CHAPTER 8
Head-Trauma Management

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Introduction[1, 17, 20, 22, 39, 56, 64, 67]

Severe head trauma is associated with a high degree of morbidity and mortality in humans and animals. Death typically results from progressive increases in intracranial pressure (ICP). Brain injury in dogs and cats is most often due to automobile trauma; other causes include missile injuries (e.g. gunshot wounds), animal bites, and falls. Traumatic brain injury has been documented to occur in 25% of severe blunt trauma cases in dogs and cats and is negatively associated with survival. Considerable controversy exists concerning therapy for severely brain-injured patients and this field is one of intense research in human neurology/neurosurgery. This chapter contains recent information regarding therapy for head-trauma victims. Retrospective and prospective clinical data pertaining to the treatment of canine and feline head trauma are lacking; therefore most of the clinical recommendations in this chapter are based upon information from human head-trauma studies and experimental head-trauma investigations. Opinions differ concerning what constitutes appropriate therapy for the severely brain-injured pet. However, few would refute that treatment needs to be expedient and aggressive for the majority of these patients. The first veterinarian the brain-injured pet encounters after the traumatic incident will likely dictate the eventual outcome for that patient. Dogs and cats can function well with considerable loss of cerebral tissue, if given time to recover from a severe brain injury. The ultimate goal in head-trauma management is to return the patient to the role in society occupied prior to the injury. It is of utmost importance to alleviate brain swelling and prevent damage to vital brain-stem structures.

Pathophysiology of head trauma[5, 6, 8, 17, 20, 22, 26, 27, 32, 34, 39, 49, 56, 64, 66, 67]

Brain injury can be conceptually divided into primary and secondary injury. Primary brain injury occurs immediately following impact and initiates a number of biochemical processes, which result in secondary brain injury. Both primary and secondary brain injury contribute to increased ICP. A basic understanding of the mechanisms of brain-tissue damage following injury and ICP dynamics is essential to logical therapy of the severely head-traumatized patient.

A. Primary brain injury

This type of injury refers to the physical disruption of intracranial structures that occurs

immediately at the time of the traumatic event. Such injury includes direct damage to brain parenchyma, such as contusions, lacerations, and diffuse axonal injury. Damage to blood vessels may result in intracranial hemorrhage (Fig. 8.1) and vasogenic edema. Skull fractures can contribute to continued trauma to the brain parenchyma and blood vessels, especially if they are unstable (Fig. 8.2). The extent of primary brain injury is a function of the force of impact. Acceleratory and deceleratory forces of both the impacting object(s) and the intracranial contents will affect overall tissue damage. Direct parenchymal damage associated with primary brain injury is generally beyond the control of the clinician. However, stabilization of skull fractures and evacuation of intracranial hemorrhage may decrease the morbidity associated with these primary injuries.

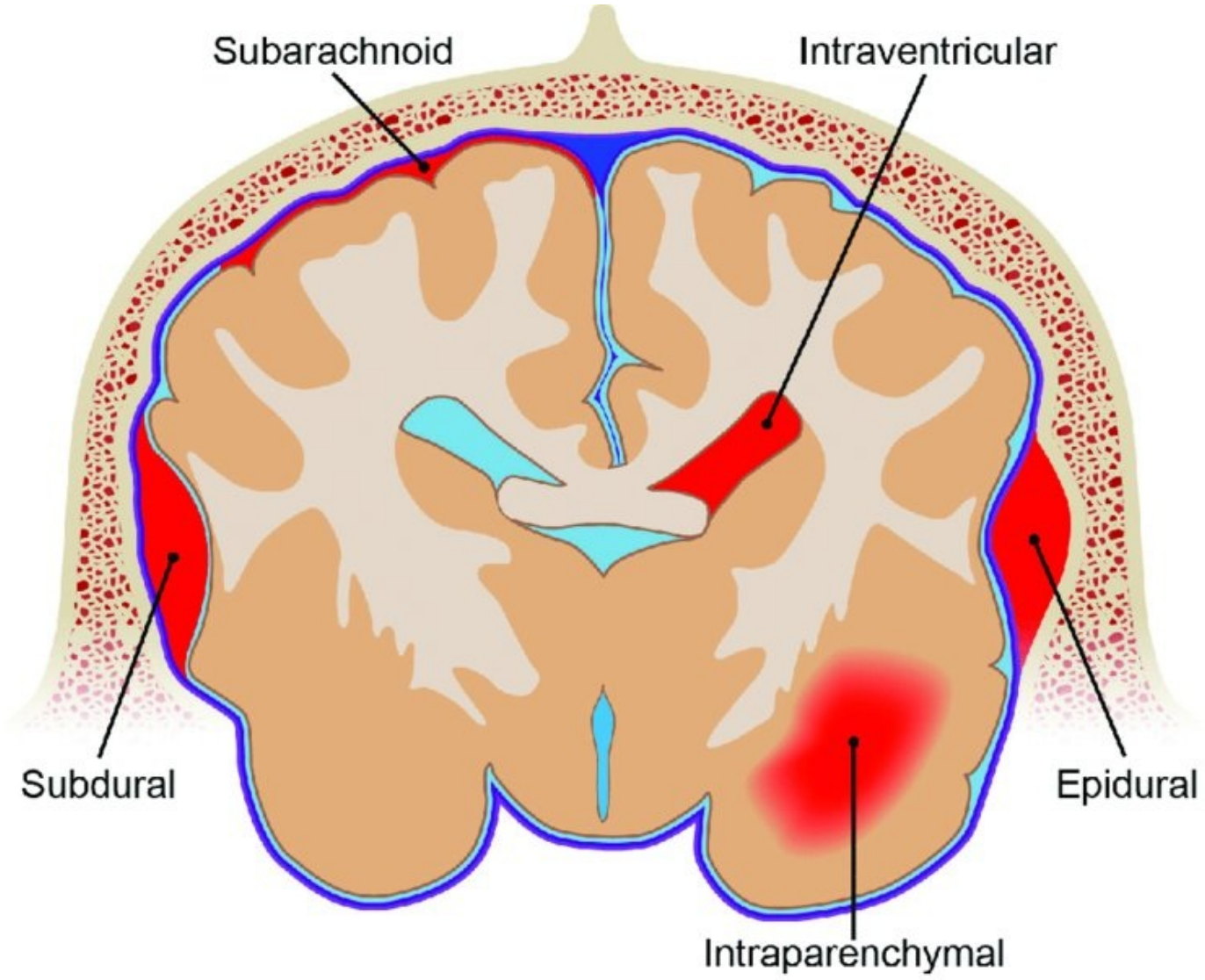

Figure 8.1 Clinically important forms of intracranial hemorrhage. Subarachnoid hemorrhage would occur as diffuse hemorrhage between the pia and arachnoid layers.

