Cerebrospinal Fluid Volume Monitoring for Hydrocephalus Therapy

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Motivation

- An abnormal accumulation of cerebrospinal fluid (CSF) leads to a condition known as Hydrocephalus. Over 150,000 people are diagnosed with this disease in the U.S. each year.
- The current standard treatment consists of pressure-regulated shunts as an open-loop control system. This technology was proposed in 1950 and has not changed significantly.
- Treatment requires many shunt revisions due to shunt malfunction or pressure setting adjustment. Inefficient control of CSF volume can be deadly; over/under-drainage can be fatal.
- No treatment exists for older patients with Normal Pressure Hydrocephalus (NPH).

Objectives:
- Explore alternative method to monitor and control the disease state of the brain.
- Develop a computational model on intracranial dynamics to better understand the system and explore the impedance technique to measure fluid volume accumulation.
- Validate the measurement in bench-top and animal models.
- Develop a chronic monitoring implantable system.

Bench-top/Animal Validation

Prior to animal testing, bench-top experiments on brain phantoms allow for calibration.
- Hydrocephalus induced in weanling rats by kaolin injection into the cisterna magna. (30% induction rate)
- After confirmation of hydrocephalus, 1-3 weeks later, sensor with internal shunt is implanted into lateral ventricles and CSF is removed acutely.

Hydropholic Volume Measurement

- Hydropholic volume measurement
  - Hydropholic fluid inswelling test by kaolin injection into the cisterna magna (20% reduction rate)
  - After confirmation of hydropholic, 1-3 weeks later, sensor with internal shunt is implanted into lateral ventricles and CSF is removed acutely.
  - 250 µL of CSF removed, yet only 30% of volume reduction was measured.
  - Perhaps incorrect calibration curve used.
  - First ever volume measurements.

Table 1: Comparison of phantom properties and brain tissue.

| Property | Agarose Gel | Silicone Gel | Brain Tissue
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<tr>
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<tbody>
<tr>
<td>Elastic modulus</td>
<td>15 ± 2 kPa</td>
<td>2.85 ± 10^3 Pa</td>
<td>2.85 ± 10^3 Pa</td>
</tr>
<tr>
<td>Density</td>
<td>1.05 g/mL</td>
<td>1.05 g/mL</td>
<td>1.05 g/mL</td>
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<tr>
<td>Electro coefficients</td>
<td>50 mS/cm</td>
<td>50 mS/cm</td>
<td>50 mS/cm</td>
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</tbody>
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Conclusions and Future Directions

- Novel treatment was proposed that directly monitors volume as opposed to passive, pressure based valves.
- Real-time changes in intracranial ventricular volume can be measured in vivo.
- Prototype designed and fabricated to test the novel CSF volume monitor technique.
- Animal model is developed to validate device and dynamic changes in intracranial ventricular volume are recorded for the first time.

Future Directions

- Use silicone based catheters instead of polymers.
- Incorporate pressure transducer to dynamically record pressure-volume.
- Program microcontroller for wireless data communication.
- Use wireless microcontroller for periodic measurements to increase battery lifespan.
- Validate device and dynamic changes in intracranial ventricular volume are recorded for the first time.

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References