Treatment of traumatic brain injury in Morepork owls: a review of diagnostic and treatment options

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Abstract

The Morepork (*Ninox novaeseelandiae*) is a small owl (150-200g adult weight) of the Family Strigidae. It is common throughout most of New Zealand and closely related to the Southern boobook (*Ninox boobook*) and Tasmanian boobook owls (*Ninox leucopsis*) found in Australia. Morepork are commonly presented to the Wildbase Hospital at Massey University, New Zealand. The vast majority of admissions are related to traumatic injuries with many showing some degree of neurological dysfunction. This review of case records indicates that only 35% of morepork admitted with a traumatic brain injury (TBI) recovered to the point of release. A failure to return to normal neurological function could be the result of direct trauma to neurological tissues acquired at the time of impact or ongoing damage with altered physiology compounding the initial trauma. While little can be done to treat primary brain insults, treatments that target minimising secondary brain injury can improved the outcome of TBI. Diagnostic and treatment options for TBI in human and small animal medicine were reviewed for their potential application to avian medicine with the aim of improving treatment of TBI cases in morepork that will increase recovery rates and long term survival of birds returned to the wild.

Case review - Morepork presented to Wildbase Hospital

Clinical case records were reviewed of 98 morepork owls admitted to Wildbase Hospital between March 2007 and July 2015. Within these records 90% (88/98 cases) were presented for traumatic injuries, while chronic internal parasitism (6/98), premature fledging (2/98), glue on feathers (1/98) and severe chronic uveitis (1/98) accounted for the remainder. A bird presenting with a traumatic eye injury is likely to have suffered concurrent neurological trauma. However, cases of ocular trauma were not included in this review unless the case records mentioned observed neurological deficits. Many of the trauma cases had suffered multiple injuries, complicating any review of treatments and outcomes. To focus more specifically on traumatic brain injury (TBI), cases with observed neurological deficits without significant additional musculoskeletal injury were collated in this review.

Seventeen cases were identified that presented with primary clinical signs consistent with traumatic brain injury, including aural haemorrhage, head tilt, circling and cranial nerve deficits. All were treated with supportive fluids (administered orally in 16 cases and intravenously (IV) in 1 case), pain relief (meloxicam, butorphanol or both) and nursing care (for example well-padded, room temperature enclosure). One case received hyperosmotic therapy (mannitol IV) and supplemental oxygen therapy. Survey radiographs revealed no detectable cranial abnormalities in any of the birds. Haematology parameters comprising packed cell volume, total solids and an estimated white cell count and differential were obtained in the majority of cases (10/17) and were within normal limits. Plasma biochemistry was infrequently reported due presumably to limited blood volumes collected and cost. Cases were monitored by repeat neurological assessment for improvement in neurological deficits. If neurological deficits resolved then birds were released or transferred to a rehabilitation facility prior to release. This was the outcome in 6 out of the 17 (35%) cases. Birds that failed to show any improvement in neurological signs over 7 to 14 days or clinically deteriorated where euthanased as it was unlikely that they would ever be fit for return to the wild. Of the 17 cases reviewed 6 (35%) were euthanased. Three birds (18%) recovered to have minimal neurological deficits and were also transferred to a rehabilitation facility for assessment of suitability for release, unfortunately records of the outcome of these 3 cases is unavailable. In 2 of the 17 cases the birds died during hospitalisation despite supportive treatment.

An equal proportion of cases (35%) that were admitted with TBI were found to recover as were being euthanased. A belief that these results could be improved has led to a review of diagnosis and treatment of TBI in avian patients. Publications specific to the treatment of avian TBI are limited. Therefore current papers in human and small

animal critical care were reviewed for applicability to avian species, particularly a small nocturnal raptor.

Anatomy of the avian head

The avian skull is a light weight compact box that both protects and restricts the size of the brain tissues. In most species of birds the skull bones are largely fused and pneumatic to varying degrees. The most prominent feature of the skull is the exaggerated orbit accommodating the proportionately large eyes and their scleral ossicles, making concurrent eye injury a common component of avian head trauma. In most birds, unlike mammals the brain is orientated almost vertically within the cranium (King and McLelland, 1984). Whether this makes the soft tissues of the brain more or less susceptible to trauma is unclear. The avian brain has markedly enlarged optic lobes, correspondingly small olfactory lobes (in most species), smooth cerebral hemispheres and a large cerebellum, when compared to the mammalian brain (King and McLelland, 1984).The smooth appearance of the cerebral cortex in birds compared to mammals, was previously believed to indicate birds were not capable of "thinking" beyond reflexes. However, bird brains have evolved with cortical cells (present on the exterior of the cerebral cortex in mammals) retained deep within the subcortical nuclei. Therefore they are capable of processing the same information they just rely on a different area of the brain to do so (Orosz and Bradshaw, 2007).

