Neurologic Consequences of Head Trauma in the Horse: Recognition and Management
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Traumatic skull injuries damage the brain or cranial nerves in three principal settings. The most common and potentially the most dangerous accident of this type occurs when a horse flips over backwards and strikes its head. This often is the case in young horses that are being halter-trained or in excitable horses forcibly restrained or led (as into a trailer or a starting gate). The second type of trauma that often is associated with brain injury is impact to the frontal/parietal area of the head as may occur when a horse (usually a foal) gets kicked or runs into a fixed object such as a fencepost. Finally, petrous temporal bone fracture is associated with the chronic condition known as temporohyoid osteoarthropathy (THO).

1. Typical Settings

Flipping Over Backwards
The biomechanics of brain and cranial nerve injury after a horse flips over backward are quite well understood. As the front end of a full-sized horse rotates upward and backward over its pelvic limbs, the poll arcs up to more than 10 feet above the ground before accelerating downward and striking the surface with tremendous force. The resultant damage is greater if the head strikes a paved or other hard surface and proportionally less if the poll hits a wall or an overhead object. Likewise, the damage is usually more severe if the horse goes straight over backwards and strikes its occipital protuberance squarely than it is if the horse falls obliquely and strikes its temporal area without primary involvement of the poll.

When the horse strikes its poll, the force of impact seldom fractures through the thick part of the occiput although a piece of the nuchal crest may be chipped off and, occasionally, one or both of the paramastoid processes or occipital condyles is fractured. The shock impulse is transmitted around the skull where it may fracture or separate the less well protected bones on the sides and base of the calvarium including the petrous temporal (most commonly), squamous temporal, and parietal bones. In most cases, however, these bones (and the joints between them) remain intact and the most serious injuries result from the actions of the rectus capitis ventralis muscles on the basilar (i.e., basioccipital and basisphenoid) bones. The paired rectus capitis ventralis muscles run from the cervical vertebrae to the ventral aspect of the basilar bones and are the principal flexors of the head.

When the motion of the poll is suddenly arrested by striking the ground, the nuchal crest acts as a pivot around which the rest of the head flips into extension. The rectus capitis ventralis muscles are convulsively stretched by the sudden extension of the head and pull ventrally and caudally on the basilar bones. Quite commonly, a boney tubercle is ripped from the basilar bones and adjacent large vessels (which may include the occipital artery or its branches) are lacerated and bleed profusely into the retropharyngeal spaces and/or guttural pouches (and from there out the nares). In its most severe presentation, this force is sufficient to transversely fracture/separate the basilar bones at or close to the basioccipital-basisphenoidal suture. Because the joint between the basilar bone fuses by 5 years of age (and as early as 2 years in some horses), it is has been suggested that older horses are less susceptible to separation of the basilar bones than are young horses. Reflecting the larger distractive force to which it is subjected, the basisphenoid may be persistently displaced several millimeters ventral to the line of the basioccipital bone; however, in most cases, the fracture site is quite stable and minimal or no persistent displacement occurs. Additional fractures/separations of supporting bones (especially occipital, temporal, parietal, or sphenoidal) destabilize the fracture site and much more dramatic and serious displacement may occur at or after the time of impact.

Hemorrhage into the middle/inner ear and fracture of the petrous temporal bone occur most commonly when side of the skull strikes the ground without involvement of the occipital protuberance. Such injury often causes unilateral damage to the facial nerve and vestibular apparatus.
Fracture of the basilar bones, even if stable, may seriously disrupt associated soft tissues. In particular, there may be bleeding into the meninges (subdural or subarachnoid) around the brainstem, and stretching and tearing of the nerves (e.g., V, IX, and X) and blood vessels traversing the adjacent foramen lacerum. If the basilar fracture is unstable, direct laceration of the brainstem and cranial nerves may occur at the time of and after the accident.

The cerebellum and cerebral hemispheres are subjected to rapid acceleration-deceleration forces. Although it is close to the point of poll impact, the cerebellum is seldom severely damaged, although cerebellar contusions and axonal injury can occasionally result in clinical signs. By contrast, the violent gyrations of the cerebrum caused by poll impact can injure the cerebral parenchyma and tear the optic nerves and other attachments.

