasible for screening every patient in the perioperative period. Additionally, not every patient is an ideal candidate for MRI given the possibility of excessive patient movement, claustrophobia, presence of metallic implants, and so forth. A serum biomarker may be an alternative to neuroimaging and aid clinical decision making. Biomarkers associated with concussion can be found in the patient’s serum and are the result of neuronal changes as depicted in Figure 2.

• Update. During the time it took to draft this article, the Food and Drug Administration approved the use of the first biomarker for TBI: the Banyan brain biomarker (Brain Trauma Indicator, Banyan Biomarkers Inc). This release may assist clinicians in deciding whether surgery can be delayed because of confirmation of concussion injury. The blood proteins measured are ubiquitin C-terminal hydrolase (UCH-L1) and glial fibrillary acid protein (GFAP). This blood test is specific to the first 12 hours after an injury. A meta-analysis from Li et al concluded that UCH-L1 was a good predictor of TBI. The extent of clinical adoption and utility remains to be seen.

Conclusion

Every day, an estimated 6,849 people in the United States report to the ED because of an event associated with TBI and 153 people will die. A large number of patients sustaining concussion, a form of TBI, present in a situation of multisystem trauma and require anesthesia services. For example, many orthopedic surgeries are associated with traumatic injury. Despite increasing knowledge of patient risk, a relatively limited number of articles have been published regarding concussion in the perioperative period. A paucity of data exists to determine the safety or efficacy of receiving anesthesia after a concussion. Furthermore, there are no definitive practice guidelines regarding preoperative screening, neurologic testing, scheduling of elective procedures, and intraoperative or postoperative management of patients who have sustained a concussion.

Standardization of screening tools is essential to detect and confirm concussions and determine if further assessment is warranted before surgery. Specific concerns include persistence of symptoms as well as alterations in ANS function and cerebral blood flow contributing to global hypoperfusion and/or ischemia. In the future, these risk factors may be routinely detected in the perioperative period by blood biomarkers or alterations in cerebral blood flow and vascular reactivity with neurologic imaging. At a minimum, anesthesia providers should be able to identify populations at risk and conduct a thorough neurologic assessment before surgery.

A standard postconcussion recovery period has yet...
to be clearly defined. Cellular dysfunction may last long after physical symptoms resolve. Receiving anesthesia safely after a concussion has not yet been confirmed or denied in the literature. In light of this, consideration should be given to delaying elective surgical cases and procedures for an unspecified time. The literature reviewed in this article indicates that cellular function is impaired for at least 10 days after a concussion. If surgery cannot be delayed for at least that interval, as is the case with many patients with orthopedic trauma, anesthetic management should be focused on reducing the risk of secondary brain injury. Techniques for preventing secondary injury are summarized in Table 3.

With further scientific inquiry, anesthesia providers can better evaluate risk, determine susceptibility of patients, and alter anesthetic management to enhance postoperative outcomes. Prospective, randomized controlled trials represent the highest level of evidence; however, such trials cannot be ethically performed in humans requiring anesthesia after a concussion. Future well-designed studies are essential and should reveal patients at risk. In addition, laboratory, neuroimaging, and physical assessment tools should be researched, developed, and validated. Preoperative guidelines should also be developed to determine safe timing of the anesthetic as well as intraoperative guidelines detailing safe anesthetic management of concussed patients. Anesthesia researchers have a remarkable potential to positively affect the future for patients with concussion.

REFERENCES


AUTHORS

Daniel King, MNA, CRNA, is a staff nurse anesthetist at Steward Medical Center.
Group in Brockton, Massachusetts. Email: daniel.king@steward.org.

Angela Collins-Yoder, PhD, RN, CCNS, ACNS-BC, is a clinical professor at the Capstone College of Nursing at the University of Alabama, Tuscaloosa, Alabama. She is also a critical care nurse specialist at Sacred Heart in Pensacola, Florida. Email: acollins-yoder@ua.edu.

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