Pathophysiology

The pathophysiology of TBI is separated into primary and secondary injury. Primary brain injury occurs at the time of impact, its severity determined by the magnitude of the forces acting upon it. These injuries can include dural tears, epidural and subdural bleeding, cortical contusions or lacerations and traumatic axonal injury (DiFazio and Fletcher, 2013). These types of direct parenchymal damage to the structures of the brain are beyond the treatment of clinicians, therefore treatment is focused on recognising and minimising secondary injury.

Secondary TBI occurs from minutes to days following the primary injury, when systemic and local factors combine to compound the primary insult and lead to greater neurological dysfunction. The systemic factors can include hypoxia, hypotension, acid-base disturbances, electrolyte abnormalities and systemic inflammation (DiFazio and Fletcher, 2013). They act by directly or indirectly contributing to compromised cerebral blood flow (Sande and West, 2010).

Local cerebral injury leads to enhanced activity of excitatory neurotransmitters, generation of reactive oxygen species and production of pro-inflammatory cytokines (Sande and West, 2010). Excessive release of excitatory neurotransmitters, such as glutamate, increases the metabolic activity of neurons and leads to depletion of ATP. This neuron energy deficit results in dysfunction of the cell membrane and leads to influx of calcium and sodium into the cell, with accompanying intracellular damage and cell death (Sande and West, 2010). Localised areas of hypoperfusion, tissue acidosis and high levels of iron liberated by haemorrhage, particularly in lipid rich brain tissues, trigger the production of reactive oxygen species that perpetuate secondary brain injury via oxidative damage (DiFazio and Fletcher, 2013). The release of pro inflammatory cytokines by damaged cells mediate a number of inflammatory processes activating the coagulation cascade, disrupting the blood brain barrier and dilating cerebral blood vessels causing a loss of cerebral blood pressure autoregulation (Sande and West, 2010).

The nervous tissue of the brain together with blood and cerebrospinal fluid, exist within a bony case that both protects and restricts its volume. Therefore an increase in the volume of any one of these internal components will necessitate a corresponding decrease in the volume of one or more of the others, called intracranial compliance. If this does not occur or the increase overwhelms the physiological compensatory pathways there will be an increase in intracranial pressure (DiFazio and Fletcher, 2013; Sande and West, 2010). Increased intracranial pressure leads to decreased cerebral blood flow, which is detected by the vasomotor centre, initiating a sympathetic response of increasing mean arterial pressure to try to increase cerebral perfusion pressure. This increased mean arterial pressure is detected by baroreceptors in the carotid arteries leading to a reflex bradycardia (Sande and West, 2010). Detection of this reflex bradycardia (Cushing's reflex) is considered a grave sign of impending brain stem herniation and death and attempts to reduce intracranial pressure should be made immediately (DiFazio and Fletcher, 2013).

Diagnostics

Diagnosis of suspected head trauma is largely dependent on an initial physical assessment and a neurological examination. Further diagnostics can provide important information about potential for ongoing secondary brain injury as well as providing indicators for monitoring and prognosis.

Physical examination

The initial triage physical examination will focus on the cardiovascular and respiratory stability of the patient and the identification of any other life threatening injuries. The early identification and treatment of hypotension and hypoxaemia is suggested to contribute more to improved outcomes from TBI than any other factor (Sande and West, 2010).

Blood analysis

Packed cell volume, total solids, CBC and plasma biochemistry (particularly glucose and electrolytes) are considered to be the minimum database in the head trauma patient. In wild raptors, blood lead analysis is also often recommended in all patients displaying neurological signs. All of these assays can provide important information but often need to be further prioritised as to the timing and size of the available blood sample. The earlier that this information is available the better it can be used to direct treatment, however, the stress of handling the bird for sampling must be considered when timing the collection of blood. It is not uncommon for blood collection to wait until the patient is stable enough for general anaesthetic and radiographs, as a result clinical indicators such as mucous membrane colour and moisture, brachial vein refill time and a general assumption that all presenting wildlife are partially dehydrated is used initially to direct treatment.

Avian neurological examination

During the initial physical examination of any patient basic assessment of neurological status can be made. When the patient is stable a complete neurological assessment can be made to assess the severity, location and consequently prognosis of traumatic brain injury patients. Throughout hospitalisation, repeated neurological assessment, either complete or of select parameters specific to each case, is also important in the evaluation of response to treatment and likely prognosis for release. The avian neurological examination is modelled on the mammalian procedure that more clinicians are familiar with, allowing for some important differences in anatomy and behaviour. The use of a standard neurological examination form adapted for avian patients will allow the examination to be thorough and assist with record keeping.

