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**A STUDY OF BRAIN INJURY**

**IN**

**NEW ZEALAND SEA LION PUPS**

A thesis presented in partial fulfilment  
of the requirements for the degree of  
Doctor of Philosophy

*at*

Massey University,  
Palmerston North,  
New Zealand

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# ABSTRACT

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The New Zealand sea lion (*Phocarctos hookeri*) is a threatened species endemic to New Zealand. The majority of breeding in this species occurs on the Auckland Islands in the sub-Antarctic, and recent population estimates indicate that pup production is declining. Trauma is a significant cause of mortality in New Zealand sea lion pups, and much of this is believed to be caused by adult and subadult males, that bite, crush, shake and throw young pups.

In this thesis, a number of techniques are used to determine the role played by traumatic brain injury in the mortality of NZ sea lion pups. The findings of gross necropsy examinations show that pups have numerous lesions indicative of traumatic brain injury, including skull fractures and subdural haemorrhages, and that pups die due to crushing and impact injuries. Although some pups have gross lesions considered in human paediatric medicine to be indicative of shaking injury, detailed histological and microbiological studies of sea lion pups show that most of these are associated with meningitis due to *Klebsiella pneumoniae*. This bacterium is a common cause of pup mortality.

Immunohistochemical techniques are used to demonstrate that axonal injury is common in sea lion pups, but show that shaking is not a common mechanism of this pathological process. Instead, most axonal injury is found to be due to hypoxia-ischaemia, and evidence that raised intracranial pressure has occurred is comparatively common in dead pups. The combined findings of histological and immunohistochemical studies suggest that lesions such as optic sheath haemorrhage, intracranial subdural haemorrhage, spinal sub-meningeal haemorrhage, and optic nerve axonal injury could be caused by perturbations to vascular, intra-ocular, intracranial and subarachnoid pressure rather than being a direct result of trauma as is proposed in shaken baby syndrome.



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# GLOSSARY

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<i>acceleration</i>	the change in velocity over time. Can be positive or negative (deceleration)
<i>AMPA/KA receptors:</i>	$\alpha$ -amino-3-hydroxy-5-methyl-4-isoxazolepropionic acid/kainic acid receptor. A membrane-bound glutamate receptor
<i>ATP:</i>	adenosine triphosphate. An energy-containing nucleotide produced by ATP-synthase
<i>axotomy:</i>	physical separation/tearing of an axon
<i>biomechanics:</i>	the study of mechanical forces as they apply to biological systems
<i>blood-brain barrier:</i>	the anatomical structures responsible for prevention of uncontrolled movement of fluid and solute between the cerebral blood vessels and the brain parenchyma
<i>brain herniation:</i>	movement of brain tissue from one anatomical compartment into another
<i>brain swelling:</i>	enlargement of the brain that occurs due to increased intravascular or extravascular fluid (e.g. cerebral oedema), resulting in flattening of gyri, shallow sulci, and herniation of brain tissue



<i>bridging veins:</i>	the veins that pass from the leptomenigeal surface through the subarachnoid space and dura mater, to empty into the intradural venous sinuses
<i>calvarium:</i>	the domed upper part of the skull comprising the frontal, parietal and occipital bones
<i>cerebral autoregulation:</i>	the maintenance of cerebral blood flow within homeostatic limits in response to changes in central venous pressure, intracranial pressure and metabolic demands
<i>cerebral oedema:</i>	accumulation of excessive amounts of extravascular fluid within brain tissue
<i>compressive strain:</i>	a force that results in tissues or structures being moved closer together
<i>concussion:</i>	transient loss of consciousness following a head injury
<i>contre-coup contusion:</i>	a contusion occurring remote to the site of impact. Historically these were said to occur opposite to the site of impact, but in human beings most occur on the frontal and temporal lobes, irrespective of impact site. The pathogenesis may involve tearing of parenchyma as it moves against bony protuberances or meningeal structures such as the falx cerebri
<i>contusion:</i>	disruption of the brain parenchyma following trauma, leading to haemorrhage and necrosis
<i>coup contusion:</i>	a contusion that occurs at the site of impact