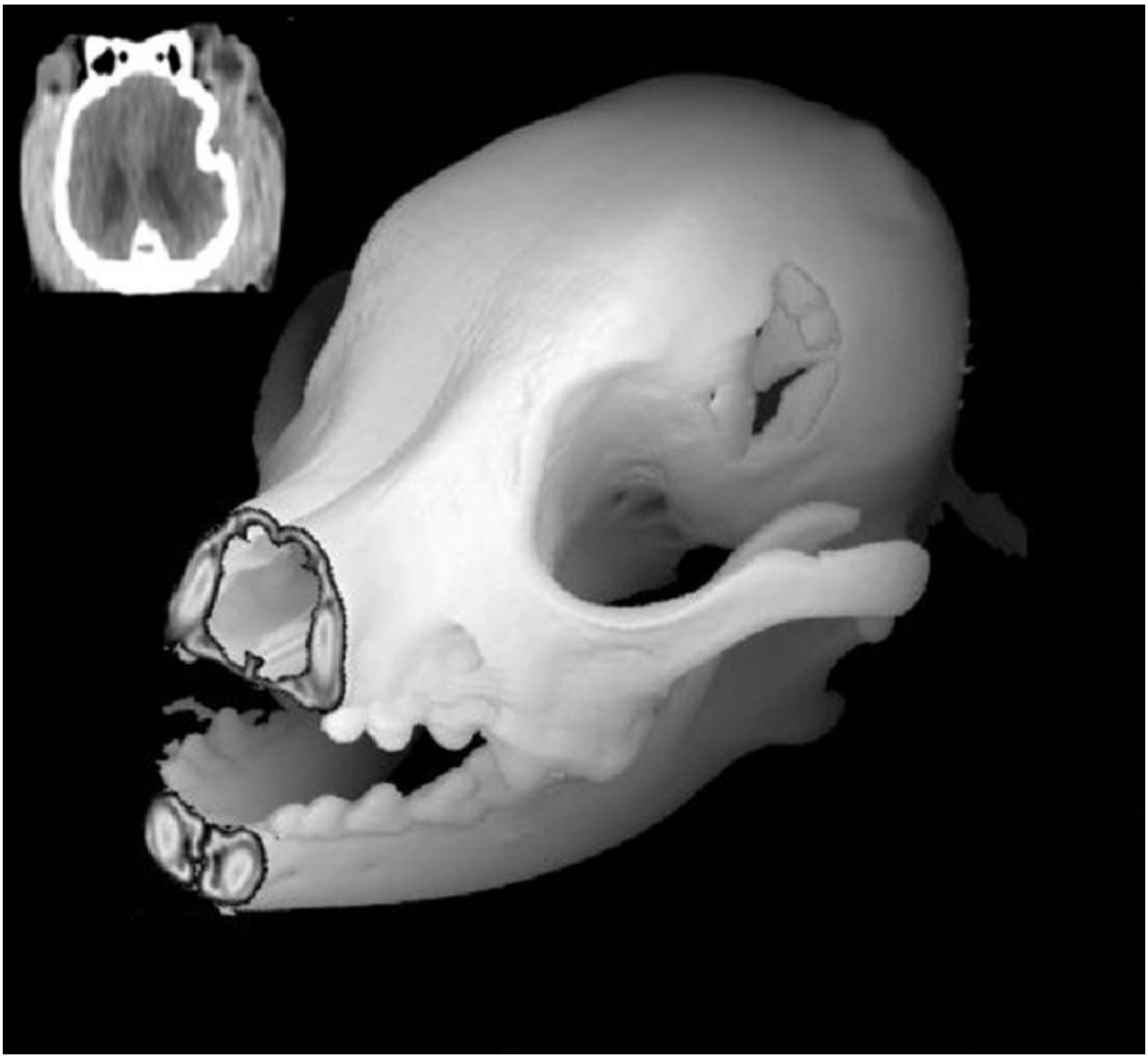

Figure 8.2 Three-dimensional CT reconstruction of a skull fracture in a dog that experienced severe head trauma. (Reproduced with permission from Dr. Charles Vite.)

B. Secondary brain injury

In addition to continued hemorrhage and edema, the damage caused by the primary brain injury activates a number of interrelated biochemical pathways that act in concert to perpetuate further brain-tissue damage and subsequent increases in ICP (Box 8.1).

Adenosine triphosphate (ATP) depletion disrupts the maintenance of cellular ionic homeostasis. Sudden, uncontrolled intracellular influx of sodium (Na^{+}) and calcium (Ca^{++}) occurs. Cellular swelling (cytotoxic edema) and depolarization result. The uncontrolled depolarization leads to the release of large amounts of glutamate, an excitatory neurotransmitter, into the extracellular environment. Glutamate causes further increases in intracellular Ca^{++} levels. Elevated Ca^{++} levels activate a number of tissue-damaging pathways, including the arachidonic acid cascade (phospholipase A_2 activation) and the xanthine oxidase (free-radical producing) pathway. Iron (Fe^{++}) is a vital cofactor in the

xanthine oxidase pathway, and free-radical species generated via the Fenton reaction (e.g. hydroxyl and superoxide radicals) are preferentially damaging to cell membranes containing high levels of polyunsaturated fats and cholesterol. Brain tissue is rich in both Fe^{++} and membranes with high levels of PUFAs and cholesterol. Intraparenchymal hemorrhage also increases the amount of Fe^{++} available for the perpetuation of oxidative damage. Free-radical species are thus particularly damaging to neuronal membranes and probably play a major role in secondary brain injury. Their production is also induced by ischemia, arachidonic acid metabolites, catecholamine oxidation, and activated neutrophils. Other secondary autolytic processes induced after severe head trauma include the complement, kinin, and coagulation/fibrinolytic cascades. Elevated levels of nitric oxide (NO) and various cytokines (e.g. tumor necrosis factor, interleukins) also contribute to parenchymal injury in the damaged brain. Most of the mediators of tissue damage produced by these various reactions perpetuate their own continued production as well as the production of other mediators. The maintenance of an ischemic environment perpetuates the above-mentioned processes and also leads to the accumulation of lactic acid (via anaerobic glycolysis). Lactic acid accumulation leads to further damage to brain tissue. Hypotension and hypoxemia, extracranial conditions that are common in the traumatized patient, can worsen brain ischemia and thereby enhance the events responsible for secondary brain injury. The result of these secondary processes is increased ICP. Unlike primary brain injury, the clinician has some control over secondary brain injury.

Box 8.1 Mechanisms of secondary brain injury in head trauma patients.

Glutamate accumulation

- Occurs secondary to
  - ATP depletion
  - Neuronal cell injury
  - Positive feedback
  - Decreased conversion
  - Potentiated by low interstitial magnesium
- Results in
  - Loss of ionic gradients
  - Excitotoxicity
  - Free-radical oxygen species generation

Influx of sodium into neuronal cells

- Occurs secondary to

- Glutamate accumulation
- Results in
  - Cytotoxic edema

Influx of calcium into neuronal cells

- Occurs secondary to
  - Glutamate accumulation
  - Primary injury
- Results in
  - Cytotoxic edema
  - Neuronal cell destruction through activation of proteases, lipases, and endonucleases
  - Reactive oxygen species production through calpain activation
  - Inflammatory mediator release
  - Mitochondrial dysfunction and ATP depletion

Free-radical production

- Occurs secondary to
  - Glutamate accumulation
  - Inflammatory mediator release
  - Increased cytosolic calcium concentrations
  - Ischemia-reperfusion injury
- Results in
  - Neuronal cell destruction

Inflammatory mediator release

- Occurs secondary to
  - Primary injury
  - Neuronal cell destruction with secondary injury
- Results in
  - Activation of nitric oxide with alterations in blood flow and vascular permeability
  - Inflammatory cell influx

- Coagulation cascade activation and thrombosis

Loss of autoregulation

- Occurs secondary to
  - Primary injury
- Results in
  - Ischemia

    All mechanisms contribute to neuronal cell death

C. Intracranial pressure (ICP) dynamics

Intracranial pressure is the pressure exerted by tissues and fluids within the cranial vault. Normal ICP values for dogs and cats range between 5 and 12 mmHg. Cerebral perfusion pressure (CPP) is a primary determinant of cerebral blood flow (CBF) and hence brain oxygenation and nutritional support. CPP is defined by the following equation:

$$CPP = MABP - ICP$$

MABP = mean arterial blood pressure

The normal contents of the cranial cavity include brain parenchyma, blood, and cerebrospinal fluid (CSF). In the normal animal, these components exist in equilibrium with each other and ICP remains within normal limits. Between the MABP extremes of 50–150 mmHg, ICP remains constant. This phenomenon is called *pressure autoregulation*. Pressure autoregulation serves to link systemic blood pressure changes to brain vascular tone. If MABP rises, vasoconstriction occurs in the brain; if MABP falls, vasodilation occurs in the brain. In the normal animal, the former scenario prevents ICP from rising by decreasing CBF, and in the latter, prevents ICP from falling by increasing CBF. *Chemical autoregulation* refers to the direct responsiveness of brain vasculature to the partial pressure of carbon dioxide in arterial blood ($PaCO_2$); elevated $PaCO_2$ levels cause cerebral vasodilation, whereas decreased $PaCO_2$ levels cause cerebral vasoconstriction. Both forms of autoregulation often remain intact in people with severe head injury, but pressure autoregulation may be compromised in approximately 30% of patients. In some of these individuals, the lower MABP extreme may become “reset” to a higher value, resulting in significantly decreased blood flow to the brain with even mild systemic hypotension. With severe head trauma, both intracranial hemorrhage and edema can add to the volume of the intracranial compartment. Due to the inexpansible nature of the skull, one or more components of the cranial cavity must accommodate for the increased volume, or increased ICP will result. This accommodation or volume buffering is accomplished by fluid shifts in the brain vasculature and CSF pathways and is referred to as *intracranial compliance*. Compliance is expressed as the change in volume per unit change in pressure. Intracranial compliance has limitations, and decreases as ICP increases. If intracranial

volume increases beyond the abilities of compensatory mechanisms, progressively larger increases in ICP result per unit of volume increase (Fig. 8.3), CPP is compromised, and ischemic death of brain tissue occurs. In cases of severe head trauma, intracranial compliance often is quickly exhausted. If MABP decreases (hypotension), especially in combination with hypoxemia, the brain vasculature will vasodilate in an effort to preserve blood flow. The increase in blood volume increases ICP, but CPP remains inadequate. In addition, the secondary autolytic processes occurring in the injured brain are enhanced by hypotension and hypoxemia, and further brain injury and edema occur with a resultant rise in ICP.