Observations are made from a distance of mentation, attitude, gait and posture. Altered mentation presenting as obtundation, stupor or coma could indicate diffuse damage to the cerebral cortex or functional damage to pathways through the brainstem. These neurological signs need to be differentiated from systemic disease, where generalised depression and lethargy can present similarly. The normal body position of the bird is achieved by a complicated interaction between sensory input, central integration, motor output and the musculoskeletal system; alterations at any of these levels could produce abnormalities in posture. Attitude changes resulting in nystagmus, head tilt, leaning, falling, rolling or circling are common in head trauma patients and can result from central (cerebellum, brainstem or spinal cord) or peripheral (inner ear, vestibulocochlear nerve) dysfunction. Normal gait and movement requires co-ordinated voluntary limb movements involving functional cerebral, cerebellar, vestibular and proprioceptive pathways (Clippinger et al., 1996). Behavioural responses of patient species can mask or make interpretation of neurological deficits difficult. The morepork, for example, has a tendency to freeze when stressed and may not behave in a consistent manner.

Together with a head tilt, cranial nerve deficits are the most commonly recorded neurological lesion in morepork suspected to have traumatic brain injuries. Table 1 outlines the major tests used in birds to assess function of cranial nerves II through VIII (Clippinger et al., 2007; Orosz and Bradshaw, 2007).

Cranial nerve I, the olfactory nerve, is difficult to evaluate objectively in birds but deficits could be indicated by changes in appetite and feeding behaviour. The remaining four cranial nerves (glossopharyngeal, vagus, accessory and hypoglossal) in birds have variable closely related origins within the brainstem and significant anastomoses between nerve fibres, making them difficult to assess individually, damage to any or all could be involved in dysphagia and regurgitation. Abnormal tongue movements or position generally results from glossopharyngeal (CN IX) or hypoglossal (CN XII) dysfunction. Dysfunction in the parasympathetic innervation to the cranial viscera or heart could be due to damage to the vagus (CN X) and/or accessory (CN XI) nerves (Clippinger et al., 2007).

Postural reactions and some spinal reflexes can be evaluated in birds as in mammals with some alterations in technique, but interpretation can be difficult due to behavioural differences and small patient size. These assessments are usually used to describe dysfunction of neurological structures below the brain and therefore will not be covered in detail in this review of TBI. Abnormalities in these reactions and reflexes may be seen with head injury; however they would be accompanied by dysfunction in other areas of the neurological exam ination already covered.

In many wildlife cases, a specific localisation of neurological lesions within the brain, brainstem or cranial nerves, is difficult and may be only of academic value. Lesions can be too diffuse to exactly locate to one brain region beyond, obvious cranial involvement. Species related behavioural characteristics can mask normal responses or make altered states hard to evaluate in the stressful environment of the examination. In most cases it will not have a significant impact on treatment choices. However, changes in neurological abnormalities over time are of more value where marked deterioration, or failure to improve, over 7-10 days carry a poor prognosis for recovery and release to the wild.

Table 1: Features of cranial nerve (II-VII) assessment in birds.
Adapted from (Clippinger et al., 2007; Orosz and Bradshaw, 2007)

Assessment	Normal function	Neurological structures involved	Comments
Menace	Eyelids close in response to perceived threat	Initiated by cerebellum Optic nerve (CN II) - sensory Trigeminal nerve (CN V) – motor	Learned response Can be difficult to assess in very frightened bird - absence does not necessarily equal blindness Air movement during the test can confuse sensory input being tested - menace being apparently present does not rule out blindness.
Pupillary Light Reflex	Pupil constricts in response to focused light source	Optic nerve (CN II) – sensory Oculomotor (CN III) – motor	Striated muscle component to iris muscle - voluntary override possible, minimised by doing early in examination. Complete decussation of the optic nerve means there should not be a consensual light reflex but incomplete bony septum between the orbits might lead to some light reaching the collateral retina.
Globe position	Centrally located and normally responsive pupil	Ventrolateral deviation – oculomotor nerve (CN III) Dorsolateral deviation – trochlear nerve (CN IV) Medial deviation – Abducens (CN VI)	
Third eyelid position	Normal retracted position	Abducens nerve (CN VI)	Striated muscle component in birds so prolapse does not indicate loss of sympathetic tone.
Palpebral reflex	Blink in response to touching the medial canthus	Trigeminal nerve (CN V)	Both sensory and motor component are within the trigeminal nerve in birds
Facial expression	Normal symmetry of the face	Facial nerve (CN VII)	Limited facial musculature in birds and feather coverage can make this hard to assess.
Nystagmus	Normal physiologic nystagmus with fast phase in direction of horizontal movement.	Vestibulocochlear nerve (CN VIII) Brainstem	If unilateral is often associated with head tilt and circling/rolling.

Ocular examination

An important part of the examination of TBI morepork is a thorough ocular examination, examining both internal and external structures of the eye. Ocular pathology will be a significant contributor to prognosis for release and even though they are night hunters, visual acuity is still important (Pauli et al., 2007). The large and prominent eyes of the morepork make them prone to concurrent damage with TBI. Altered cranial nerve function can lead to lack of the normal protective mechanisms of the eyes and can predispose to secondary eye pathology that may also adversely affect the prognosis for release of a wild raptor.