**Frontal/Parietal Impact**

A blow anywhere to the dorsal surface of the head has the potential to injure the brain; however, the risk is highest when the impact site overlies the cerebral cortex, i.e., is caudal to a line between the supraorbital processes and rostral to the poll. Such an impact is usually over the frontal or parietal bones. Brain injury is most likely to occur when the "footprint" of contact between object and skull is narrow or uneven as it would be after a kick or collision with a narrow post. By contrast, when the contact is distributed broadly across the front of the skull (as may occur when a horse pitches headfirst into the ground while traveling at speed), the main force of the impact is more likely to be transmitted through the occipital condyles to the cervical vertebrae, resulting in damage to the upper cervical area. The most common neurologic sequel to the latter type of accident is spinal cord injury; however, it is also possible for components of a fractured atlas to be driven rostrally around the occipital condyles where they may traumatize cranial nerve XII as it exits the hypoglossal foramen.

Brain contusions and lacerations are most likely when there is fracture of overlying bone, especially if there is displacement of bone fragments. Even with closed head trauma, the area most subject to damage (with or without hemorrhage) is the cortical surface directly underlying the site of impact. Additional injuries may occur as the brain is tossed around inside the calvarium. For example, the optic nerves can be stretched as described in the previous section, and the caudal part of the cortex (occipital pole) is subject to damage as it is suctioned away from the tentorium cerebelli immediately after the initial impact.

**Temporohyoid Osteoarthropathy**

Temporohyoid osteoarthropathy (THO) is characterized by fusion between the temporal and stylohyoid bones, stricture of the external ear canal and obliteration of the lumen of the tympanic bulla. These changes are thought to be secondary to chronic otitis media. Ankylosis of the temporohyoid joint interferes with the interdependent coordinated movements of the tongue, hyoid apparatus and larynx during swallowing, vocalizing, and combined head and neck movements. Sudden mechanical forces applied to this immobilized joint (e.g., by teeth floating, passage of nasogastric tube, pressure on the bit, etc.) via the thickened stylohyoid bone act to cause acute stress fractures of the skull, usually through the adjacent petrous part of the temporal bone. Such fractures frequently damage the vestibular apparatus and/or cranial nerve VII. After fracture, there also may be extension of middle/inner ear infection around the brainstem and involvement of additional cranial nerves and hindbrain structures.

2. **Clinical Signs**

**Non-Neurologic**

**Epistaxis** is common after a blow to the head of sufficient severity to cause neurologic signs. After frontal/parietal or poll trauma, blood may flow from either or both nostrils and typically is dark (venous) and of low to moderate volume. This usually reflects hemorrhage from a paranasal sinus, ethmoid turbinate, or nasal cavity. With poll trauma, epistaxis also may be bilateral, copious, and occasionally bright red. In such cases, the hemorrhage is from one (usually) or both guttural pouches and originates from adjacent veins and/or arteries. If the tympanum is perforated, blood additionally may flow from the external ear. Profuse hemorrhage into the retropharyngeal area may cause obvious swelling behind the vertical ramus of the mandible and **inspiratory dyspnea** which can be life-threatening.
Respiratory distress also may be associated with a poorly understood syndrome of non-cardiogenic pulmonary edema that is reported to occur after serious head injury.

Head trauma in humans is often complicated by systemic arterial hypotension. The cause is not completely understood, but may be explained in part by brain-heart syndrome wherein myocardial damage is inflicted by the reflex actions of sympathetic nerves.

**Forebrain Syndrome**
Immediately after the injury (usually impact to the frontal/parietal area), there often is a period of apparent concussion. These signs may last minutes to hours. The most severely affected animals transiently lose all reflexes and are sometimes thought to be dead. Even after recovery of consciousness, such horses typically are depressed and remain in sternal recumbency for up to a few hours before attempting to stand. Disorders of consciousness obviously occur on a continuum from mild to severe; however, it is useful for the purposes of description to rank the degree of depression; thus, depressed horses may be **lethargic** - apathetic but capable of normal responses; **delirious** - disoriented, restless, fearful, capable of responding to stimuli albeit inappropriately; **seminotose** (stuporous) - standing or recumbent, responsive only to strong stimuli; or **comatose** - recumbent, unconscious and unresponsive to strong stimuli.

Altered behavior (i.e., dementia) is another characteristic of forebrain injury - there can be loss of affinity of a suckling foal for its dam, failure to respond to training cues, yawning, head-pressing, compulsive walking, often in circles around the inside of an enclosure (usually towards the side of the injury) or, rarely, hyperreactibility or aggression. In horses that compulsively circle, the head and trunk may be twisted in the direction of circling when the horse is forced to stop moving. Cerebral injury should not affect gait, although it may be possible to demonstrate delayed responses when the horse is forced to hop on the thoracic limb opposite to the side of the injury. Delayed hopping responses usually are more obvious if the horse is blindfolded during testing.