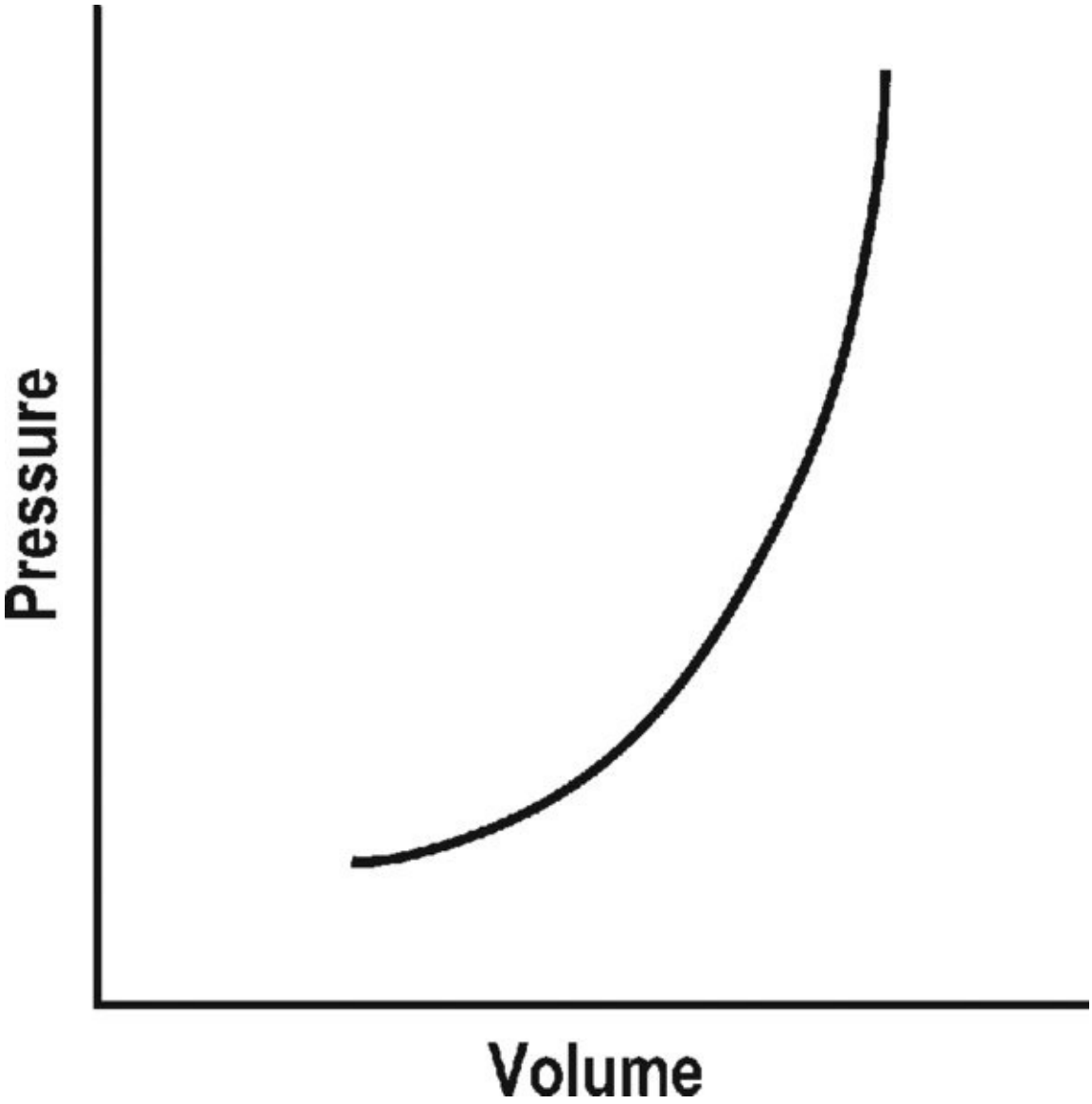

Figure 8.3 Typical pressure/volume curve for the intracranial compartment. (Dewey, 2000. Reproduced with permission from Elsevier.)[17]

Initial assessment and emergency treatment[2, 9, 11, 17, 19, 20, 22, 24, 32, 36, 46, 50, 53, 57, 59, 62–64, 74, 78, 79] (Video 17)

Initial physical assessment of the severely brain-injured patient focuses on imminently life-threatening abnormalities. Many patients suffering severe head trauma present to the clinician in a state of hypovolemic shock. Do not be in a rush to focus initially on the patient's neurologic status; it may well improve once the shock state is corrected. Remember that traumatized, hypovolemic patients with no appreciable brain injury often exhibit depressed mentation, due primarily to the hypotensive state. The clinician must first focus on the ABCs of trauma management (airway, breathing, cardiovascular status). In doing so, the brain will benefit as well as the rest of the patient. Quick assessment tests (QATs)—including packed cell volume (PCV), total solids (TS), Azostix (AZO), and blood glucose (BG)—are part of the initial patient assessment. Since hypovolemia and hypoxemia are strongly correlated with elevated ICP and increased mortality in human head-trauma victims, they need to be addressed immediately.

A. Fluid therapy (Table 8.1)

Table 8.1 Intravenous fluid therapy and recommended doses for head trauma patients.

Fluid type	Recommended dose
Isotonic crystalloid (0.9% NaCl preferred)	20–30 ml/kg dogs 10–20 ml/kg cats Administered over 15–20 min Reassess after
Synthetic colloid (e.g. 6% hydroxyethyl starch)	5–10 ml/kg Administered over 15–20 min Reassess after
7.5% sodium chloride	4 ml/kg Administered over 15–20 min Reassess after Always follow with crystalloid therapy
3% sodium chloride	5.4 ml/kg Administered over 15–20 min Reassess after Always follow with crystalloid therapy
1:2 ratio of 23.4% sodium chloride and 6% hydroxyethyl starch or other synthetic colloid	4 ml/kg Administered over 15–20 min Reassess after Always follow with crystalloid therapy
Packed red blood cells	~1 ml/kg Administer over less than 4 hrs/unit Target normalization of perfusion parameters and PCV = 25–30%
Whole blood	~2 ml/kg Administer over less than 4 hrs/unit Target normalization of perfusion parameters and PCV = 25–30%
Fresh frozen plasma	10–15 ml/kg Administer over less than 4 hrs/unit Target normalization of coagulation times

B. There is often concern that aggressive intravenous fluid therapy to counteract hypotension in the brain-injured patient may aggravate brain edema. There is both evidence to support and evidence to refute this concern. Because of this concern, there have been recommendations to volume-limit victims of severe head trauma. Such recommendations

are not only unfounded, but *strictly contraindicated*. There is no debate over the disastrous consequences to the injured brain if hypotension is allowed to persist. Hypotension has been repeatedly shown to be a reliable predictor of sustained elevations of ICP and increased mortality in human head-trauma victims. Blood pressure must be restored to normal levels as soon as possible. A patient with a systolic blood pressure of less than 120 mmHg is considered hypotensive. Some volume replacement fluids (hetastarch, hypertonic saline) afford some protection to the edematous brain, even if used with large volumes of crystalloids (LRS, 0.9% NaCl). Hetastarch and hypertonic saline can improve MABP and thus CPP without exacerbating brain edema. If the patient is anemic, whole-blood or packed red blood cell (pRBC) transfusion may assist in maintaining normovolemia as well as adequate tissue oxygenation by improving blood oxygen content, the major determinant of which is hemoglobin concentration. Fluid support may include one or more of the following choices:

1. Synthetic colloids: 10–20 ml/kg to effect (up to 40 ml/kg/hr) for shock. This can be given as a rapid bolus in dogs; give it in 5 ml/kg increments over 5–10 min in cats. Hetastarch is the author's fluid of choice in restoring normal blood pressure in the euhydrated head-trauma victim. Dextran-70 is an acceptable alternative, but given as a sole fluid support it has not exhibited the beneficial effects demonstrated with hetastarch and hypertonic saline. Dehydrated trauma victims should receive isotonic crystalloid resuscitation.
2. Hypertonic saline (7%): 4–5 ml/kg over 3–5 min for shock. Hypertonic saline is also available as 23.4% solution, which cannot be administered undiluted, but may be mixed 1:3 with hetastarch or dextran-70 (e.g. 20 ml of 23.4% hypertonic saline + 40 ml hetastarch or dextran-70 in a 60 ml syringe) to produce a solution of synthetic colloid suspended in a 7% hypertonic saline solution. Sodium does not freely cross the blood–brain barrier (BBB); therefore, hypertonic saline can reduce cerebral edema via an osmotic pull of fluid out of the brain parenchyma and into the intravascular space. It also has positive inotropic effects, immunomodulatory effects, and reduces endothelial swelling. Although hypertonic saline has been shown to improve MABP and CPP and protect against increased ICP, sodium has recently been implicated as the major osmotic agent contributing to brain edema. Hypertonic saline may have a global protective effect on the brain, but theoretically may lead to increased compromise to focal areas of damaged parenchyma due to compromise of the BBB in these regions.
3. Isotonic crystalloids (LRS, 0.9% saline): 20–30 ml/kg bolus over 15–20 min for shock. May be repeated as necessary after reassessment. Since overhydration with subsequent worsening of brain edema and increased ICP is a concern with crystalloid administration, the “shock dose” (90 ml/kg in the dog, 60 ml/kg in the cat) of crystalloids should be given incrementally to effect as described above. If the entire volume is not necessary to restore euvolemia and normal MABP, fluid administration should be tapered when these physiologic goals are met. Since 0.9% saline has less free water than LRS, this crystalloid may be preferable for use in the brain-injured pet.