Auricular examination

Examination of the external ear canals for obvious damage and haemorrhage can increase the suspicion of TBI and also provide prognostic information, particularly in nocturnal raptor species.Nocturnal hunting species, including the morepork require accurate hearing, making the aural examination potentially more important in these species than an ocular examination. Hearing can be extremely difficult to assess in the avian patient and not many rehabilitation facilities have the ability to evaluate hunting ability. In the absence of post-rehabilitation survival data it is impossible to know if morepork assessed clinically recovered enough for release are fully functional in the wild.

Radiology

Survey radiographs when the patient is stable are used to identify concurrent injuries and possibly skull fractures (Clippinger et al., 2007). The multiple super-imposed, often pneumatic bones of the avian skull make interpretation of cranial radiographs difficult. The endotracheal tube in anaesthetised animals should be removed while skull radiographs are taken to avoid further obscuring detail.

Computer tomography

In small animal medicine, computed tomography (CT) is the recommended diagnostic imaging method for assessment of TBI. The perceived benefits of CT are; faster acquisition time, less expense and better imaging of bone and acute haemorrhage compared to MRI (Sande and West, 2010). The increasing availability of CT equipment in veterinary practices may lead to the increase in its use in avian TBI cases. However, there are two enduring problems with avian cranial CT imaging; the often small size of the patient can negatively affect detail, and the pneumatic structure of avian skull bones makes it difficult for computer algorithms to differentiate between bone and soft tissue structures as well as it does in mammals. The use of iodinated contrast media can enhance soft tissue detail, particularly where there is increased blood flow, dose rates described in the literature vary from 0.45 mg/kg to 2.22mg/kg (Clippinger et al., 2007). To date CT has been attempted at Wildbase in only one of the reviewed Morepork cases; and no detectable abnormalities were observed nor were any apparent on gross post mortem in this bird, despite significant functional neurological impairment.

Magnetic resonance imaging

MRI is used in human medicine and increasingly in small animal veterinary medicine for better imaging of subtle cerebral parenchymal damage. Like CT the often small size of the patient is a technical limitation to the use of MRI, slices of 3mm are recommended as a balance between imaging small lesions and achieving satisfactory resolution, or alternatively continuous image capture if available and anaesthesia time permits (Clippinger et al., 2007). Even if technical considerations can be minimised, the cost and poor availability of MRI makes its widespread use in avian medicine uncommon for now. In small animal medicine the recommendation with head trauma cases is initially the use of CT, with MRI reserved for those cases that are refractory to treatment and other diagnostics have not indicated a conclusive cause of the neurological signs (DiFazio and Fletcher, 2013).

Cerebrospinal fluid analysis

The analysis of CSF would be of most use in infectious, neoplastic or inflammatory neurological disorders and differentiating them from TBI. Anatomical features of the avian patient makes collection of a CSF sample by lumbar puncture almost impossible. Instead collection is done by inserting a needle through the foramen magnum between the cerebellum and dorsal surface of the medulla and aspirating fluid from the subarachnoid space or fourth ventricle (Clippinger et al., 2007). Venous sinuses that are in close proximity to the sampling site make haemorrhage and subsequent death a risk of this procedure. This procedure is also contraindicated in cases with increased intracranial pressure and therefore is not applicable in TBI.

Electroencephalography (EEG)

EEG is the study of the electrical events that occur within the cerebral cortex, the summation of resting potentials of neurons in various states of depolarisation and repolarization. The normal EEG responses to various stimuli have been well documented in domestic poultry. However, there are known to be considerable between species variations, causing great difficulty in interpreting results as different from a normal baseline (Clippinger et al., 2007). Therefore its use is largely restricted to research settings.

Treatment

There is marked variation in the chronicity of traumatic brain injury at time of presentation in wildlife cases. Initial assessment and triage must also be made on the probability of recovering full function and having a releasable patient at the end of any treatment. Wild raptors presenting with serious ocular abnormalities or severe spinal trauma are considered very poor prospects for release and are euthanased on admission (Pauli et al., 2007). If there is deemed a reasonable chance of full recovery from TBI, treatment often commences before full diagnostics have been completed. The focus of TBI treatment is to minimise secondary brain injury by maintaining normal systemic blood pressure (and therefore tissue perfusion), optimising systemic oxygenation and decreasing intracranial pressure.

Fluid therapy

Cerebral perfusion pressure is determined by systemic blood pressure and intracranial pressure. After traumatic brain injury the increased intracranial pressure means that the effect of any decrease in the systemic blood pressure on cerebral perfusion is going to be magnified. Correction of hypovolaemia in the head trauma patient is the first priority in avoiding ongoing secondary brain injury (Sande and West, 2010). Historically in human and small medicine there were concerns that rapid intravenous fluid administration would exacerbate brain oedema. A lack of evidence that dehydration reduces brain

oedema and substantial evidence that hypotension leads to significantly worse outcomes in humans with traumatic brain injury has resulted in recommendations to immediately restore normotension and adequate cerebral perfusion pressure (Sande and West, 2010).

