BIOMECHANICAL RESPONSES IN AN OVINE MODEL OF NON-ACCIDENTAL HEAD INJURY (SHAKEN BABY SYNDROME)

1Baptiste Sandoz, 1Robert Anderson, 2Qinqin Liu, 2Stephen Helps, 2John Finnie, 2Peter Blumbergs and 2Robert Vink

1CASR, The University of Adelaide, Engineering Annex, Gate 5, Frome Road, Adelaide SA 5005, Australia, 2Hanson Institute Centre for Neurological Diseases, Institute of Medical and Veterinary Science, PO Box 14 Rundle Mall, Adelaide SA 5000, Australia; email: baptiste.sandoz@free.fr

SUMMARY
The main physiological consequences of a shaken baby syndrome (SBS) are well characterized, whereas the nature of the forces and accelerations of the head during the assault, and their relationship with the clinical presentation of SBS remain unknown. One of the dominant controversies in the SBS is whether a head impact is necessary to produce pathology or whether shaking alone is sufficient to injure the brain. There is currently no satisfactory animal model in which to investigate the biomechanics of the SBS. The principal aim of this study was to record the acceleration levels of a juvenile ovine head during a shaking event. One triaxial accelerometer and one motion sensor were glued on the skull of 10 lambs that were manually shaken. The accelerations, positions and orientations of the heads were collected and assessed. Further studies will correlate neuropathological changes with these biomechanical events.

INTRODUCTION
One of the major unresolved issues in SBS is to determine if a head impact is necessary to produce pathological injuries or if shaking alone is sufficient [1]. While some physical or numerical model exists, validations of injury criteria are still lacking [2]. To correlate brain injuries with mechanical thresholds, a large animal model is needed [3].

The lamb has a disproportionately large head, a relatively large gyrencephalic brain, and weak neck muscles, similar to that of a human infant, which permits significant movement of the immature brain within the skull during shaking. A previous study detailed the pathological changes occurring in the brains of lambs after manual shaking [4] and the aim of the present study was to examine the acceleration of the lamb head during these shaking events.

METHODS
The following protocol was approved by both animal ethics committees of the University of Adelaide and the Institute of Medical and Veterinary Science.

Ten 7 to 10-day-old lambs were anaesthetised (isoflurane) in oxygen-enriched air and ventilated for the duration of the experiment. During the period of shaking, the endotracheal tube remained in place and reconnected to the anaesthetic machine immediately after shaking to ensure that no hypoxic episode occurred. The lambs were manually grasped under the axilla of the forelimbs and vigorously shaken for 30 seconds with enough force to snap the head back and forth onto the back, similar to the actions believed to occur in the SBS. This was repeated 10 times over a total period of 30 minutes, including 3 minutes of rest time between each shake. After cessation of shaking, lambs were placed in the sphinx position for 6 hours. They were maintained under anaesthesia until killed by perfusion fixation of the brain with 4% paraformaldehyde. At no time did the animals regain consciousness.

Two probes were screwed into the skull in order to measure intracranial pressure (ICP) and the brain oxygen levels, before and after the shaking episodes. Arterial pressure was measured continuously.

Prior to the shaking, one triaxial accelerometer and one motion sensor were screwed in a plastic support and glued onto the skull. In order to assess the relative motion between the head and the torso, a second motion sensor was sutured under the axilla. The acceleration of the head was acquired at 2000 Hz using an 8 gram triaxial piezoresistive accelerometer from Endevco© (model 7268C). The position and orientation of the lamb’s head was registered using the Fastrak© system (Pholemus): the two 9.1 gram motion sensors were alternately detected into a generated magnetic field at 60 Hz. The instrumentation of the lamb's head is shown Figure 1.

Figure 1: Instrumentation on the lamb's head.
The sensors were located in a skull anatomical reference frame using a coordinate measuring machine (Microscribe©, Immersion) with an accuracy of 0.38 mm. The center of mass position of the lamb head was previously calculated by processing CT-Scan images of one lamb, based on pixel HU density.

**RESULTS AND DISCUSSION**

Accelerations, positions and orientations of each lamb’s head were collected during the shaking episodes. An example of the resultant acceleration (at the accelerometer location) is shown Figure 2. Shaking often produced contact between the lamb’s head and the chest and back. The acceleration reached up to 60 g when the head struck the dorsal surface of the thorax, and about 20 g otherwise. The frequency of shaking was about 2 Hz, with each episode producing 50-60 cycles of shaking.

The data are currently being processed to calculate the linear and rotational accelerations and velocities of the head's center of mass, after which head injury parameters will be available.

![Figure 2: Trace of the resultant acceleration of the lamb's head during one episode of shaking.](image)

Injury data are still being collated, but the model is known to produce neuronal perikaryal and axonal changes. Neuronal perikaryal changes are widely distributed in the brain and spinal cord, but axonal immunoreactivity is largely confined to the rostral cervical spinal cord [4].

**CONCLUSIONS**

This study presents for the first time mechanical data from an animal model of Shaken Baby Syndrome. Further experiments, including the addition of a head impact, will be performed in order to compare the present data with that derived from impact-shaking. Ultimately, mechanical data will be correlated with the pathophysiology in this ovine model.

**ACKNOWLEDGEMENTS**

The authors wish to thank Andrew van den Berg, Jeff Dutschke, Adam Wells, Renee Turner, Jim Manavis, Peter Blumbergs and Roger Byard for their assistance. This research was funded by a project grant from the Australian National Health and Medical Research Council.

**REFERENCES**