Because of damage to the visual (occipital) cortex, vision and menace response(s) may be impaired in the eye contralateral to the lesion; however, pupillary light reflexes should be intact. Typically, such a horse will bump its blind side (especially the head) along the walls of an enclosure as it circles compulsively within its boundaries. Injury to the sensory (parietal) cortex interferes with awareness of (and thus response to) touch on the opposite side of the head in a manner analogous to the way in which trauma can cause cortical blindness and abnormal menace response. This **avoidance response** is best evaluated by comparing the horse’s reactions to tapping the nasal septal mucosa on either side.

Seizures occasionally occur shortly after the initial concussion. These seizures are likely to be generalized, with loss of consciousness and uncontrolled autonomic activity (e.g., salivation, urination, defecation, pupillary dilatation, and chewing movements) and abnormal motor function (e.g., muscular rigidity, followed by running and paddling movements of the limbs).

In comatose horses with cerebral injury, the breathing pattern may be irregular with periods of either Cheyne-Stokes breathing or hyperventilation.

**Optic Nerve Syndrome**
The optic nerve(s) of one or both eyes can be stretched and damaged by the violent to-fro gyrations of the brain after impact to the head. This is particularly likely after a blow to the poll. In most cases, vision and pupillary light responses are impaired or absent and pupils are dilated immediately after the injury. Because the secondary phase of nerve injury continues for many hours after the initial trauma, visual function may progressively deteriorate during at least the first 24 hours post-trauma.

**Midbrain Syndrome**
This is a relatively uncommon and serious complication of head trauma of any type. It may occur immediately after the injury, or be secondary to subventricular herniation of forebrain components, rostral herniation of the cerebellum, or intra-parenchymal bleeding. Because of involvement of the ascending reticular activating system (ARAS), affected horses are usually depressed and may be comatose. Ataxia and weakness of limbs is seen bilaterally or on the side opposite to an asymmetric midbrain lesion. In recumbent horses with severe midbrain injury, the neck, back, and limbs may be rigidly extended in a decorticate posture. If the nucleus of cranial nerve III (oculomotor) is involved, there is strabismus, and a
dilated, unresponsive pupil. With severe diffuse injury, bilateral pupillary miosis may be seen initially, followed by gradual progression to fixed, dilated pupils. Vision is normal unless there is involvement of other parts of the brain.

**Vestibular Syndrome**
The vestibular syndrome is seen commonly in horses after flipping over backwards (usually obliquely) or because of THO. Clinical signs may arise because of injury centrally or, more commonly, because of involvement of the vestibular apparatus or nerve (VIII). With peripheral vestibular disease, there is head tilt, neck turn, body lean, and staggering in tight circles, all toward the side of the lesion. These signs can be revealed or exacerbated by blindfolding. With acute severe vestibular dysfunction secondary to THO, there may be sudden recumbency with flailing and thrashing movements. These signs of vestibular disease can easily be mistaken for seizures. The ipsilateral eye is usually rotated ventrally and laterally, especially when the horse’s nose is elevated, and there may be horizontal or rotatory nystagmus, with the fast phase away from the side of the lesion. There also may be facial paralysis attributable to damage to cranial nerve VII as it passes close to the middle/inner ear. With central vestibular disease, signs are similar to those seen when the injury is peripheral; however, there will likely be additional signs suggestive of brainstem damage, including spontaneous vertical nystagmus, signs of other cranial nerve dysfunctions (see “Hindbrain syndrome”), mental depression, and limb ataxia and weakness. In horses, central lesions quite commonly result in a paradoxical vestibular syndrome in which the lesion (usually in the caudal cerebellar peduncle or the flocculonodular lobe of the cerebellum) is located on the side opposite to that which is expected from the clinical signs. An important clue to the presence of this syndrome is the finding of other signs of cranial nerve dysfunction (e.g., facial paralysis) on the side opposite to the direction of circling.

**Hindbrain Syndrome**
In horses with traumatic damage to the pons and medulla, there is evidence of dysfunction of multiple cranial nerves in association with mental depression (ARAS involvement) and limb ataxia/weakness. There may be reduced jaw tone (Vm), reduced facial sensation (Vs), facial paralysis (VII), vestibular syndrome (VIII), dysphagia and respiratory stridor (IX and X), or tongue paralysis (XII). The gait may appear hypometric (spastic) like that seen in horses with compression of the cervical spinal cord. With severe hindbrain lesions, rapid deep breathing or other abnormal respiratory patterns are sometimes seen.