4. Blood products: Administration of 1 ml/kg of pRBCs or 2 ml/kg of whole blood will increase the PCV by 1%. The severity of anemia will dictate the total dose to be administered, but 10–15 ml/kg of pRBCs is a reasonable starting dose. Blood products are typically administered over 4 hrs, but may be given faster (to effect) if the patient is unstable. Boluses of blood products are acceptable in the severely anemic trauma patient. Goals of therapy with blood products are a PCV between 25 and 30%. Patients with demonstrated coagulopathy should also be treated with fresh frozen plasma (FFP) at a dose of 10–15 ml/kg 2–3 times per day until coagulopathy has resolved.

C. Oxygenation and hyperventilation

Hyperoxygenation is recommended for most acutely brain-injured animals. Oxygenation status of a head-trauma victim can be initially assessed based upon breathing rate and pattern, mucous membrane and tongue color, and thoracic auscultation. Pneumothorax and pulmonary contusions are common sequelae of trauma, and need to be addressed if present. It should be noted that, in the face of increased respiratory rate and effort, lung sounds may not consistently be decreased on auscultation in patients with pneumothorax. A rapid, shallow breathing pattern, pale oral mucous membranes, and evidence of respiratory distress should raise the clinician's index of suspicion for the presence of pneumothorax. Thoracentesis should be done in any trauma patient in whom there is a suspicion of pneumothorax, and should be considered a diagnostic test as well as a therapeutic intervention. If negative pressure cannot be obtained via thoracentesis, a chest tube should be placed immediately. If arterial blood gas analysis is available, the partial pressure of oxygen in arterial blood (PaO_2) should be maintained at or above 90 mmHg for dogs, and 100 mmHg for cats. Pulse oximeters are extremely useful and relatively accurate estimators of oxygenation status. However, the reliability of pulse oximeters varies with model used, with the PaO_2 level (pulse oximeters may overestimate oxygenation status at lower PaO_2 levels), and with the patient's hemodynamic status. In general, oxyhemoglobin saturation values (SpO_2) from pulse oximeters should be interpreted as shown in Table 8.2.

Table 8.2 Interpretation of pulse oximeter SaO_2 values

SaO_2	PaO_2	Interpretation
95%	80 mmHg	Normal
89%	60 mmHg	Serious hypoxemia
75%	40 mmHg	Lethal hypoxemia

Patients who are conscious and not obviously deteriorating neurologically should be administered supplemental oxygen via facemask, nasal cannula, nasal oxygen catheter, or transtracheal oxygen catheter. Facemasks tend to stress dogs and cats, and should only be used temporarily, until another form of oxygen (O_2) delivery can be instituted (e.g. nasal O_2). The use of an O_2 cage is generally an ineffective method of administering supplemental O_2 to the severely brain-injured patient, as most of these patients require

frequent or constant monitoring. Oxygen cages do not allow for concomitant close patient observation (requires opening the cage door) and maintenance of a high-oxygen environment. With nasal (Fig. 8.4) and transtracheal O_2 catheters, an inspired oxygen concentration of 40% is provided with flow rates of 100 ml/kg/min and 50 ml/kg/min, respectively. Oxygen concentrations as high as 95% can be delivered with proportionally higher flow rates. Nasal O_2 catheters must not be placed farther than the level of the medial canthus (to avoid entering the cranial vault through a fracture site), and inadvertent jugular vein compression should be avoided while placing a transtracheal O_2 catheter. High flow rates with nasal O_2 catheters may induce sneezing, which has the potential to raise ICP. Patients who are losing or have lost consciousness should be intubated and ventilated. Also, if adequate oxygenation cannot be maintained with high fractional inspired oxygen concentrations (FiO_2) greater than 60%, mechanical ventilation should be instituted. In the patient with oscillating levels of consciousness or airway obstruction secondary to trauma, a tracheostomy tube may be indicated for assisted ventilation. Arterial blood gas measurement is the best way to monitor $PaCO_2$ levels. End-tidal CO_2 measurement is a useful monitoring tool, but tends to underestimate the true $PaCO_2$ levels. Venous CO_2 levels ($PvCO_2$) are also helpful, and are usually less than 5 mmHg greater than $PaCO_2$. However, in patients with perfusion deficits, peripheral $PvCO_2$ levels can be significantly higher than arterial values, and should be interpreted cautiously. Ventilatory rates of 10–20 breaths per minute should keep $PaCO_2$ levels between 25 and 35 mmHg in the absence of significant pulmonary parenchymal disease. While this has been the recommended range of $PaCO_2$ levels to prevent excessive brain vasodilation, recent evidence suggests that $PaCO_2$ less than 30 mmHg may lead to excessive vasoconstriction with the subsequent impairment of CPP. Hyperventilation may be deleterious to patients whose ICP elevation is not due to hypercarbia-induced dilation of brain vasculature. Indiscriminate use of hyperventilation to decrease ICP should be avoided, as excessive vasoconstriction of brain vasculature can decrease CPP.

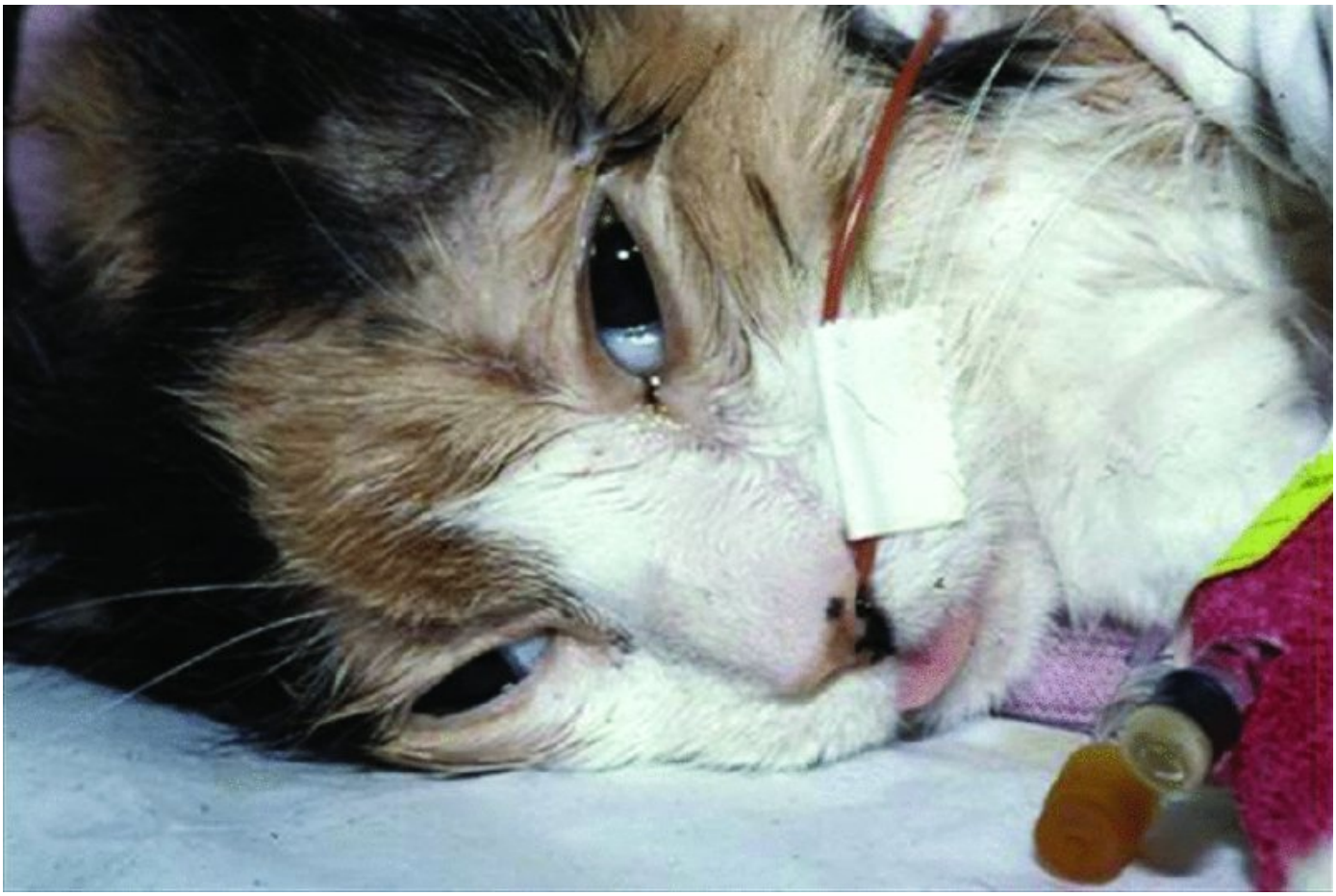

Figure 8.4 Nasal oxygen administration in a head-traumatized cat. (Dewey and Budsberg, 1993.)[19]

