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Military and civilian penetrating eye trauma: Anesthetic implications

In 20th century warfare, wounds from fragmentation weapons have become the number 1 cause of military hospital admissions during combat. Specifically, grenades, landmines, mortars, and artillery weapons have replaced guns and bullets. Consequently, penetrating eye injuries and maxillofacial injuries in the military have escalated dramatically. In the civilian sector, pipe bombs, explosive bottles used in gang warfare, and terrorist bombs, which are all fragmentation weapons, have generated new studies in the care of patients with penetrating eye injury. This change in the wounding pattern is documented internationally in military-medical literature and in civilian-medical literature of relief agencies such as the International Committee of the Red Cross and the Red Crescent.

The anesthetic management of open eye injuries has been a running controversy for 40 years in terms of the use of muscle relaxants. Nondepolarizing agents carry the risk of aspiration and increased intraocular pressure when trauma patients are intubated prematurely during rapid-sequence induction for "full stomachs." Succinylcholine would be the logical relaxant of choice for a rapid-sequence induction, but succinylcholine raises intraocular pressure. In many cases, the literature specifically contraindicates succinylcholine in the open eye injury for fear of extruding the content of the eye.

A review of the vital assessment for the patient with a penetrating eye injury, as well as a comparative analysis of the literature, is presented. The conclusion favors pretreatment with a nondepolarizing agent and the use of succinylcholine during rapid-sequence induction. The eye injury itself is not the primary concern of this article. The primary concern is that open eye injuries serve as hallmarks for far more dangerous injuries. Penetrating open eye injuries merit extensive clinical assessment that can be life saving.

Key words: Anesthesia, eye injury, military, terrorist bombings, trauma.

Introduction

Open eye injuries in war have been occurring in ever-increasing numbers.[1] After serving in Pleiku, Vietnam, for the 71st Evacuation Hospital, a concerned ophthalmologist, Albert Hornblass, MD, compared eye injury rates in American and other military conflicts. He noted that during the American Civil War, eye injuries were 0.5% of all casualties, but in the Vietnam War, eye injuries occurred at a rate between 5% and 9%. During Desert Shield and Desert Storm (Kuwait), the rate climbed even higher, to 13%. The eye injury rate is expected to increase significantly in future military conflicts.[2]

The number of civilians injured by military conflict increased during the 20th century. The civilian injuries during war have reached 90% internationally of the total injuries per military conflict.[3] Fragmentation weapons are predominantly the cause of increased eye injuries in these conflicts.[4,5] Overseas, the number of civilian patients treated[1] during war by the US military field hospitals also has been on a dramatic rise since World War II.

Between 1980 and 1990 there were 12,216 incidents of bombing in the United States, most of them involving pipe bombs. Domestically in the United States, assault and violent crimes have escalated the number of penetrating eye injuries, as well as firearm-related deaths. In addition, motor vehicles crashes continue to account for a substantial portion of penetrating ocular trauma in the United States.

For the anesthetist, the management of open eye injury for trauma patients has been controversial for more than 40 years. There is also an inherent legal significance for patients with penetrating eye injury.[6] The literature contains about 20 articles favoring the use of succinylcholine and about 20 against its use.[7] More important, for a patient with an open eye injury, there are unique considerations that need to be made before ophthalmic surgery.

From the perspective of teaching trauma, the penetrating eye injury scenario portrays how to manage complex patients with serious "coincidental" problems.[8] This article addresses such problems and suggests evaluations to assist the anesthetist in the decision-making process before and during ophthalmic surgery. In the United States, one fourth of all preventable trauma death occurs in the operating room. In trauma centers, preventable deaths are related primarily to errors in judgment. In nontrauma hospitals, virtually all preventable deaths are the result of failure to understand the severity or multiplicity of the injuries.[9]

Open eye injuries: Neurologic considerations

By itself, penetrating eye injury serves as an indicator of severity of wounding. Penetrating cranial injuries that enter the brain through the eye are fatal twice as often as any other route. Fragments, which enter the brain through the eye, often end up in the inferior aspect of the frontal lobes or the anterior temporal lobes. Clinically, these are large "silent areas" that do not exhibit motor, respiratory, or cardiovascular symptoms.[10] This is the reason that the neurosurgeon can do a more radical initial debridement of a penetrating wound in the nondominant frontal and temporal areas.