Assessment of hydration status during initial physical examination is essential with estimates of fluid deficits based on clinical findings and blood analysis. A wild avian patient could be presented to the hospital anywhere from immediately following the head trauma to several days afterward. Cases will therefore vary across the spectrum from hypovolaemic shock with increased heart rate and decreased capillary refill time through apparent fluid homeostasis to advanced dehydration. The major implication of variable hydration status is in the choosing a route of fluid administration. Some mildly affected birds with normal swallow reflexes and righting ability will be able to be managed by minimally invasive oral fluid boluses. Other more neurologically affected patients with significant blood pressure abnormalities will require intravenous or intraosseous fluids. The placement of intravenous or intraosseous catheters in small birds, like the morepork, can be highly stressful without anaesthesia. The use of inhalational gaseous anaesthetics (as are commonly used in avian patients) are not recommended in small animal patients with TBI due to the risk of cerebral vasodilation increasing intracranial pressure in patients where it is already elevated and autoregulation is disrupted (Armitage-Chan et al., 2007). Presumably this risk also exists for avian patients and consequently the need for a catheter must be measured against the danger the anaesthetic may exacerbate the problem you are trying to correct. In birds severely neurologically affected the placement of the catheter will be made technically easier by their inability to resist, but stress related changes in blood pressure may still occur. Chemical restraint without the use of inhalational anaesthetics may be possible with protocols of intranasal midazolam/butorphanol combinations at a variety of published dose rates up to 2mg/kg midazolam and 1mg/kg butorphanol (Mans and Sladky, 2013). The ability to reverse the midazolam component with flumazenil (0.05mg/kg) might make these protocols useful for the short term restraint of compromised TBI patients. The effect of these sedation protocols on TBI patients is unknown and requires further investigation.

There is disagreement between published recommendations for fluid type used to restore normovolaemia in the small animal TBI patient. Fluid options available include isotonic crystalloids, hypertonic crystalloids, artificial colloids and blood products or any combination of these. In the normal brain the blood brain barrier is readily permeable to water but nearly impermeable to ions and larger molecules, with the movement of water between vascular and extravascular compartments determined more by osmolality than plasma oncotic pressure (Syring, 2005). However, in the injured brain the blood brain barrier may be locally or globally disrupted, increasing permeability to both ions and colloidal particles with both main types of fluid at equal risk of increasing cerebral oedema. The conclusion that has been drawn in human and small animal medicine, is that the overall benefit of restoring cerebral perfusion pressure is greater than any aforementioned risk (DiFazio and Fletcher, 2013; Sande and West, 2010; Syring, 2005).

Isotonic crystalloids, such as 0.9% saline or Hartmann's solution, would be the fluid type of choice in birds stable at admission that are able to tolerate oral fluids. In these birds initial oral gavage with 1-2.5% of body weight and then calculation of fluid deficit (assuming 5-10% dehydration depending on clinical presentation) and maintenance requirements (50mL/kg/day) for replacement over the following 48 hours.

Artificial colloids and hypertonic saline both have the capacity to rapidly expand circulating blood volume and improve cerebral perfusion. Colloids may have a more prolonged effect on intravascular volume than hypertonic saline; however, there are additional benefits to the use of the latter in TBI patients that will be discussed further below. A combination of hypertonic saline followed by artificial colloids has been advocated in both small animal and avian medicine as more effective in small volume resuscitation than either product alone (Rivas et al., 2011; Sande and West, 2010). The recognised side effects of artificial colloids include transient impaired coagulation and acute kidney injury (Cazzolli and Prittie, 2015; Gauthier et al., 2015). The increased risk of haemorrhage may be particularly relevant to TBI patients where it may exacerbate intracranial bleeding. There is currently controversy over the use of colloids in both human and small animal medicine. An association between colloid use and increased mortality in human sepsis patients has led to a banning of the use of artificial colloids in these patients in Europe (Adamik et al., 2015). The small animal veterinary community are currently highlighting the lack of data on this topic and in the interim recommending the cautious use of colloids (Adamik et al., 2015; Cazzolli and Prittie, 2015). Data on the safety of colloids in avian medicine is even more lacking that in small animal medicine. Even if the human findings do not prove to be true in veterinary medicine, the decline in use of colloids in human medicine may make them increasingly less available and/or higher cost to veterinary medicine. Irrespective of the resuscitation fluid type chosen all should be followed with isotonic crystalloid therapy to maintain normotension.