Secondary assessment and diagnostic procedures[1, 9, 11, 17, 20, 22, 32, 45, 64, 80]

Once normovolemia and appropriate oxygenation/ventilation are attained, the patient should be more carefully assessed for other injuries to the nervous system (e.g. vertebral fractures/luxations), as well as to other body systems (lungs, abdominal organs, musculoskeletal system). A complete neurologic examination should be performed at this time. If possible, it is best to perform a neurologic assessment of the patient prior to the administration of any sedative drugs (e.g. narcotics). Specific medical therapy for brain injury should begin coincident with the secondary assessment. Additional bloodwork as well as radiographs may be warranted. Imaging of the patient's head is often indicated, especially in those animals that fail to respond to aggressive medical therapy, or deteriorate after responding to such therapy. Skull radiographs are unlikely to reveal clinically useful information in cases of severe head trauma, but on occasion may reveal evidence of depressed fractures of the calvaria (Fig. 8.5). Computed tomography (CT) is the preferred modality for imaging the head in cases of severe brain injury. CT is preferred over magnetic resonance (MR) imaging in head-trauma cases for several reasons. CT images are obtained much more quickly than MR images (an important advantage in the critical patient scenario), patients may be more closely

monitored with standard monitoring systems during CT than during MR because of the large magnetic field required for MR, and acute hemorrhage and bone are better visualized with CT than with MR imaging (Fig. 8.6).

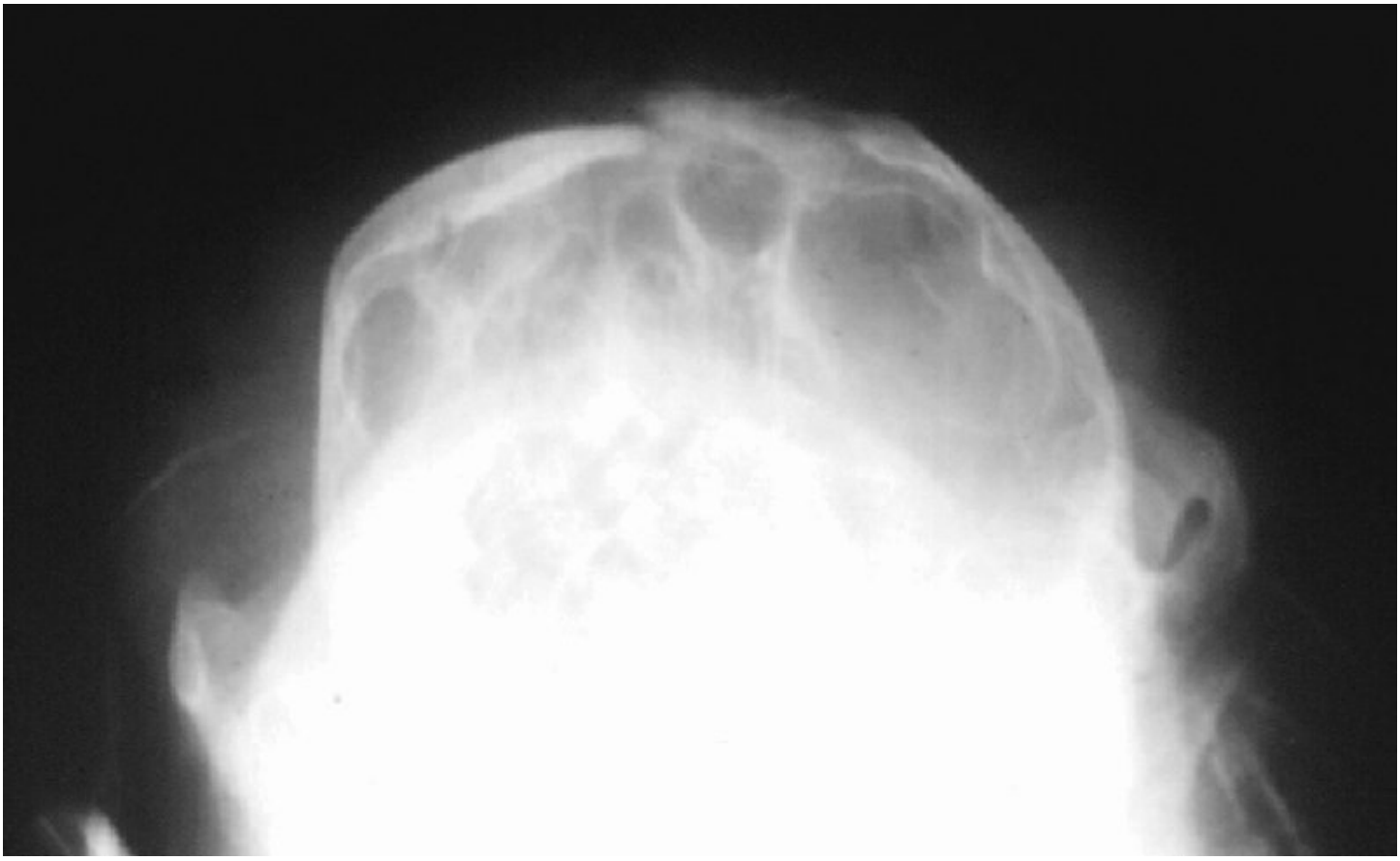

Figure 8.5 Depressed skull fracture in a dog with deteriorating neurologic status following severe head trauma. (Dewey and Budsberg, 1993.)[19]