When fragments are limited to the frontal lobes, symptoms of hematoma formation may be fewer and have a slower onset. Similarly, hematomas of the frontal lobes due to tumors are less common. This results in fewer signs and symptoms of intracranial hypertension. Even pathologists are impressed by the frequency of fatal head wounds that are not detected during trauma assessment.

Patients with a penetrating eye injury are a testament to the resiliency of the human body to trauma. These patients can be talking and responding to questions coherently on their arrival to the emergency department.[11] Their condition can begin to deteriorate in an impressive and life-threatening manner by the time they reach the operating room.[12]

In the Vietnam War, more than 15% of the patients with ocular injury had a foreign body inside the cranial vault and the brain. Consequently, neurosurgical consultation is necessary for penetrating eye injuries, just as neurosurgical consultation is necessary in extensive wounds of the face and neck. Thirty percent of the combat casualties with penetrating-fragment eye injury during the Vietnam War had a foreign body that weighed more than 100 mg. In contradistinction, bullet eye injuries are a rarity in the operating room, because these injuries are fatal more than 95% of the time.

The main reason fragments enter the brain easily through the eye is that the eye provides direct access to the cranial cavity without involving fractures of bone. The eye is directly connected to the optic canal. The orbital roof offers little resistance to objects. The superior orbital fissure is directly connected to the cranial cavity's frontal lobes.[13] The frontal bones and lobes incur more than 70% of the injuries to the head.[14] Patients who have a persisting decreased level of consciousness, unequal pupils, or lateralized extremity weakness, even if they can follow commands well, need a neurosurgical consultation.[12]

In comparison with other fragment wounds of the head, which have the protection of bone, penetrating-fragment eye wounds logically require a higher rate of neurosurgical consultation. During the war in Bosnia, in cases of frontoethmoid fracture adjacent to the eye with the protection of bone, craniotomy was necessary in almost 20% of the patients. It seems reasonable for patients with penetrating eye injuries due to fragments that a craniotomy would be necessary for more than 20% to 30%.

Fragment weapons disperse their spheres, flachettes, and pellets by an explosion. Because the eye contains 30 mL of aqueous humor, it is not a barrier to metal fragments. If they penetrate deeply into the brain, not only the ophthalmic artery is vulnerable, but also its supplying artery, the internal carotid. When intracranial hemorrhage is suspected because of a deteriorating level of consciousness, rapid intubation and hyperventilation have long been proven to be the best course of action in patients with head trauma.

In civilian trauma settings, ultrasonography and computed tomography scan have proven quite useful, whereas magnetic resonance imaging is contraindicated for metallic intraocular foreign bodies. Metallic foreign bodies exposed to magnetic resonance imaging become high-velocity intraocular projectiles, which ricochet around and cause catastrophic ocular effects.

In the military, consultation with a neurosurgeon, or even a physician, may be impossible. In the 1983 Beirut, Lebanon, bombing, all physicians and corpsmen died in the medical receiving station, which had been the target of the second explosion. In the main blast, head injury was the most common specific injury associated with death (71% of the immediate deaths). More important, 33% of the immediate survivors during the 1983 Beirut bombing had head injuries.[15] For patients who survive the blast, the trauma team must assess the level of consciousness and the face, neck, and eyes for penetrating injury, even before assessment for eardrum rupture, which is a standard for assessing the severity of the blast.

Associated multisystem injury

Patients with eye injuries also have major injuries of the trunk, extremities, back, and face in 50% of cases. Ocular injuries often accompany facial trauma. One of the largest studies of facial trauma in the Vietnam War found that almost 7% of patients with facial trauma required cricothyrotomy in the emergency receiving area. By the time they reached the operating room, almost 44% required intubation or tracheotomy for airway control or as part of their surgery. The percentage of tracheotomies, which were performed on an emergency basis, was not disclosed, but it was clear that some were solely for airway control. More recently, during intense military conflict, tracheotomy rates as high as 67% were noted for patients with facial wounds requiring surgery.[5]

Civilians exposed to fragmentation weapons usually do not wear protective gear, such as helmets and flak jackets. In this respect, they are at even greater risk than military personnel. Twenty-two percent of patients who were admitted to the hospital at the Tower of London bomb explosion had eye injuries. In fact, some studies show an increased severity of wounding to civilians compared with military personnel in terrorist bombings, whereas primary blast injuries traditionally have been considered more characteristic of military terrorist bomb casualties.[16] Civilian patients, in particular, need early airway control for this type of multisystem trauma. These patients will have a significantly improved outcome with early airway control. Now, the number 1 indication for cricothyrotomy in the civilian sector is maxillofacial trauma.

