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Implantable Wireless Intracranial Pressure Sensors for the Assessment of Traumatic Brain Injury

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Introduction

Background:

•Increased Intracranial Pressure (ICP) is a consequence of various neurological disorders such as brain tumors, traumatic brain injury (TBI), blast induced brain injury (bTBI), and hydrocephalus.

•Each year, at least 1.7 million people sustain a traumatic brain injury (TBI) in the United States, and 70,000 people, including 10,000 babies, suffer from hydrocephalus.

•Without a prompt and appropriate management of elevated ICP, there remains a considerable risk of secondary brain injury following TBI and long term severe disability.

Importance:

1. Implantation in animals to elucidate sequelae of human head injury using animal models.
2. Help to determine prognosis, and aid in determining the outcome of treatment.
3. A reliable mean of assessing the therapy method.
4. Bring insight to the mechanism of head injury.

Two Different Designed ICP Sensors

Analog ICP Sensor (AICP):

Top and bottom views of complete wireless analog ICP device

Design Features:

1. Subdural sensor placement using capacitive MEMS sensor (Murata Electronics Oy, Vantaa, Finland).
2. Pressure information varies the oscillation frequency of Schmitt trigger oscillator modulating a 2.4 GHz RF oscillator, and is coupled to a planar inverted-F (PIFA) antenna.
3. Biocompatible and MRI compatibility.

Digital ICP Sensors (DICP):

Top and bottom views of complete wireless digital ICP device

Advanced Design

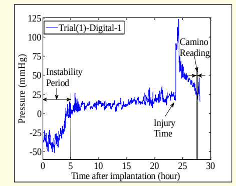
Design Features:

1. Texas Instruments' eZ430-RF2500
   - CC2500 2.4 GHz transceiver.
   - MSP430 ultra-low-power microcontroller.
2. Capacitive MEMS sensor.
3. PIFA/Annular Slot antenna – In-house design.

Added advanced features:

•Computer interface. •Multi-sensor operation.
•Sensor calibration. •Power management and control.

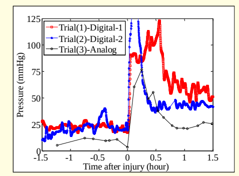
Results



Pre-injury baseline:
15.6 ± 5.3 mmHg

The Camino ICP reading: 22-26 mmHg and our wireless ICP measured 23.79 ± 2.94 mmHg.

Digital ICP measurements for two days

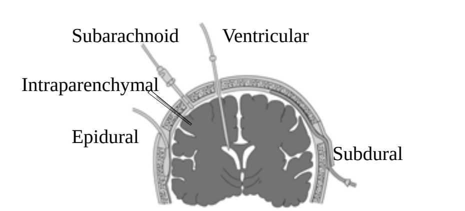


Results from three independent ICP trials of digital and analog devices. Trial (1) is the DICP-1 device, i.e. the one described with the entire ICP results provided above. Trial (2) is for a preliminary DICP device (i.e. DICP-2, an earlier version with a larger housing, not shown here). Trial (3) is for an AICP device.

Common ICP Monitoring Technique

Various Modalities:

Widely used monitoring techniques are catheter based, subdural bolts, fiber optic sensors.

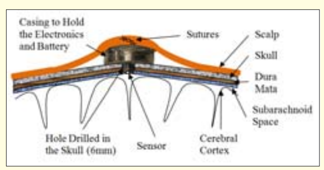


Major types of ICP monitoring. Coronal Section of the brain shows potential sites of placement of the monitoring devices (Adapted from Kerr and Crago).

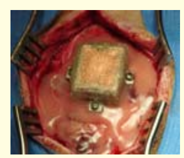
Limitations:

1.Complex implantation.
2.Patient confinement.
3.Infection/cerebral damage.

Assessment of TBI in a Swine Model by Using Both Sensors



Device placement in head – Subdural Placement

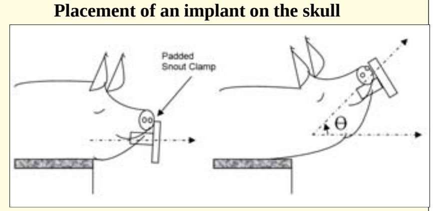


Placement of an implant on the skull

Method (Injury Model):

1.The HYGE device: induce a non-impact brain trauma via rotational acceleration.

2.The animal's head was attached to a HYGE pneumatic actuator via a padded snout clamp and the device was set to deliver a rotational velocity(105-138 rad/sec) in the sagittal plane over 12ms.

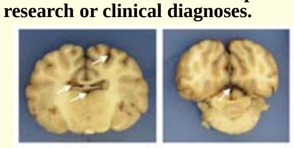


Schematic depicting the position of the piglet on the HYGE device

Conclusion

•Successfully demonstrated the ability and robustness of the wireless ICP devices in measuring intracranial pressure as a consequence of rotational head injury mimicking a moderate-to-severe TBI in a large animal model.

•Such small fully embedded wireless ICP devices will enable future trends in the use of implantable wireless systems for research or clinical diagnoses.



Brain gross pathology. a) coronal section (arrows showing blood accumulation within the third ventricle as well as within a cortical sulcus) and b) coronal section (arrow showing blood accumulation within the fourth ventricle).

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