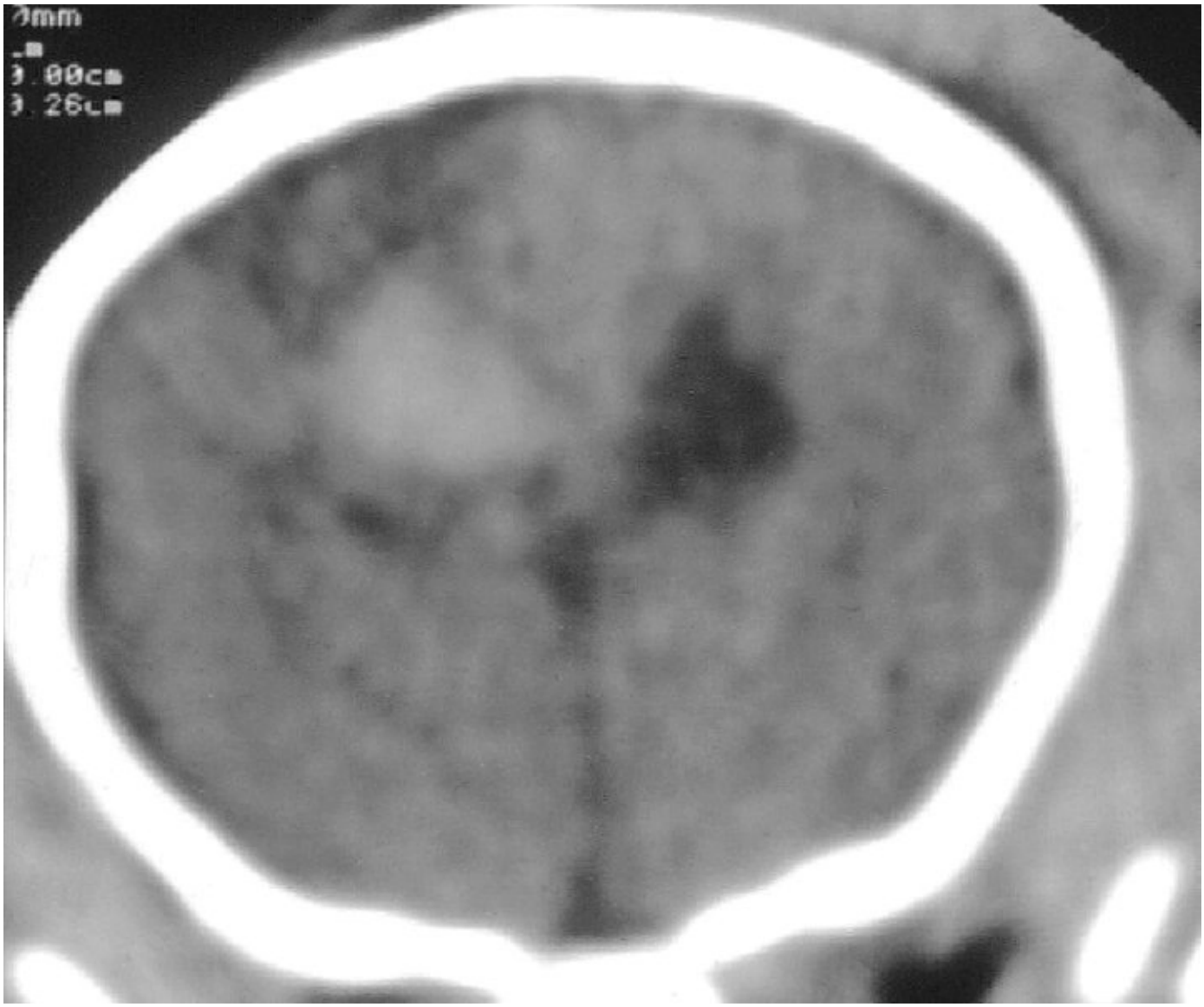

Figure 8.6 Noncontrast, CT brain image of a brain-injured dog. Note the evidence of intraparenchymal hemorrhage. (Dewey, 2000. Reproduced with permission from Elsevier.)[17]

Specific medical therapy for the head- trauma victim[3–5, 9, 11, 13, 16, 17, 19, 22, 23, 27, 29, 30, 32, 33, 39, 43, 44, 48, 51, 52, 57, 58, 59, 64, 65, 68, 70–73, 75, 77, 80–82]

A number of medical therapies have been recommended for the head-trauma victim, most of which are controversial and not definitively proven to affect outcome. In addition to these treatments, proper physical therapy and nutritional support are vital to a positive outcome. In the recumbent patient, the head should be kept slightly elevated (15°–30°) to assist in lowering ICP by facilitating venous drainage from the brain. This should be accomplished using a slant board that prevents lateral flexion of the neck, which can impede jugular venous flow.

A. Mannitol (20–25%)

Mannitol is an osmotic diuretic that has demonstrated efficacy in reducing brain edema and ICP in cases of severe brain injury. There are multiple proposed mechanisms of actions by which mannitol decreases ICP, including reflex vasoconstriction of brain vasculature via decreasing blood viscosity, reduction of CSF production, scavenging free-radical species, and osmotically drawing extravascular edema fluid into the intravascular space. The mechanism thought to be primarily responsible for mannitol's most immediate and profound effects on ICP is reflex vasoconstriction. This response of the brain vasculature to the decreased blood viscosity caused by an intravenous mannitol bolus is linked to the brain's pressure autoregulation mechanism; it allows for improved CPP at a lower brain-blood volume (decreased ICP). The effect of reflex vasoconstriction on ICP occurs within a few minutes, whereas the osmotic action has an effect within 15–30 min. Mannitol's effect on decreasing brain edema lasts between 2 and 5 hrs.

Mannitol is administered intravenously over 10–20 min at a dosage of 0.5–1.5 g/kg. Recent evidence in the human literature supports the concept that higher doses of mannitol (1.4 g/kg) are associated with better outcomes than lower doses (0.7 g/kg) in patients with severe brain injury; this concept, however, has been subsequently challenged by other investigators. Serum osmolality and electrolytes should be monitored with repeated mannitol use; osmolality should be maintained at or below 320 mOsm/l (to reduce the risk of acute kidney injury due to renal vasoconstriction), and electrolytes should be kept within normal limits. It is important to note that measured (by a technique such as freezing point depression), not calculated, osmolality should be monitored, as the increased osmolality is due to an unmeasured osmole (mannitol). Although monitoring measured osmolality and the osmolal gap (the difference between measured and calculated osmolality), and avoiding large changes in either, is recommended, a recent retrospective study of 95 human patients with head trauma showed that neither was correlated with the development of acute kidney injury in patients with head trauma. A useful guideline to prevent possible unwanted side effects of mannitol use is to limit the administration of mannitol to three boluses in a 24-hr period. However, due to the conflicting evidence in the literature regarding the potential for patients to develop kidney injury secondary to mannitol infusion, the authors recommend that mannitol be aggressively administered to patients with progressive neurologic signs that are responding to it. Since mannitol tends to crystallize at room temperature, it should be warmed to approximately 37°C (99°F) and administered through an in-line filter. A frequently raised theoretical concern about mannitol administration is the possibility of exacerbating ongoing brain hemorrhage due to mannitol's osmotic action. This concern is unfounded clinically and should be ignored. Another concern about mannitol use in the head-trauma victim involves the concept of “reverse osmotic shift”; with prolonged contact time (multiple doses or continuous infusions), the extravascular concentration of mannitol in the brain can accumulate and exceed the intravascular concentration. The result of this phenomenon is increased brain edema. With the appropriate use of mannitol, “reverse osmotic shift” is extremely unlikely to occur. In general, once the head-trauma victim is hemodynamically stable, mannitol should be considered a first-line therapy for decreasing ICP and improving CPP. It is important to maintain hydration in patients receiving mannitol, especially if multiple doses are

administered. Key aspects of mannitol and hypertonic saline (discussed below) are presented in Table 8.3. Although previously proposed as having a synergistic effect on reducing cerebral edema when administered with mannitol, recent experimental evidence suggests that furosemide does not reduce cerebral edema alone or in combination with mannitol. Given that the administration of furosemide causes a reduction in intravascular volume, the authors do not recommend administration of this drug in patients with head trauma.

Table 8.3 Comparison of mannitol with hypertonic saline

	Mannitol	**Hypertonic saline**
Mechanism of action	Increases osmotic gradient across BBB Plasma expansion with decreased blood viscosity improves brain oxygen delivery and autoregulation results in cerebral vasoconstriction decreasing cerebral blood volume and ICP Free-radical scavenger	Increases osmotic gradient across BBB Volume expansion Increases cardiac output and blood pressure
Recommended dose	0.5–1.0 g/kg slow over 15–20 min Effects begin within minutes, peak within 15–120 min, duration 1–5 hrs No benefit of CRIs over boluses	7.5% NaCl: 4 ml/kg 3% NaCl: 5.4 ml/kg 1:2 ratio 23.4% NaCl: 6% Hetastarch: 4 ml/kg; Administered over 15–20 min Reassess after Always follow with crystalloid therapy
Side effects	Volume-depletion Electrolyte abnormalities (hyponatremia (pseudo-), hypernatremia, hypokalemia) Acid-base derangements (i.e. metabolic acidosis) Congestive heart failure Acute kidney injury (osmolality > 320 mOsm/l)	Electrolyte abnormalities (hypernatremia, hyperchloremia) Acid-base derangements (i.e. metabolic acidosis)

		Congestive heart failure Acute kidney injury (less common than with mannitol)
Relative contraindications	Hypovolemia	Significant sodium derangements Dehydration

CRI = continuous rate infusion.

B. Hypertonic saline (7%)

Hypertonic saline is a hyperosmotic solution that may be used as an alternative or adjunct to mannitol in patients with head injury. Because sodium does not freely cross the intact BBB, hypertonic saline has similar osmotic effects to mannitol. Other beneficial effects include improved hemodynamic status via volume expansion and positive inotropic effects, as well as beneficial vasoregulatory and immunomodulatory effects. Rebound hypotension is uncommon with hypertonic saline administration because, unlike mannitol, sodium is actively reabsorbed in the kidneys, especially in hypovolemic patients. This makes it preferable to mannitol for treating patients with increased ICP and systemic hypotension due to hypovolemia. Combining hypertonic saline with a synthetic colloid can prolong this volume expansion effect. It is contraindicated in patients with hyponatremia, as it can cause rapid rises in serum sodium concentrations, leading to central myelinolysis and subsequent neurologic dysfunction. In euvolemic patients with evidence of intracranial hypertension, both mannitol and hypertonic saline can have beneficial effects. If an individual patient is not responding to one drug, the other may yield a beneficial response.