Proximal vascular injury

The anesthetist who receives a trauma patient for ophthalmic surgery must seriously suspect concomitant vascular head and neck injuries. On the trauma team, the anesthetist is often the person most sensitive to swelling in the neck, and just about as often, it is the anesthetist who is tasked to secure the airway. Vascular injury is the most common injury in penetrating neck trauma. The head and neck area of the body constitute only 12% of the body surface area, but the area receives a much higher incidence of wounds, including penetrating eye injuries, due to the fragmentation weapons.[15] In the area of the eye, hemorrhage can be profuse and life-threatening if a major artery or dural sinus is involved.[12]

This higher incidence of penetrating eye, face, and neck injuries is particularly apparent in civilian blast-related injuries where explosions are not anticipated. A comprehensive study of terrorist bombings in Northern Ireland and in the United Kingdom from 1972 to 1982 and found 66% of the fatally wounded had injuries to the face. This injury pattern was confirmed in larger studies of more than 3,000 terrorist bombings. Seventy-one percent of the people who died immediately had facial injury. Most important, 52% of the immediate survivors who later died had facial injuries.[15]

The proximity of the face and neck to the major vessels makes the possibility of serious vascular-associated injuries likely. Behind each eye is the ophthalmic artery, the first major offshoot of the internal carotid. In the civilian sector, vascular injuries of the face usually are confined to the facial and lingual arteries. Carotid artery injuries of the neck are not seen as frequently as in military trauma, but the problem is significant in terms of civilian shotgun and knife injury. In civilian trauma, the common carotid artery is injured with greatest frequency of all penetrating neck injuries, accounting for 72% of the total carotid artery injuries. The war literature traditionally indicates that the external and common carotid arteries are at substantial risk.

Modern penetrating eye trauma in war: Causes and alternatives

In contrast with the predominance of blunt injuries in civilian trauma, which is primarily due to motor vehicular trauma, penetrating injuries account for 85% to 95% of combat injuries. The eyes and face receive disproportionately high percentages of the penetrating injuries during war for several reasons. Modern weapons are designed to maim soldiers and inflict multiorgan damage.[4,5] In Kuwait, at the second-echelon medical facilities, fragment weapons were responsible for 63% of hospital admissions. Gunfire and bullets were the cause of only 20% of admissions. In the trauma casualties in Vietnam, more than 60% of multiorgan damage was due to artillery, rockets, mortar, and recoilless rifles (fragmentation-type weapons).

In terms of military hospital admissions, a major study during the Vietnam War of 25,000 patients showed that fragments were the cause for admission in 70% of cases. Bullets were the cause for only 15% of admissions. The wounds caused by fragment weapons require an astute clinical assessment. The ballistic properties of fragment munitions are difficult to calibrate and categorize, even when the fragments are shaped similarly.[17] By design, the fragment weapons, which affect the eyes in particular, are designed to injure the face.[14,18] Part of the tactics of delivering these types of wounds is to use up hospital resources and beds quickly.

In modern military conflicts, eye casualties exceed their expected rate of occurrence by 20 to 50 times, when based on the body surface area of the eyes. In Desert Shield and Desert Storm, the eye casualty rate exceeded by 48 times the expected eye injury rate by body surface area. There are 3 major causes for this trend: (l) weapons of war have increased in firepower and explosive thrust; (2) battlefields are now filling up with people, and the number of urban conflicts has increased;[19] and (3) in addition, the soldier's helmet has not been modernized to include a face shield or a flip-up-and-down visor. This military problem of bravado vs eye protection stems as far back as Phillip the Second (the father of Alexander the Great), who lost his right eye in battle because of the lack of proper eye shielding. Yet, in the civilian sector today, an enormous investment is being made for protective goggles for sports.[17]