<i>cytoskeleton:</i>	the microtubules, neurofilaments and microfilaments that make up the structural elements of a cell
<i>cytotoxic oedema:</i>	swelling of glial cells that results from damage to the energy-requiring membrane ion pumps, with subsequent influx of ions and fluid
<i>depressed fracture:</i>	the result of a focal impact where the outer table of the skull is depressed below the surface of the unaffected bone, and the inner table of the skull is pushed into the parenchyma
<i>diffuse axonal injury:</i>	both a neuropathological and clinical entity. The clinical syndrome injury involves immediate loss of consciousness followed by prolonged coma in the absence of a mass lesion. The neuropathological entity comprises widespread damage to axons throughout the parasagittal cortex, corpus callosum, internal capsule and long tracts of the brainstem
<i>dynamic loading:</i>	rapid application of a force, usually over a period of between 2 and 25 milliseconds
<i>excitotoxicity:</i>	excessive activation of excitatory glutamate receptors in the brain, resulting ultimately in cell death
<i>fast axonal transport:</i>	rapid (up to 400mm per day) transport of intracellular substances along microtubules
<i>global ischaemia:</i>	inadequate blood supply to the entire brain
<i>hypoxia:</i>	decrease in availability of oxygen to a tissue

<i>impact loading:</i>	the force resulting from direct contact between a tissue and a rigid object
<i>impulse loading:</i>	the force resulting from sudden acceleration or deceleration of tissue
<i>inertia:</i>	acceleration or deceleration forces without impact
<i>intracranial pressure:</i>	pressure within the cranial cavity, dependent upon central venous pressure, cerebral perfusion pressure and soft tissue/fluid volume of the brain and vasculature
<i>intradural haemorrhage:</i>	haemorrhage that originates within the dense fibrous layer of the dura mater
<i>ischaemia:</i>	lack of blood supply to a tissue relative to its needs
<i>lamina cribrosa:</i>	part of the sclera that is penetrated by axons of the optic nerve
<i>mechanical loading:</i>	the application of force(s) to a tissue
<i>mechanoporation:</i>	rapid movement of calcium ions into a neuron following transient membrane depolarisation which occurs as a result of mechanical deformation of the neuronal soma or axon
<i>microtubule:</i>	polymers of tubulin that make up part of the neuronal cytoskeleton and play a role in intra-cellular transport

*mitochondrial membrane permeability transition pore:*

a protein-lined 'hole' (pore) in the inner membrane of the mitochondria, which can open following traumatic brain injury and allow flux of ions across the membrane

*neurocranium:*

the portion of the skull that encloses the brain, including the calvarium as well as the temporal and basisphenoid bones.

*neurofilament:*

the class of intermediate filament found in neurons

*NMDA receptors:*

*N*-methyl *D*-aspartate receptor. A voltage-dependent membrane-bound glutamate receptor

*node of Ranvier:*

unmyelinated portions of axons found between myelinated internodes

*otariids:*

eared seals (fur seals and sea lions)

*pan-necrosis:*

Death of neurons as well as other cellular elements in an area of brain affected by focal ischaemia

*phocids:*

'true' seals. These species do not have pinnae

*pinnipeds:*

a suborder of carnivorous marine mammals with limbs specialised as flippers

*polygynous:*

an hierarchical social system whereby mature males defend a territory within which a group of females is sequestered. Females are comparatively free to enter and leave the territory

*pond fracture:* similar to a depressed fracture, but with no displacement of the inner table of bone

*rotational acceleration:* acceleration about an axis

*selective neuronal necrosis:* necrosis of specific populations of neurons that are particularly susceptible to ischaemia. Occurs with global ischaemia

*shaken baby syndrome:* a syndrome seen in human infants with inflicted brain injury proposed to be due to shaking. The typical syndrome comprises encephalopathy with subdural and retinal haemorrhages

*shear forces:* sliding forces involving differential movement between layers of tissue

*skull:* the bones of the head exclusive of the mandibles but including the neurocranium, zygomatic processes and the facial, maxillary, and palatine bones

*spinal sub-meningeal haemorrhage:*

haemorrhage between the spinal dura mater and the spinal cord. Can involve haemorrhage between the dura mater and the parietal layer of the arachnoid mater (subdural haemorrhage) or haemorrhage between the parietal layer of the arachnoid mater and the spinal cord parenchyma (subarachnoid haemorrhage)

<i>static loading:</i>	the gradual application of a force over a period of greater than 200 milliseconds
<i>strain:</i>	deformation of tissue resulting from the application of a force
<i>stress:</i>	application of force to a tissue
<i>subdural haemorrhage:</i>	haemorrhage into the subdural compartment, which is made up of loose dural border cells at the inner aspect of the dura mater
<i>tensile strain:</i>	a force that results in tissues or structures being moved further apart
<i>translational acceleration:</i>	acceleration in a linear plane
<i>vasogenic oedema:</i>	loss of intravascular fluid into surrounding parenchyma following damage to cerebral blood vessel walls