C. Glucocorticoids

Despite their traditional role in the treatment of central nervous system (CNS) trauma, there is little evidence to support the use of glucocorticoids in victims of severe head trauma. “Standard” dosing protocols of prednisone and dexamethasone are particularly unlikely to benefit brain-injured patients. Limited experimental evidence of efficacy exists for the “high-dose methylprednisolone” protocol in severe head trauma. This protocol involves the intravenous administration of a 30-mg/kg bolus of methylprednisolone sodium succinate (Solu-Medrol) at time 0, and 15 mg/kg boluses at 2 hrs and 6 hrs. The “high-dose” protocol was suspected to provide therapeutic benefit via free-radical scavenging action, rather than by the activation of steroid receptors. Recent evidence from a large, prospective, randomized, placebo-controlled clinical trial showed significantly increased mortality in people with traumatic brain injury treated with this high-dose protocol. Given this evidence of a detrimental effect in head- injured people and the potential side effects of these drugs in dogs and cats, including gastrointestinal hemorrhage, immunosuppression,

and hyperglycemia, the authors do not recommend the use of corticosteroids in patients with head trauma.

D. Anticonvulsant therapy

Seizures are common after head trauma in people, with reported incidence rates of up to 54%, and patients who have at least one seizure after traumatic brain injury have an 86% risk of having additional seizures within the next 2 yrs. There is recent evidence in dogs that head trauma does lead to an increased likelihood of seizures when compared with the general canine population, but the incidence rate is lower (6–7%) than that reported for people. Posttraumatic seizures are divided into three groups: immediate, occurring within 24 hrs of the trauma; early, occurring 24 hrs to 7 days post trauma; and late, occurring longer than 7 days after trauma. Several controlled clinical trials have been undertaken in human medicine to investigate the efficacy of prophylactic anticonvulsant therapy after head trauma, and a meta-analysis showed an overall reduction in the risk of immediate and early seizures with prophylactic anticonvulsant therapy (relative risk (RR) = 0.3, 95% confidence intervals (CI) = 0.21–0.52), but no effect on risk of late seizures (RR = 1.28, 95% CI = 0.9–1.8). Given these data, short-term prophylactic therapy for 7 days after trauma may be indicated in patients with head trauma, and anticonvulsant therapy should always be instituted for all patients with head trauma who develop immediate or early seizures.

E. Miscellaneous therapies

A number of free-radical scavenging agents have been investigated for potential use in victims of severe head injury. Some examples include lazaroids, dimethyl sulfoxide (DMSO), allopurinol, deferoxamine mesylate, and liposome-encapsulated forms of superoxide dismutase and catalase. Despite experimental evidence of efficacy for these drugs, clinical evidence to support the use of these agents in the head-trauma victim is currently lacking. Similarly, there exists some experimental, yet not clinical, evidence of efficacy for antagonists of opiate and glutamate receptors, as well as several calcium channel blockers. Induction of a barbiturate coma with pentobarbital has been advocated as a “last ditch” effort to decrease metabolic demands of the injured brain, thereby mitigating effects of ischemia and decreasing ICP. In addition to limited evidence of clinical efficacy, induction of a barbiturate coma in a brain-injured patient may be detrimental to survival. Barbiturates may lead to hypotension and/or hypoventilation, both of which will cause increased ICP. Recent experimental and clinical evidence in human head-injured patients supports the induction of moderate hypothermia (32°–34°C, 89.6°–93.2°F) as a means to decrease ICP and improve outcome. Although traditionally thought to decrease ICP via decreasing brain metabolic demands, induced hypothermia is now thought to provide beneficial results, mainly by inhibiting the release of inflammatory cytokines and glutamate. Hyperglycemia (over 200 mg/dl) has been associated with an increased mortality in severely head-injured people. In one veterinary study, the degree of hyperglycemia was found to be correlated with the severity of neurologic dysfunction in brain-injured dogs and cats; however, an association between the level of hyperglycemia and survival was not

found. It is postulated that the provision of extra glucose to the ischemic brain helps to fuel anaerobic glycolysis, with resultant increases in brain lactic acid. Intensive insulin therapy to maintain euglycemia in patients with head trauma has recently been proposed; however, a small prospective clinical trial failed to show an outcome benefit from intensive insulin therapy. Larger clinical trials will be required to determine the utility of insulin therapy in hyperglycemic patients with head trauma.

Indications for surgery[5, 7, 9, 12, 14, 15, 17, 19, 21, 22, 28, 31, 32, 35, 39, 42, 59, 64]

In general, indications for surgical intervention are clearly defined in human head-trauma management. The guidelines for when to pursue surgery in brain-injured people center on the presence and extent of intracranial hemorrhage. Measurements of focal hemorrhage and accompanying midline shifts of the falx cerebri from CT images are combined with ICP measurements in making surgical decisions in people with severe head trauma. Surgical intervention has traditionally played a relatively minor role in canine and feline head-trauma management, due to the belief that clinically significant intracranial hemorrhage is rare in these species. There is some evidence that brain-injured dogs and cats may experience surgically manageable intracranial hemorrhage, similar to people (Fig. 8.7). With the increased availability of CT facilities for dogs and cats, surgery may begin to play a larger role in canine and feline head-trauma management. Other potential indications for surgery in the brain-injured dog or cat include open skull fractures, depressed skull fractures (with associated neurologic impairment), and the retrieval of potentially contaminated bone fragments or foreign material lodged in brain parenchyma (Fig. 8.8). While the surgical removal of focal intracranial hemorrhage is an accepted and proven aspect of human head-trauma management, the use of decompressive craniotomy in human patients with diffuse traumatic brain injury is controversial. A recently completed randomized prospective study in humans with diffuse traumatic brain injury found no advantage to decompressive craniotomy compared with standard treatment methods; in fact, the craniotomy patients had worse Modified Glasgow Coma Scale (MGCS) scores than standard therapy patients, and there was no difference in the mortality rates between the two groups. The value of craniotomy solely as a decompressive surgery is unknown in canine and feline head trauma. It has been demonstrated, however, that in normal dogs and cats combined craniotomy/durotomy results in dramatic decreases in ICP. Surgical intervention should be strongly considered in head-traumatized dogs and cats that are deteriorating neurologically despite aggressive medical therapy.

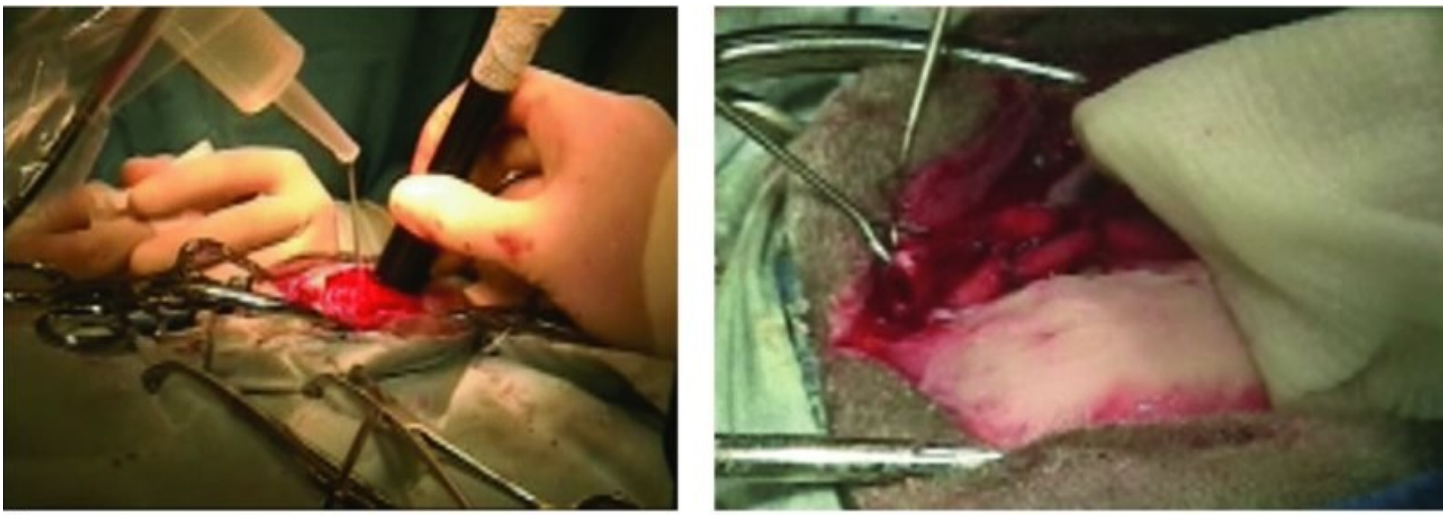

Figure 8.7 (A) location of an intraparenchymal hematoma in a dog using intraoperative ultrasound. (B) removing the intraparenchymal hematoma.