Signs of cerebellar injury occur rarely and are usually a result of poll trauma. Coarse head tremors are the most consistent sign; these are especially obvious during attempts to eat or suckle (intention tremor). The horse with cerebellar injury typically has a broad-based swaying stance and limb movements may be spastic, clumsy, faltering, and jerky. Infrequent signs of cerebellar trauma include absent menace response(s) with normal vision and paradoxical vestibular syndrome (see above).

**Multifocal Syndrome**
Because multiple regions of the brain usually are damaged by the primary or secondary effects of brain trauma, clinical signs involving any to all the above syndromes may be seen in a single horse. For example, a (very unlucky) horse after poll impact could have peripheral damage to the vestibular apparatus because of petrous temporal bone fracture, hindbrain syndrome because of unstable basilar fractures, cerebellar dysfunction because of direct trauma, and midbrain and forebrain syndromes because of intraparenchymal hemorrhage and secondary hydrocephalus. As a result of flipping over backwards, such a horse also could show cauda equina syndrome associated with sacral or caudal vertebral fracture, or local pain and swelling caused by fracture of thoracic dorsal spinal processes.

In addition to causing the commonly recognized forebrain syndrome, impact to the frontal/parietal area also may injure the midbrain via subtentorial herniation of the forebrain or by contrecoup injury. Tongue paralysis may result when the atlas shears off the hypoglossal nerve(s) as the caudal part of the skull is forced through the atlantal ring. Associated with this type of injury there also can be cervical vertebral fracture/luxation and spinal cord damage.
Horses with THO usually have some form of vestibular dysfunction, but may also have hindbrain syndrome secondary to temporal bone fracture, basilar empyema, epidural abscess, or bacterial leptomeningitis.

3. TREATMENT
Relevant treatments for brain injury can be classified in 2 levels according to evidence-based support for their use. All applicable level 1 treatments should be used in every case of clinically apparent brain injury, whereas level 2 treatments are less clearly indicated and can be considered optional.

Level 1
These are therapies that are strongly supported by the results of large, controlled, multi-center clinical trials in human beings. Many are elements of the guidelines for the management of severe head injury that were promulgated by the Brain Trauma Foundation in 1996 and 2000 and still serve as the blueprint for treatment of head trauma in humans. Equally importantly, level-1 treatments are practicable in a well-equipped equine referral hospital.

Treat other injuries or diseases. The normal principles of critical care medicine apply to the brain-injured patient. An airway must be established, vascular access obtained, wounds cleaned and dressed, bleeding staunched, and the horse sedated if necessary and moved to a cool, well-padded area. If necessary, a padded helmet can be used to minimize additional head trauma. A regimen of broad-spectrum antibiotics should be begun if there is an open wound or fracture.

Treat hyperthermia. Hyperthermia after head trauma results either from a resetting of the hypothalamic temperature set-point (fever) or from excessive heat production in horses with normal set-points. High brain temperature accelerates all of the destructive forces unleashed during the secondary phase of brain injury so must be detected and treated vigorously. Rectal temperature should be checked frequently and efforts at cooling should begin when the temperature exceeds 101 F. Heat dissipation strategies have been reviewed. In brief, ambient temperature can be reduced, the body can be clipped, ice water or isopropyl alcohol repeatedly applied to and removed from the skin (including the head), and overhead or box fans can be placed close by. Anti-pyretic medication (e.g., flunixin meglumine 1.1 mg/kg IV) is particularly useful when the horse has a fever, but should be tried in all cases of hyperthermia. Non-steroidal anti-inflammatory drugs have the additional advantages of analgesic and anti-inflammatory action.

Prevent or treat hypotension. Blood pressure must be at or close to normal to sustain adequate cerebral perfusion. The old notion that head trauma patients should be “kept a little dry” is no longer viable. Blood pressure should be monitored frequently and heart base-adjusted systolic blood pressure maintained above 110 mm Hg. Blood volume should be maintained or expanded by IV infusion of isotonic (Normosol-R; Plasmalyte-A; Lactated Ringer’s Solution) or hypertonic (Hypersaline) crystalloid or colloid (plasma, hetastarch, hemoglobin solution (Oxyglobin)) solutions. Plasma possibly has additional useful effects including anti-oxidant and protease-inhibiting activities. In the case of significant blood loss, cross-matched whole blood is the fluid of choice. If volume resuscitation alone is inadequate to restore normal pressure, pressor/inotropic drugs may be used (e.g., dopamine, dobutamine, norepinephrine). Remember that the effects of these drugs on cerebral vascular tone are difficult to predict.