There are 3 patterns of wounding due to landmine explosions. Two patterns involve above- or below-the-knee damage. The third pattern of injury pertains to soldiers "demining" a battlefield area and to civilians who inadvertently activate landmines while playing with them as toys and involves explosions around the face. Some mines are brightly colored and appear to have "wings" on them. In fact, they have wings on them when dispersed by airplanes, and children find them attractive. Penetrating eye injury is a frequent and dangerous surgical aspect of landmine explosions. This type of injury accounts for 8% to 10% of all landmine injuries.

Anesthetic management

For the anesthetist, the initial patient assessment may be in the emergency department. In this situation, the first 5 steps in the Table can be helpful. Once a patient with an open eye injury enters the operating room, 3 basic principles are important to the induction of anesthesia: (1) careful management of the "full stomach," including preoxygenation, the use of the head-up position, and cricoid pressure; (2) avoidance of external pressure on the globe by the mask or ophthalmic instruments; and (3) minimizing any potential cause of increased venous pressure or intraocular pressure (IOP), such as vomiting, straining, or coughing due to early intubation.[20] Even crying or squeezing the eyelids closed before induction are to be avoided.

Some authors favor the "head-up" position for induction in the adult patient. Increasing venous return reduces IOP. If the head in a low position, it promotes venous congestion and increases IOP. Keeping low venous pressure in the patient with an open eye injury is even more important to control of IOP than keeping the arterial pressure on the low side.

The muscle relaxant controversy

During induction of anesthesia, if standard rapid-sequence induction with succinylcholine is selected, the anesthetist must weigh the value of rapid-sequence induction against exuding the contents of the eye. Some military and civilian anesthetic literature contraindicates the use of succinylcholine in this situation. Yet recent studies indicate that the prudent approach is to proceed with rapid-sequence induction, using a nondepolarizing agent to pretreat and to prevent tonic contraction of the extraocular muscles, which can be caused by succinylcholine.

At the crux of the controversy is the ultimate consequence of aspiration pneumonitis. The decision to use succinylcholine in a rapid-sequence induction for the trauma patient with a full stomach is favored because the consequences of aspiration pneumonitis are far more lethal than the potential of worsening the eye injury. In addition to using decision analysis to support this view, Bourke[21] studied the opinions of ophthalmologists who agreed that only a small percentage of patients with penetrating eye injuries could recover useful sight.

Bourke's[21] decision analysis supporting the use of succinylcholine would be particularly true in war, when the severity of the eye wound is expected to be more devastating than in civilian trauma. In Vietnam, the most common indication for a major eye operation was the presence of a disrupted globe (50%), which ended up requiring enucleation. If the anesthetist proceeds without a rapid-sequence induction and then finds the airway difficult to intubate, even cricoid pressure may not prevent silent aspiration. Aspiration of stomach contents can lead to pneumonitis and death.

Prolonged attempts to intubate due to inadequate relaxation or premature attempts to intubate before complete relaxation, can raise IOP dramatically. What happens to IOP during intubation? Intraocular pressure rises during intubation and it is the IOP that exudes the eye content. Which has a greater affect on IOP, succinylcholine or intubation? Consistently, the literature shows that when the precurarizing technique is used, it is intubation that substantially raises IOP, not the succinylcholine.[22] All intubations with nondepolarizing agents do not cause "bucking," but *early* intubation with a slower acting, nondepolarizing muscle relaxant can result in bucking on the endotracheal tube and can increase the IOP by 60 mm Hg. This is clearly the *detrimental* response, and it has spe-

Table. **Anesthetic considerations for managing the penetrating open eye injury**

1. Assess the level of consciousness. Could the foreign body be in the brain?
2. Ask what the causative agent might have been. High-velocity metal fragments are not stopped by aqueous humor.
3. Assess for collateral damage as you continue to develop rapport with the patient on the way to the operating room.
4. Request the patient not to squeeze the eye to close it.
5. Consult an ophthalmologist, a neurosurgeon, or a head and neck surgeon.
6. Prepare for intubation in the head-up position.
7. If general anesthesia is selected, proceed with preoxygenation, rapid-sequence induction and intubation, and cricoid pressure. Use the fastest drugs, thiopental and succinylcholine, with pretreatment of a nondepolarizer (soon there will be faster drugs).
8. Remember: gentle intubation is most important for maintaining low intraocular pressure.
9. Use lidocaine (1 mg/kg) and antiemetic of choice just before emergence.
10. Keep a high index of suspicion for associated multiple injuries for any patient who exhibits signs of cardiovascular instability under anesthesia.