Oxygen therapy

Decreased oxygen delivery to the cerebral tissues perpetuates ongoing secondary brain injury. Once steps have been taken with fluid support to correct hypovolaemia and hypotension in the TBI patient consideration should be given to maintaining normal oxygen levels in

the blood. This may or may not require oxygen supplementation. Oxygenation status can be assessed by respiratory rate and pattern, mucous membrane colour and auscultation (DiFazio and Fletcher, 2013). If hypoxaemia is suspected in the avian TBI patient supplemental oxygen can be supplied via a number of delivery methods. In the conscious patient an oxygen rich cage is the preferred method as additional handling will lead to increased stress and consequently increased intracranial pressure. In human and small animal medicine hyperoxaemia is a concern with oxygen therapy for brain injury when 100% oxygen is supplied via intranasal or intratracheal delivery (DiFazio and Fletcher, 2013). The potential for respiratory inflammation and vasoconstriction effects of hyperoxia, has led to calls for a reassessment of oxygen therapy in human medicine (Sjöberg and Singer, 2013). Birds are susceptible to pathology of the respiratory tract when chronically exposed to oxygen concentrations approaching 100% (Jaensch et al., 2001), therefore concerns similar to those in human medicine might be valid in avian medicine. However, the oxygen level achievable in a non-airtight enclosure and an oxygen flow rate of 2-3L/min are unlikely to reach these concentrations. The effects of exposure to lower oxygen concentrations for prolonged periods in birds are unknown, but clinically appears to be beneficial to birds presenting in respiratory distress.

Temperature

Unlike most avian emergencies, active warming of the TBI patient is contraindicated. With increasing temperature there will be increased cerebral cellular metabolism and vasodilation leading to increased intracranial pressure. Therapeutic hypothermia has been advocated in human medicine and there are occasional reports in small animal veterinary medicine. The mechanisms of action of hypothermia in brain injury are unclear and there are conflicting results on the whether periods of hypothermia improve patient outcome (Sande and West, 2010). While the value of hypothermia is still debated, it can be agreed that hyperthermia should be avoided in brain injury patients. Therefore, the best current recommendation is to maintain patients at a temperature of around 21 to 23 degrees Celsius.

Positioning

In recumbent patients elevating the head to 15-30 degrees above the horizontal can improve venous drainage from the brain. This reduction in cerebral blood volume can reduce intracranial pressure and increase cerebral perfusion pressure without impacting on cerebral oxygenation (DiFazio and Fletcher, 2013). Care should be taken, both when positioning and in the placement of any bandaging material, to avoid impeding jugular venous drainage, this is particularly a consideration in avian species with a longer neck.

Pain management

Pain and agitation can increase intracranial pressure and hence contribute to secondary brain injury, making analgesia an important part of managing the TBI patient (Sande and West, 2010). Potential side effects of various analgesics, including hypotension, hypoventilation and sedation, can also exacerbate secondary brain injury. Therefore drug choices and dose rates must be balanced carefully to provide adequate analgesia without adding to secondary brain injury or impeding neurological assessment. Opioids are often the analgesic of choice because to their reversibility and relative safety when titrated to effect (DiFazio and Fletcher, 2013). In small animal medicine constant rate infusions (CRI) are the preferred method of administration of opioids in head injury cases (DiFazio and Fletcher, 2013). A lack of pharmacokinetic and pharmacodynamics studies on opioid CRIs in avian species means that current protocols are centred around repeated opioid injections, for example butorphanol IM at 4 mg/kg q6-8hr. Nonsteroidal anti-inflammatories are not recommended until normovolaemia has been restored and adequate renal perfusion is assumed.

Hyperosmotic agents

Mannitol and more recently hypertonic saline have been used in the treatment of increased cranial pressure in TBI patients. Both act to increase the osmotic gradient across the intact parts of the blood brain barrier to draw water from the cerebral tissues into vessels and reduce oedema and therefore intracranial pressure. Mannitol is administered in small animal medicine by slow intravenous infusion at 0.5 to 1.0 g/kg over 20 minutes inducing osmotic effect 15 to 30 minutes later (DiFazio and Fletcher, 2013). In contrast doses of as low as 0.25 to 2mg/kg have been recommended for birds (Rockwell, 2015). Transient plasma expansion and decreased blood viscosity leads to cerebral vasoconstriction and decreased cerebral blood volume, therefore lowering intracranial pressure without compromising cerebral blood flow. Mannitol is also thought to have free-radical scavenging effects that may reduce oxidative damage in secondary brain injury. Diuretic effects of mannitol can exacerbate hypotension and dehydration, lead to electrolyte abnormalities and acute renal injury (Sande and West, 2010). Consequently Mannitol is contraindicated in hypovolaemic patients and should not be administered in TBI until this has been addressed. If the blood brain barrier is significantly compromised a translocation of the mannitol molecules into cerebral tissue could cause an increase in cerebral oedema, the direct opposite to the aim of treatment (Rockwell, 2015). Another theoretical concern with the strong osmotic effects of mannitol is the exacerbation of intracranial haemorrhage, clinical evidence for this effect in any species is limited and the benefits probably outweigh this risk (Sande and West, 2010).