Optimize oxygen content of blood. Oxygen is carried in blood either bound to hemoglobin (predominantly) or as free gas. Thus, it is important that both hemoglobin concentration and PaO₂ are at least in the normal range. Hypoxemia (arterial oxygen saturation < 94% in this setting) should be treated by establishing airway patency, treating underlying pulmonary disease (e.g., head trauma-associated non-cardiogenic pulmonary edema), and beginning nasal or tracheal insufflation with oxygen. Foals may be intubated and mechanically ventilated. At several equine hospitals, there are hyperbaric oxygen chambers that theoretically could be used to dramatically increase blood oxygen content in horses with brain injury. The efficacy and safety of this approach has not been established. Hemoglobin concentration must be kept above 11 g/dl (PCV of 33%). Anemia can be treated with whole blood (preferable in the case of blood loss anemia), packed red blood cells, or hemoglobin solutions.
**Ensure adequate pulmonary ventilation.** High pCO₂ has the potential to exacerbate CNS acidosis and cerebral edema. In foals, hypercapnia can be addressed by mechanical ventilation of the lungs. In all horses with head trauma, pulmonary ventilation must be optimized by ensuring a patent airway and treating lung disease. For example, acute pulmonary edema may be treated with furosemide (0.5–1 mg/kg every 8 h). Ventilation-induced hypocapnia has been advocated as a way to lower intracerebral pressure (ICP); however, low pCO₂ may cause reflex cerebral vasoconstriction and probably should not be used in foals with brain injury.

**Control pain.** Alleviating pain in brain-injured horses is not only humane but also may reduce ICP. A nonsteroidal anti-inflammatory drug (e.g., flunixin meglumine, 1.1 mg/kg BID) or opioid (e.g., morphine, 0.1–0.3 mg/kg IV or IM QID) can be used for this purpose. Useful analgesic effects also have been seen with transdermal fentanyl patches (Duragesic-100) (one 10-mg patch/150 kg bodyweight) or constant-rate infusion of butorphanol or lidocaine.

**Regulate blood glucose and maintain nutrition.** Experimental studies have shown that at least 140% of maintenance energy is expended by animals with severe brain injury. Even during the first 24 h after injury, nutrition (enteral or parenteral) probably should be provided to anorexic horses with head trauma. Blood glucose concentration ought to be kept > 80 mg/dl in order to provide adequate substrate for brain cells and < 150 mg/dl so as to prevent hyperglycemia-induced exacerbation of CNS acidosis and apoptosis of brain cells. IV infusions of dextrose and regular insulin can be used as necessary to maintain normal blood glucose concentration.

**Prevent or treat brain swelling.** If possible, the neck should be free of constrictive wraps and only one jugular vein should be punctured or catheterized in order to prevent obstruction of venous flow from the head. Likewise, any recumbent horse should have its head elevated at least 10 degrees in order to facilitate blood flow. If the horse is significantly depressed (i.e., at least stuporous) or has signs of worsening brain function, a hyperosmolar infusion should be given to try to reduce the extravascular volume of the brain. The solution of choice is hypertonic saline (1232 mmol Na/l) which is given as a continuous IV infusion of 1 ml (1.2 mmol)/kg/h for 6 h and then 0.2 ml/kg for another 12 h. Alternatively, boluses of 2 ml/kg can be given every 4 h for 5 infusions. Further treatment with hypertonic saline should be based on reassessment of clinical signs and plasma Na concentration (keep < 150 mmol/L). Hypertonic saline has additional salutary actions including plasma volume expansion, anti-inflammatory effect, and reduction of microvascular permeability. Mannitol (20% solution) also can be used for this purpose as a series of bolus infusions of 0.25–1 g/kg every 4–6 h.

**Treat seizures.** There is no justification for prophylactic anti-seizure medication. Seizures should however be treated vigorously when they occur. They may be treated with diazepam phenobarbital, or pentobarbital. Once a horse seizes for the first time, anti-seizure medication (usually phenobarbital) should be continued for at least a week. If delirious thrashing or recurrent seizures remain a problem, the horse can be immobilized by continuous infusion of propofol or pentobarbital for up to 24 hours.

