**Treatment of Nervous System Trauma**

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**Head Trauma:** Head trauma is an important cause of morbidity and mortality in both humans and animals. Immediate and appropriate treatment is critical to potentiate an acceptable recovery. Although treatment recommendations in veterinary medicine remain controversial, there are several guidelines for head trauma management. Accurate and frequent assessment of both systemic and neurological injuries can allow for a successful outcome. Additionally, treatment strategies should remain flexible, adjusting to the patient’s needs and changes in neurological status. A complete understanding of intracranial physiology and the effects of injury will aid in the management of dogs and cats with head trauma. The following definitions are useful when discussing head trauma in small animals:

• ICP is the pressure exerted within the skull by the intracranial contents. Normal ICP in a dog is between 5 and 12 mmHg.

• CPP, the pressure of blood flowing to the brain, is reliant on a balance between MAP and ICP: CPP = MAP minus ICP. Elevations in ICP can have a significant impact on CPP, leading to decreased brain perfusion.

• CBF is the rate of blood delivery into the brain and is driven predominantly by CPP. CBF is regulated by cerebral metabolic activity, partial pressure of oxygen and partial pressure of carbon dioxide. The relationship between CPP, CBF and cerebral vascular resistance (CVR) is CBF = CPP/CVR. CVR depends primarily on blood viscosity and vessel diameter.

• Autoregulation is the intrinsic ability of the brain to maintain cerebral perfusion.

• Compliance is the ability of the intracranial contents to decrease in volume in an attempt to maintain normal ICP.

• Concussion is a reversible traumatic paralysis of nervous system function and is immediate in onset. The effects of concussion on brain function may last for a variable amount of time. This term does not describe underlying brain pathology.

• Contusion is a common result of severe head injury, often associated with a concussion. It represents a bruising of the brain surface without rupture of the pia-arachnoid and/or interruption of the brain architecture.

**Neural Energy and Blood Flow:** The brain makes up about 2 percent of the body's weight, yet receives 15 percent of the cardiac output and consumes 20 percent of the body's available oxygen. Since the central nervous system has virtually no oxygen storage capacity, it is absolutely dependent on a continuous, uninterrupted supply of oxygen from the cerebral circulation. Within seconds of cessation of blood flowing to the brain, consciousness is lost and irreversible damage to neural tissues will occur in minutes. One of the important functional properties of cerebral circulation is its ability to maintain a constant blood flow over a wide range of system blood pressure. This ability to autoregulate cerebral blood flow by changing the diameter of cerebral arteries and arterioles is controlled primarily in response to changes in the partial pressure of CO2 in blood. In addition to CO2, secondary control of cerebral blood flow is under regulation by sensing the partial pressure of O2 and by neural regulation by catecholinergic neuron which innervate cerebral blood vessels.

In addition to providing a constant supply of oxygen, cerebral blood flow also provides adequate supply of the major energy source used by the central nervous system, glucose. Neural tissue is dependent upon aerobic glycolysis. When either oxygen or glucose are deprived from the nervous system, lactic acid builds up within the tissue and is one of the factors which results in structure damage following interruption of blood supply to the brain. The nervous system, due to the presence of a carrier-mediated system to capture glucose from blood is very efficient in regulating glucose delivery to the brain. The only other natural substances which can substitute for up to 60 percent of the nervous systems glucose requirements are ketone bodies.

Small amounts of energy go to the production of proteins and neurotransmitter substances. As expected, most of the energy utilized by the central nervous system is used to maintain the sodium/potassium pump to support maintenance of the electrical properties of neurons.

**Spinal Trauma:** Spinal trauma implies external trauma to the vertebral column. The consequences include vertebral fractures, luxations and subluxations, acute disc herniations and soft tissue injuries. Spinal cord contusion, laceration and compression, and nerve root entrapment can all occur as a result of spinal trauma.

Contusive injury to the spinal cord causes primary mechanical injury to the parenchyma and vasculature, and secondary damage that is responsible for an expanding zone of necrosis and apoptosis. The majority of the secondary damage occurs in the 24–48 hour period after the initial injury, but ongoing apoptotic cell death can be detected months and even years later. Primary damage to the spinal cord can be devastating, resulting in transection of the spinal cord. Indeed, displaced vertebral fractures coupled with the clinical finding of paralysis and loss of nociception indicates an extremely poor prognosis for recovery of neurological function.