The benefits of hypertonic saline in addressing hypovolaemia have been discussed previously in this review. There has been increasing interest in human and small animal medicine in the use of hypertonic saline in TBI for its hyperosmotic potential (Thongrong et al., 2014). Like mannitol the mechanism of action of hypertonic saline in reducing secondary brain injury is believed to be the osmotic effects across the BBB reducing cerebral volume and reducing blood viscosity therefore improving cerebral blood flow. Clinical data in human medicine has suggested additional mechanisms of action of hypertonic saline in TBI. These other potential mechanisms included shrinkage of endothelial cells improving cerebral blood circulation, a reduction in cerebrospinal fluid production and immunomodulatory effects (Mortazavi et al., 2012). Dose rates for hypertonic saline treatment of TBI vary but in small animal medicine doses of 5.3mL/kg IV of 3% NaCl or 4mL/kg IV of 7.5% NaCl are most often recommended (DiFazio and Fletcher, 2013; Sande and West, 2010). The increase in intravascular volume after hypertonic saline administration can be transient lasting as little as 15 minutes, but these effects can be prolonged by the concurrent administration of colloids (Sande and West, 2010). Research suggests however, that with or without colloids, hypertonic saline induced reductions in intracranial pressure persist for much longer than the vascular effects and significantly longer than mannitol (Sakellaridis et al., 2011). Hypertonic saline should be avoided in patients with significant sodium derangements or advance dehydration.

Current human medicine recommendations still favour mannitol over hypertonic saline in the treatment of increased intracranial pressure in TBI. Clinical and research data is gathering which suggests hypertonic saline may reduce ICP faster, more significantly and for longer than mannitol with less undesirable effects (Mortazavi et al., 2012; Sakellaridis et al., 2011; Thongrong et al., 2014). Hypertonic saline may also promote neurocellular survival beyond that which could be expected from just the reduction in intracranial pressure (Soustiel et al., 2006).

Anticonvulsant therapy

Seizure activity leads to increased cerebral metabolic demand, cerebral oedema, hyperthermia and increasing intracranial pressure (DiFazio and Fletcher, 2013). The end result is additional secondary brain injury, therefore any seizures in the TBI patient should be rapidly controlled.

Prophylactic antiepileptic medications are recommended in the first 7 days following TBI in human patients as preventing seizures occurring has led to improved outcomes (Sande and West, 2010). Without the monitoring equipment available to human medical practitioners, ongoing monitoring of the avian head trauma patient is often dependent on the repeated assessment of neurological function and behaviour. Many of the anticonvulsants used are also sedatives that would complicate these repeated evaluations. As a result, in avian TBI, as in small animal medicine, the recommendation is the aggressive treatment of seizures if they occur but not prophylactic anticonvulsant therapy (DiFazio and Fletcher, 2013). Birds in status epilepticus are initially treated with diazepam at 0.5mg/kg IV or 1mg/kg IM, repeated at 2 minute intervals for up to 3 doses (Delk, 2012). If seizures continue despite this protocol, continuous-rate infusions can be considered (1mg/kg/hr), however are unlikely to be considered in wild birds due to cost and a very poor prognosis for return to the wild.

Corticosteroids

Corticosteroids have been long advocated in neurological disease for their anti-inflammatory action, however in human medicine the use of glucocorticoids in head trauma patients has been shown to increase mortality (Edwards et al., 2005). Corticosteroids will also induce hyperglycaemia which has been linked with increased free radical production, excitatory amino acid release, cerebral oedema and altered cerebral vasculature, hence potentiating further neurological injury (Sande and West, 2010). Consequently the use of corticosteroids in human and veterinary brain injury is contraindicated. The sensitivity of birds to the systemic side effects of corticosteroids, particularly immunosuppression, makes their use also contraindicated in avian TBI.

Implications for morepork TBI

One case included in this case review was the first morepork to received hypersmotic therapy, intravenous fluids and oxygen therapy. Unfortunately this bird showed deteriorating neurological signs over 14 days in hospital and was euthanased. Severe TBI in human and small animal medicine has a guarded prognosis for moderate or better return to function. Aggressive intervention, particularly in restoring normal blood pressure and managing intracranial pressure improve the outcome in human and small animal medicine (Sande and West, 2010; Soustiel et al., 2006). In wildlife cases we require nothing less than an apparent full return to function in order for the bird to be releasable. To date fluid replacement, pain relief and supportive care have been the cornerstones of TBI treatment in morepork owls at Wildbase. This review has highlighted the diagnostic and treatment options for TBI and will contribute to the application of more targeted treatment in the future. Improved treatment of TBI cases may not only improve the proportion of owls that make it to release but may also improve the long term survival of those that do.