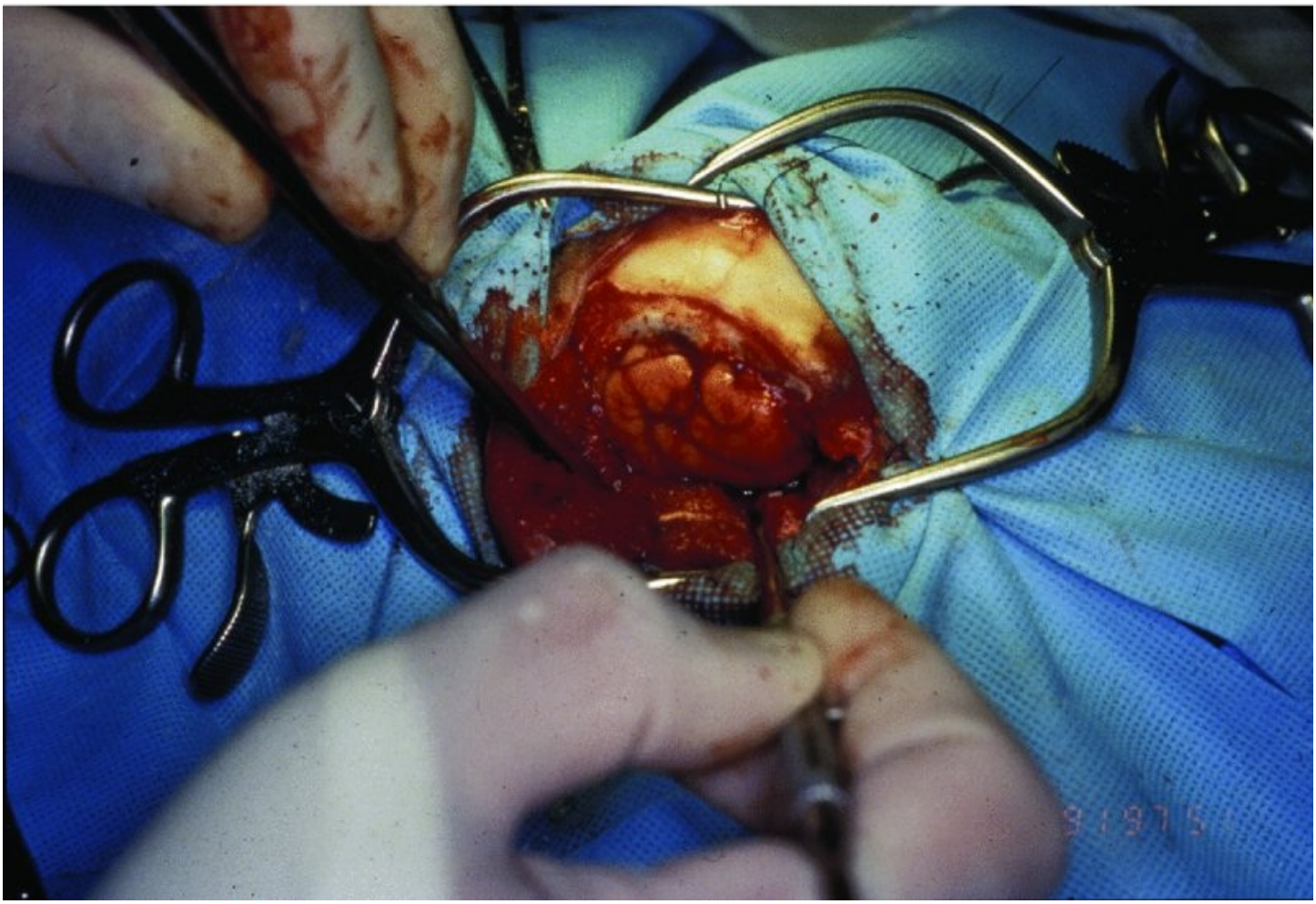

Figure 8.8 Decompressive craniotomy in a dog. The patient had a large bone fragment lodged in the cerebral parenchyma and a midline shift evident on CT imaging. (Reprinted with permission.)[19]

Intracranial pressure (ICP) monitoring[3, 5, 7, 9, 11, 17, 18, 25, 35, 39–41, 47, 49, 60, 61, 64]

Medical and surgical decisions based upon ICP measurements, rather than on gross neurologic findings, have decreased morbidity and mortality in human head-trauma victims. In general, recommendations for human head-trauma victims are to maintain ICP below 20 mmHg and CPP at a minimum of 70 mmHg. Prognostic information can also be obtained from ICP measurements. ICP monitoring is a standard procedure for human head-trauma management, but has only recently been investigated in dogs and cats. A fiberoptic ICP monitoring device has been shown to be both technically easy to place and reliable in dogs and cats. With this monitor, ICP can be measured directly from brain parenchyma. The extremely high cost of the fiberoptic system will likely limit its use in veterinary medicine. An inexpensive, easily implantable, epidural ICP monitoring system has been evaluated in normal cats; this system was found to be comparable in accuracy to the fiberoptic ICP system.

Prognosis and complications[10, 17, 19, 22, 54, 55, 64, 69, 76]

The overall prognosis for victims of severe head trauma is considered guarded to poor. However, the recuperative ability of brain-injured dogs and cats is tremendous, and aggressive therapy may be successful in many apparently hopeless cases. Predicting the outcome of an individual patient is difficult, but several factors may assist the clinician in estimating prognosis. These factors include level of consciousness, presence or absence of brain-stem reflexes, age and general physical status, and presence and extent of other concurrent injuries. A dog or cat that is comatose with absent brain-stem reflexes from the time of impact is generally less likely to recover than a patient who is obtunded with intact brain-stem function. The MGCS scoring system, adapted from a human coma scale, has been shown in one retrospective study to predict survival to 48 hrs in dogs with head injury. Table 8.4 describes the components of the MGCS. The score in each domain is summed, yielding the overall MGCS, which ranges from 3 (severe neurologic deficits) to 18 (neurologically normal). Table 8.5 provides three categories of coma scale severity and the suggested prognosis for each. It is the authors' opinion that the severity of neurologic deficits at admission is poorly correlated with outcome in most dogs and cats with head injury, especially in neonatal or juvenile patients. Even patients with severe neurologic signs at admission can show dramatic improvement in the first 24–48 hrs. Trends in neurologic status over the first 48 hrs are likely to be more predictive of outcome in these patients than isolated evaluation of neurologic status at a single point in time. The MGCS provides a quantitative method for monitoring trends in neurologic status over time. Potential complications associated with brain-injured patients include coagulopathies (e.g. disseminated intravascular coagulation; DIC), pneumonia, fluid/electrolyte abnormalities (e.g. central diabetes insipidus), and sepsis. Seizure activity may develop around the time of trauma (suggesting intraparenchymal hemorrhage) or months to years after trauma (development of a glial “scar” seizure focus). Most of these complications are treatable and/or preventable. Client education is of paramount importance, as persistent or

permanent neurologic deficits in patients with head trauma are common.

Table 8.4 Modified Glasgow Coma Scale

Motor activity	
Normal gait a reflexes	6
Hemi/tetraparesis or decerebrate activity	5
Recumbent, intermittent ext. rigidity	4
Recumbent, constant ext. rigidity	3
Recumbent, constant ext. rigidity and opisthotonus	2
Recumbent, hypotonic muscles, ↓ or absent reflexes	1
Brain-stem reflexes	
Normal PLR and oculocephalic reflexes	6
Slow PLR, normal to ↓ oculocephalic reflexes	5
Miosis OU, normal to ↓ oculocephalic reflexes	4
Pinpoint pupils, ↓ to absent oculocephalic	3
Unilateral, unresponsive mydriasis, ↓ to absent oculocephalic reflexes	2
Bilateral, unresponsive mydriasis, ↓ to absent oculocephalic reflexes	1
Level of consciousness	
Occasional alertness, responsive to environment	6
Depression/delirium, responsive but inappropriate	5
Obtunded, responsive to visual stimuli	4
Obtunded, responsive to auditory stimuli	3
Stuporous, responsive to noxious stimuli	2
Comatose	1

PLR = pupillary light reflex.

Source: Adapted from Platt *et al.*, 2001.[55]

Table 8.5 Modified Glasgow Coma Scale Score Category and Suggested Prognosis.

Score category	**Actual MGCS score**	**Suggested prognosis**
I	3–8	Grave
II	9–14	Guarded
III	15–18	Good

Source: Adapted from Platt *et al.*, 2001.[55]

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