Secondary injury develops because of biochemical and metabolic events that interact to produce cell death. The mechanisms can be summarized as energy failure, changes in membrane permeability, excitotoxicity, oxidative damage and inflammation. Damage to the vasculature by the initial impact causes energy failure in neurons and glia, which in turn causes failure or reversal of ion pumps, loss of membrane polarization and entry of sodium and calcium into cells, producing cytotoxic edema. Reactive oxygen species (ROS) (free radicals) produced as a result of hemorrhage, ischemia and mitochrondrial failure cause damage to cell membranes and ongoing destruction of the microvascular bed, increasing the zone of ischemia. Intraparenchymal hemorrhage has also been linked to a rapid increase in expression of Trmp4, a gene that encodes monovalent cation channels. Although the mechanism of this phenomenon is poorly understood, prevention of Trmp4 expression results in reduced hemorrhage and improved outcome. Finally, local perfusion is reduced by increased intraspinal cord pressure due to cytotoxic edema and hemorrhage and by a failure of autoregulatory mechanisms.

The importance of decreased perfusion in initiating and perpetuating secondary damage is clear. It is critical, therefore, to maintain BP and oxygenation within normal limits. Both hypotension and hypoxemia can greatly exacerbate injury severity.

Membrane permeability is increased by the initial mechanical injury, thus exacerbating the imbalance of intra- and extracellular ions. In addition, extracellular concentrations of the excitotoxin glutamate (and, to a lesser extent, aspartate) are elevated. This results from neuronal release caused by the initial mechanical injury and energy failure, and by failure of astrocytic uptake. Activation of NMDA, alpha-amino-3-hydroxy-5-methyl-4-isoxazole propionic acid (AMPA) and kainite receptors by glutamate increases sodium and calcium entry into neurons. Calcium entry causes cell death by activation of apoptosis-inducing proteases such as calpain and caspase, initiation of an inflammatory response by activation of phospholipase A2 and further diminishing energy sources by binding intracellular phosphates.

The inflammatory response has both beneficial and detrimental effects. Early production of thromboxane and prostaglandins by activation of phospholipase A2 and microglial production of cytokines, such as interleukin-1 (IL-1) and tumour necrosis factor-alpha (TNF-α) initiate the inflammatory response. There is massive recruitment of neutrophils to the injured tissue within a few hours, followed by macrophage recruitment that peaks around 5 days after injury. Necrotic tissue is removed eventually, leaving a cystic cavity (syrinx). Activated phagocytic cells can release substances that are toxic to adjacent intact tissue, causing demyelination and axonal damage; a reduction in macrophage influx has been associated with an improved outcome. However, the inflammatory reaction plays an important role in tissue repair, revascularization and axonal sprouting.

**Peripheral Nerve Injury:** The most common cause of monoplegia is injury to a nerve plexus or peripheral nerve. The traumatic insult produces immediate neurologic deficits, which either improve or stay the same over time.

Neurapraxia is a transient loss of nerve function following injury, with no resultant nerve degeneration. Neurapraxia is analogous to concussion in the brain and spinal shock in the spinal cord, and is a physiologic dysfunction of the nerve. Because neurapraxia has a better prognosis than does structural damage, the two must be differentiated. The duration of neurapraxia in animals is unknown, but in man it is thought to last from 3 to 12 weeks. Serial neurologic examinations and EMG can be used to differentiate neurapraxia from neurotmesis and aid in forming an accurate prognosis for recovery of function.

Neurotmesis is the complete severance of a nerve. The nerve function is never recovered unless surgical repair is performed. Axonotmesis is a rupture or severance of axons within a nerve but with the supporting structures of the nerve spared. Ruptured axons may regenerate and eventually reinnervate the muscles.Most nerve injuries are caused by stretching, direct blows, excessive pressure, or injections and are a combination of neurapraxia and axonotmesis. Associated local hemorrhage and edema also contribute to the loss of nerve function.When the axon is ruptured, the portion detached from the cell body completely degenerates, a process referred to as Wallerian degeneration. The portion still attached to the cell body may degenerate toward the cell body one or two nodes of Ranvier. After about I week, regeneration begins. Distally, the axon and myelin degenerate but the Schwann cells proliferate to form a neurolemmal tube through which regrowing axons can find their way back to the appropriate muscle to reinnervate it. The rate of axon growth is about 1 to 4 mm per day, or an average of 1 inch a month. The distance an axon can regrow is limited by continual shrinking of the neurolemmal tube. Function is also inhibited by fibrosis of denervated muscles fibers, which occurs after time.The closer the nerve injury is to the muscle it must reinnervate, the better the prognosis for anatomic contact and reinnervation of muscle before fibrosis occurs. Any injury over 12 inch from a muscle will probably be unable to make anatomic contact with the muscle before the neurolemmal tube closes. If anatomic contact can be made, the neurolemmal tube may be so small that proper myelinization of the new axons is impossible. Slow axonal conduction time and muscle fibrosis severely retard function. When an injury can be localized to a certain portion of the nerve, the distance from the injury to the muscle to be reinnervated may be measured and time for regeneration may be estimated using the 1 inch per month as a guide. The minimal recovery time is usually several months.