cial importance in the military field hospital, where the dose of succinylcholine has been underestimated.[23] Yet, civilians using the same dosage criteria on a milligram per kilogram basis had safe results in terms of adequate relaxation for intubation.

What is the advantage of succinylcholine for the patient with an open eye injury? It produces a rapid and profound neuromuscular blockade, which attenuates the most substantial rise in IOP—during intubation. Another disadvantage of the current nondepolarizing agents is that they do not allow for rapid return of spontaneous breathing, which can be invaluable if the situation turns out to be an unrecognized difficult intubation.

Murphy[24] concluded that the effect of laryngoscopy and endotracheal intubation on IOP is so great that, by comparison, the effect of succinylcholine is inconsequential. Normal IOP is 10 to 20 mm Hg. After the administration of succinylcholine, IOP increases 6 to 8 mm Hg in 1 to 4 minutes. The IOP then returns to the control level by 5 to 7 minutes.

The classical case — Against the use of the depolarizing agent

Historically, the controversy began when succinylcholine's reputation in open eye surgery was questioned in 1955. The expulsion of vitreous contents was reported when succinylcholine was used to "forestall impending vitreous prolapse."[25] During this episode, no *d*-tubocurarine had been given as pretreatment. The situation was very different than a controlled rapid-sequence induction. In the controlled rapid-sequence induction, the eye has been open to air, ie, no elevated IOP, and, just as important, there is no manipulation by the surgeon as there had been in the case of impending vitreous prolapse.

The logical outcome should have been to recommend that "succinylcholine alone" is contraindicated for use in patients with open eye injuries. In the 1950s, the case of impending vitreous prolapse was reported, when the use of succinylcholine (without a preceding nondepolarizing agent) was much more popular than it is today.

In 1985, Libonati and associates[26] found, by retrospective analysis, not even a single case of extrusion of intraocular contents in 63 patients who underwent a general anesthetic for open eye procedures using succinylcholine preceded by *d*-tubocurarine 3 to 3.5 minutes before induction. In most of these patients, an 8-hour fasting period was possible. There were also 17 patients who were considered to have full stomachs. In terms of nothing-by-mouth (NPO) status, they were just like combat casualties. Even when succinylcholine was used in these patients, no untoward rise in IOP was reported by the observing ophthalmologists. In 1986, a retrospective analysis of 2,500 patients who underwent open eye surgery and received succinylcholine with a pretreatment of nondepolarizing muscle relaxant also documented no reported untoward effects.[27]

Moreno et al[28] demonstrated that IOP in cats rises 10 to 15 mm Hg after nondepolarizing pretreatment and succinylcholine are administered. Despite the large eye wall defects adjacent to the intraocular contents, there was no extrusion of intraocular contents during this study.[28] This compares to the normal blink, which raises IOP only 10 to 15 mm Hg.

Once the patient is asleep, succinylcholine has been the historical suspect of being the potential cause of contraction of the extraocular muscles. In terms of clinical significance, experience has shown that as long as nondepolaring agents are used as pretreatment, there have been no clinically significant increases in the IOP reported by ophthalmologists observing the anterior segment of the eye.

Finally, in 1992, an important study of the posterior segment showed that the posterior segment and the retina were not involved in disruption. Acuity outcome analysis demonstrated with 98% certainty that the posterior chamber and anterior segments were also protected by the pretreatment technique of a nondepolarizing muscle relaxant.[29]

Ophthalmic surgical consultation

Last but not least, the ophthalmic surgeon can be your best advisor for selecting a course of anesthetic management. The discussion with the ophthalmic surgeon about the predicted viability of the injured eye is essential. Many surgeons consider it important to paralyze the orbicular muscle with a local anesthetic to prevent forceful blinking or blepharospasm, even during procedures that use general anesthesia. Before induction, the patient's forceful blinking at the sight of the facemask could produce tonic squeezing of the eyelids and raise the IOP to a dangerous level.