References

Adamik, K. N., Yozova, I. D., and Regenscheit, N. 2015. Controversies in the use of hydroxyethyl starch solutions in small animal emergency and critical care. Journal of Veterinary Emergency and Critical Care 25, 20-47.

Armitage-Chan, E. A., Wetmore, L. A., and Chan, D. L. 2007. Anaesthetic management of the head trauma patient. Journal of Veterinary Emergency and Critical Care 17, 5-14.

Cazzolli, D., and Prittie, J. 2015. The crystalloid-colloid debate: Consequences of resuscitation fluid selection in veterinary critical care. Journal of Veterinary Emergency and Critical Care 25, 6-19.

Clippinger, T. L., Bennett, R. A., and Platt, S. R. 2007. The avian neurologic examination and ancillary neurodiagnostic techniques: A review update. Veterinary Clinics of North America: Exotic Animal Practice 10, 803-836.

Clippinger, T. L., Bennett, R. A., and Simon, R. P. 1996. The avian neurologic examination and ancillary neurodiagnostic techniques. Journal of Avian Medicine and Surgery 10, 221-247.

Delk, K. 2012. Clinical management of seizures in avian patients. Journal of Exotic Pet Medicine 21, 132-139.

DiFazio, J., and Fletcher, D. J. 2013. Updates in the management of the small animal patient with neurologic trauma. Veterinary Clinics of North America: Small Animal Practice 43, 915-940.

Edwards, P., Arango, M., Balica, L., Cottingham, R. et al. 2005. Final results of MRC CRASH, a randomised placebo-controlled trial of intravenous corticosteroid in adults with head injury-outcomes at 6 months. Lancet 365, 1957-1959.

Gauthier, V., Holowaychuk, M. K., Kerr, C. L., Bersenas, A. M. E., and Darren Wood, R. 2015. Effect of synthetic colloid administration on coagulation in healthy dogs and dogs with systemic inflammation. Journal of Veterinary Internal Medicine 29, 276-285.

Jaensch, S. M., Cullen, L., and Raidal, S. R. 2001. The pathology of normobaric oxygen toxicity in budgerigars (*Melopsittacus undulatus*). Avian Pathology 30, 135-142.

King, A. S., and J.McLelland. 1984. Birds: Their structure and function. Bath, United Kingdom: The Pitman Press.

Mans, C., and Sladky, K. K. 2013. Clinical management of an ectopic egg in a Timneh African grey parrot (*Psittacus erithacus timneh*). Journal of the American Veterinary Medical Association 242, 963-968.

Mortazavi, M. M., Romeo, A. K., Deep, A., Griessenauer, C. J., Shoja, M. M., Tubbs, R. S., and Fisher, W. 2012. Hypertonic saline for treating raised intracranial pressure: literature review with meta-analysis. Journal of Neurosurgery 116, 210-221.

Orosz, S. E., and Bradshaw, G. A. 2007. Avian neuroanatomy revisited: From clinical principles to avian cognition. Veterinary Clinics of North America: Exotic Animal Practice 10, 775-802.

Pauli, A., Klauss, G., Diehl, K., and Redig, P. 2007. Clinical techniques: considerations for release of raptors with ocular disease. Journal of Exotic Pet Medicine 16, 101-103.

Rivas, A. E., Whittington, J. K., and Emerson, J. A. 2011. The use of hypertonic saline and hetastarch in an american kestrel (falco sparverius) with traumatic brain injury. Wildlife Rehabilitation Bulletin 29, 9-12.

Rockwell, K. 2015. Therapeutic review: Mannitol. Journal of Exotic Pet Medicine 24, 120-122.

Sakellaridis, N., Pavlou, E., Karatzas, S., Chroni, D., Vlachos, K., Chatzopoulos, K., . . . Karaouli, V. 2011. Comparison of mannitol and hypertonic saline in the treatment of severe brain injuries. Journal of Neurosurgery 114, 545-548.

Sande, A., and West, C. 2010. Traumatic brain injury: a review of pathophysiology and management. Journal of Veterinary Emergency and Critical Care 20, 177-190.

Sjöberg, F., and Singer, M. 2013. The medical use of oxygen: A time for critical reappraisal. Journal of Internal Medicine 274, 505-528.

Soustiel, J. F., Vlodavsky, E., and Zaaroor, M. 2006. Relative effects of mannitol and hypertonic saline on calpain activity, apoptosis and polymorphonuclear infiltration in traumatic focal brain injury. Brain Research 1101, 136-144.

Syring, R. S. 2005. Assessment and treatment of central nervous system abnormalities in the emergency patient. Veterinary Clinics of North America: Small Animal Practice 35, 343-358.

Thongrong, C., Kong, N., Govindarajan, B., Allen, D., Mendel, E., and Bergese, S. D. 2014. Current purpose and practice of hypertonic saline in neurosurgery: A review of the literature. World Neurosurgery 82, 1307-1318.