**Perform emergency skull surgery.** After initial stabilization of the patient, depressed fractures of the frontal/parietal area that impinge upon the cerebral cortex may be carefully elevated and reduced under general anesthesia using techniques described in standard texts. No surgical approach to basilar fractures has been described for the horse - such an approach would be extremely difficult and risky. Although no prospective study has been performed to document the efficacy of the procedure, it is the author’s opinion that, in all horses with neurologic signs referable to THO, the stylohyoid bone on the affected site should be cut or the ceratohyoid removed in order to prevent or help stabilize skull fractures. The technique of mid-body stylohyoidectomy has been described.

**Level 2**

Such treatments are technically possible in horses and their use is supported either by strong anecdotal data from equine practice or by convincing experimental data in other species. The downside of these treatments is either that they are somewhat impractical in an equine hospital or do not meet the standard of evidence-based medicine.

**Treat with antioxidants.** Oxidant damage is known to be an important part of the secondary phase of brain injury, yet clinical evidence supporting the therapeutic use of antioxidants is scant. If given
within the first 8 hours post-injury, high-dose methylprednisolone sodium succinate (SoluMedrol), used at an initial bolus dose of 30 mg/kg, then followed by continuous infusion of 5.4 mg/kg/h for 24–48 h, is effective treatment for spinal cord trauma in humans. It is thought that anti-oxidant effects are largely responsible for this salutary effect of high-dose steroids, even though the potent lazaroid antioxidant, tirilazad mesylate, lacked efficacy in the same study. Unfortunately, high-dose steroids have not proven effective in humans with brain trauma. A large multi-centered study of high-dose methylprednisolone in humans failed to detect improvement and there was a significant negative effect in several parameters. Dimethyl sulfoxide (DMSO) is very widely used by equine practitioners for treatment of CNS trauma (and almost everything else). The potential advantages of this drug’s antioxidant and diuretic actions are obvious; however, there is virtually no evidence for effectiveness in the setting of brain injury. Common use suggests a protocol of 1 g/kg as a 10% solution in isotonic solution given IV or by NG tube every 12 hours. Vitamin E (α tocopherol; 20 IU/kg PO daily), vitamin C (ascorbic acid, 20 mg/kg PO daily), mannitol (see above), and allopurinol (5 mg/kg PO every 12 h), are all antioxidant therapies that can be used in the horse, and can be rationalized as part of the overall approach to brain trauma.

**Give conventional doses of corticosteroids.** Traditional anti-inflammatory doses of dexamethasone (0.05–0.1 mg/kg IV or 0.1–0.2 mg/kg PO every 12 to 24 h) or prednisolone (1–4 mg/kg PO BID) likely inhibit production and action of injurious mediators in the brain and may be of some value. Obviously, if megadoses of methyl prednisolone sodium succinate are given, no other corticosteroid is indicated.

**Place an intraventricular drainage catheter.** Core protocols for human head trauma all mandate transcalvarial insertion of a valved indwelling catheter into a lateral ventricle. The indwelling catheter is used both for monitoring of ICP and drainage of CSF in order to keep pressure below 20–25 mm Hg. CSF drainage is technically possible in horses, but the clean conditions and prolonged head immobilization required likely make this procedure impractical in all but valuable neonates.

**Give magnesium sulfate.** Magnesium sulfate has the potential to inhibit several aspects of the secondary injury cascade including glutamate release, activity of the N-methyl-D-asparate and calcium channels, and lipid peroxidation. Studies have shown that 250 µmole/kg improves neurologic outcome when given 30 minutes after brain impact injury. In light of these findings and its demonstrated safety in horses, it seems reasonable to give a single IV infusion of MgSO₄ at 50 mg/kg (approximately 250 µmole/kg). This dose (25 g in a 500-kg horse) can conveniently be administered with the first 5–10 liters of IV fluids.

4. **Future Directions**

The recent revolution in the understanding of the pathogenesis of brain injury has created intense interest in exploring the potential usefulness of new and better inhibitors of the mediators of secondary injury. These include reactive oxygen and nitrogen species, excitatory amino acids, calcium-activated proteases, metalloproteinases, cytokines, eicosanoids, and inducers/mediators of apoptosis. While these approaches will probably not identify a “silver bullet”, it is likely that incremental improvements will continue to be made, some of which may be applicable to the treatment of brain-injured horses.