Positive waves and fibrillation potentials are seen in denervated muscles 5 to 7 days following the nerve injury. The presence of motor unit action potentials (MUAP) indicate that some axons are still intact, even though no function may be found on the neurologic examination.

Nerve stimulation and the ability to elicit an evoked response indicate that some axons within the nerve are still intact. The amplitude of the evoked response may be a guide to the prognosis for recovery. A small amplitude, between 100 to 200 mcV, indicates a poorer prognosis than a 1,000 to 5,000 mcV or greater response. Serial evaluations of motor nerve conduction velocities may aid in determining the prognosis. If the initial motor nerve conduction velocity is slow and remains slow, the prognosis is poorer than if the initial motor nerve conduction velocity is slow and returns to normal. A severed nerve responds to electric stimulation distal to the site of injury for about 72 hours, but loses the response to electric stimulation immediately proximal to the site of injury. With brachial plexus avulsions, it is often difficult to place the electrode proximal to the lesion site; therefore, if there is no response to electric stimulation distal to the injury site 72 hours or more after the trauma, the nerve most likely is not intact.

Serial examinations, noting improvement in voluntary movements, sensory levels, spinal reflexes, and serial EMG studies, are the greatest aids in determining an accurate prognosis for peripheral nerve injuries.

**Therapy:** If the nerve has intact axons following an injury, if the distance that the ruptured axons have to regenerate is not prohibitive, and if the owner is willing to make the commitment for daily nursing care, then a physical therapy program may be outlined. Most physical therapy programs combine heat, massage, and joint manipulation to keep the circulation in the limb as good as possible to prevent stasis and local hypoxia, which contribute further to muscle atrophy and fibrosis. Joints develop tendon contractures because of the decrease in tendon movements. The carpus and tarsus are often the last joints to be reinnervated, so they commonly contract and the animal walks on the dorsum of the paw. The elbow joint may also become contracted in a flexed position in brachial plexus injuries that spare the musculocutaneous nerve. The limb is often carried flexed at the elbow; the tendons contract and hold it in this position.

Hot towels may be placed around the denervated limb and the muscles massaged or a whirlpool of warm water used to increase circulation to the muscles. A regimen of 15 minutes twice daily is preferred. Then the affected carpus, tarsus, or elbow should be stretched in extension twice daily for 10 to 15 minutes to keep the tendons supple. A spoon splint may be applied to keep the digits, carpus, or tarsus extended and to aid the animal in using the limb without these joints collapsing. The splint should be placed on the limb for only a few hours a day between physical therapy sessions, as it restricts circulation to the muscles. The splint should be removed overnight.The animal may drag the dorsum of the paw on the ground or rough surface and because of the loss of sensation may develop severe abrasions. The lesions can become infected and osteomyelitis of the digits can result. A protective stocking or boot should be placed over the digits to prevent abrasions. If abrasions occur, they should be kept clean and treated with topical antibiotics and further protection provided. The animal should be kept from licking the wounds, as this only further abrades the denervated skin.

During certain stages of the regeneration period, the animal may begin to mutilate the paw. This may be caused by a regeneration of sensory nerves and a tingling or itching sensation. This period is usually transient, but can be very frustrating to the owner and veterinarian, as the animal may produce severe lesions by selfmutilation, regardless of attempts to bandage and protect the foot. Elizabethan collars, muzzles, wire-mesh foot guards, and leather boots are among the many things that have been tried in individual cases. Prednisone 1 mg/kg orally divided every 12 hours, then reduced by half every 3 to 5 days may be tried during this period, but often has little effect.

The overall prognosis for most nerve injuries depends on the severity of the injury, how much of the dysfunction is caused by neurapraxia, and how much by axonotmesis, how far the injury occurs from the muscles denervated by it and on the owner's commitment to provide months of physical therapy.If no change has occurred over 1 month or if there is no response to electric stimulation, surgical exploration of the nerve may be made for possible repair if the distance from the nerve injury to the muscles the nerve needs to innervate is less than 5 to 6 inches. Peripheral nerve surgery techniques are well described elsewhere.If electromyography is not available, serial neurologic examinations should be performed over several months. If there has been no change for several months and surgical repair is impossible, then surgery for joint fusion or tendon transplants of the carpus or tarsus may be considered. Amputation of the limb is a last resort, considered only when no improvement occurs after several months of critical evaluation.

**TCM Diagnosis and Treatment:** Peripheral nerve injury in TCM is still trauma which is one of the mishaps of life. The treatment principles are to activate blood, ease tendons and muscles and to activate meridians that pass through the region involved. Acupuncture points chosen would be to achieve these principles including local points, points at the ends of the meridians (to activate them) and special paralysis points within the region involved, such as the lie feng points on the involve leg. General Qi and blood points can also be added (ST36, caudal shen shu, BL17, and SP10). TCM herbal therapy may include Ding Tong San with additional constituents to direct it and support neural repair.