When the eye is not considered salvageable, the anesthetist can use succinylcholine with less trepidation. A retrobulbar block would be a consideration, even though it would be contraindicated in the salvageable eye, since it may increase IOP secondary to extrinsic compression of the globe. An awake intubation also would be a consideration. When the eye is salvageable, an awake intubation is inadvisable because there is no reliable way to prevent coughing during the intubation or during the transtracheal block. In the eye that is to be enucleated or is unsalvageable in terms of regaining sight, an awake intubation could be preferable to prevent aspiration. In addition, the laryngeal mask airway, which is not recommended for ophthalmic open eye injuries, has been used successfully for this purpose. But I and others[30-31] still regard a full stomach as a contraindication for use of the laryngeal mask airway.

Pharmacologic considerations

The normal trauma induction agents are permitted when the eye is nonsalvageable. When the NPO period has been sufficient, a modified rapid-sequence induction (thiopental and rocuronium) can be effective without resulting in any significant rises in IOP. Thiopental in the range of 3 to 4 mg/kg will cause a 25% decrease in IOP that lasts 3 to 5 minutes.[20]

Etomidate, because of the resulting clonus, is not recommended. Ketamine is considered inadvisable, also due to the nystagmus and blepharospasm that can be induced by its use.[20] In addition, ketamine raises IOP in some cases by increasing muscle tone. Postoperatively, 3 cases of transient blindness lasting 30 minutes have been reported after ketamine use.[7]

Propofol has one of the most unusual side effects in patients recovering from anesthesia. Patients respond to verbal commands and have full return of muscle power, except in the eyelids for up to 30 minutes. This may include a transitory loss of all ocular or periocular muscle movements. Eyelid rash and edema also have been reported with propofol.[7] During surgical repair of retinal detachment, intravitreal injection of sulfur hexafluoride gas or air may be used. Nitrous oxide can enlarge the bubble of sulfur hexafluoride gas and thus compromise retinal blood flow.[20]

Future pharmacologic considerations

To maintain a low IOP during intubation, many pharmacologic agents have been studied.[32] For the most part, investigators attempted to pretreat the patient with open eye injury by lowering IOP before intubation. None of the agents have had consistent results. One study[33] seemed particularly promising in the use of intranasal nitroglycerin. Intranasal nitroglycerin spray is available, usually in obstetrics to delay labor and in the emergency department and the coronary care unit for the cardiac patients. To date, only a single study of nitroglycerin nasal solution has been published in relation to open eye injuries and IOP.[33]

Emergence

An antiemetic given near the end of the procedure can be effective and desirable. In addition, lidocaine can be given just before emergence to prevent coughing because of the endotracheal tube and nasogastric tube.[20] Upon return of spontaneous ventilation, some authors find it useful to use an awake extubation with the patient in a lateral, head-down position.[32]

Conclusion

Patients injured by fragmentation weapons can be admitted as "camouflaged," simple ophthalmic surgical cases, but inherent to the fragmentation weapons of today is the possibility of deep penetration of the fragments into the brain. Large fragments may ricochet and damage the deeper areas of the respiratory and circulatory centers, but it is just as common for the fragments to remain in the frontal and anterior temporal lobes, areas that can be silent in terms of clinical symptoms.

If the fragments traverse deep into the brain, intracranial pressure due to bleeding may mandate intubation and hyperventilation. Behind each eye is the ophthalmic artery, the first major offshoot of the internal carotid artery. Around the face and neck, fragments dissect the external carotid, the facial, and the lingual arteries. This blood loss also can involve the airway and be important in terms of shock by the time the patient arrives in the operating room. Also, around the neck, penetrating fragments can cause substantial bleeding, leading to airway compromise due to swelling.

Be aware in military and civilian trauma, emergency airway control is of utmost concern for the anesthetist when confronted with a patient who has a penetrating eye injury. This is particularly true when confronted with blast injury and associated multiple-trauma injuries. In a patient in unstable condition, the eye injury itself may very well be the last injury addressed by the expertise of the trauma team.

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