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Detection of brain herniation with spectral coherence analysis of somatosensory evoked potentials

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Abstract - **Brain herniation was induced in a rat model by expansion of a balloon in the epidural space. Somatosensory evoked potentials (SEPs) from median nerve stimulation were recorded on the cranium and analyzed with spectral coherence algorithm. Post-experimental MRI evaluation of the brains was correlated to coherence analysis results.**

Keywords - **SEP, coherence, herniation, balloon expansion**

I. Introduction

In current clinical practice, intra- and postoperative neurological monitoring has become an integral component. It is desirable to provide effective and robust analysis tools to the medical team that will enable quick detection of neural injury. This is especially important in surgery because intraoperative trauma, such as cerebral artery occlusion, spinal cord and peripheral nerve compression/ischemia, requires immediate intervention and treatment to prevent or minimize subsequent injury [1]. In a survey of 150 US board certified clinical neurophysiologists [2], 74% reported using somatosensory evoked potential (SEP) monitoring (one of the most common methods employed in brain and spine surgery) during spinal surgeries (scoliosis stabilization), with only 11% of those having an EP physician present during entire procedure. One way to improve could be to implement fully automated methods of abnormality and injury detection in clinical EP systems that would reduce the workload on the monitoring team and provide robust measures of patient status. Our goal is to present an application of the spectral coherence algorithm to processing of SEPs and prediction of brain injury in a rodent model of cerebral herniation.

II. Methodology

A. Injury Protocol

To simulate brain trauma, brain herniation in rats (n=6) was chosen as a representative model. Our goal was to produce visible changes in the SEPs due to variance of intracranial pressure (ICP), which was changed with an expanding balloon in the epidural space. In addition to brain compression, balloon expansion also produces a shift of the brain and the brainstem, damaging somatosensory pathways. Similar approach has been used in [6] to show variation of SEP amplitude and latency, which are the most common indicators of injury. For EP recording, five screw electrodes were implanted in the cranium in a circular pattern at the distance of ~1 cm from each other with penetration depth enough not to damage the dura. Two needle electrodes were positioned on either side of the right median nerve for stimulation. The stimulation current was 20 mA, frequency was 1 Hz, and pulse duration was 500 ìs. Baseline EPs were recorded for 15 minutes. The injury was produced with a balloon inserted into the epidural space of the left hemisphere. To monitor ICP, a catheter was inserted into the epidura at the same distance from the midline as the balloon, over the right hemisphere. The balloon was kept inflated for five minutes with an inflation pressure-volume control gun. During the inflation, the ICP rapidly increased. Injury was noted if EP waveforms changed their shape or suffered >50% reduction in amplitude. Post-experimental MRI was taken to assess the degree of injury (Fig. 1).

B. Spectral Coherence Algorithm

The spectral coherence method is described in detail in [2] and has been used for Event Related Potentials (ERPs) processing in [4]. Previous methods utilize an adaptive approach for coherence evaluation that monitors changes of the EP signal with respect to a baseline signal under the assumption that EPs are deterministic and exhibit steady behavior in response to the same stimuli [5]. An EP waveform $x(n)$ of length L can be modeled as a sum of the pure signal $s(n)$ and a zero-mean real valued non-stationary process $u(n)$:

$$x(n) = s(n) + u(n),\ n = 1...L. \quad (1)$$

Consider a set of EP sweeps obtained in succession and concatenated to create a periodic signal. The *coherence function* can be used to measure the relative stability of each frequency component:

$$\gamma(r) = \sqrt{\left|\overline{X}(r)\right|^2 / \overline{\left|X(r)\right|^2}}, \quad (2)$$

where $X(r)$ is the Fourier transform of a region of interest within the EP, and $\overline{}$ denotes the averaging operation over

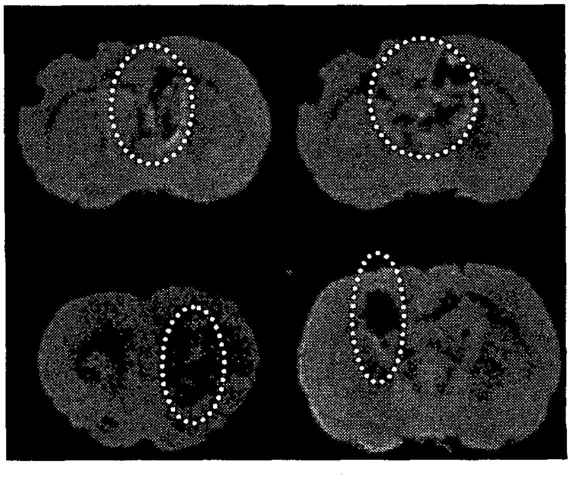

Fig. 1. Deformation in the central region (top row) and lateral regions (bottom row) in the brain revealed by MRI imaging (anterior coronal view).

a number of acquired EPs. The numerator is the power spectrum of the *averaged EP*, while the denominator is the average of *raw data power spectra*. The simplicity of the method allows robust implementation for real-time analysis, and automatic thresholding algorithms can be applied to the coherence estimator for easy-to-follow monitoring. To make a simple combined measure of coherence, a *coherence index* was formed as:

$$i_T = \sum_{k=0}^{k=6} \gamma(\omega_k)/7, \qquad (3)$$

where $\omega_k = 10k + 5$ is the center frequency in Hz on the lower 7 bands, each having width of 10 Hz.

III. RESULTS

After balloon inflation, ICP increased and was followed by hypertension. SEPs were observed to lose amplitude over a period of time after the inflation and recover partially in some cases. Sudden death was observed in one rat. Gross evaluation of harvested brains showed hematoma at the site of the balloon. In three cases, there was a slight imprint of the ICP catheter on the contralateral (right) side of the brain with deformations in lateral regions of the brain (11.5 mm^3 average volume on the balloon side, 13.3 mm^3 contralateral) shown by MRI (Fig. 1). In two other cases, there was a puncture through the dura from the ICP catheter and deformation concentrated in the central region (15 mm^3 average volume) in MRI (Fig. 1). Coherence tracking results are summarized in Table 1 and an example is seen in Fig. 2.

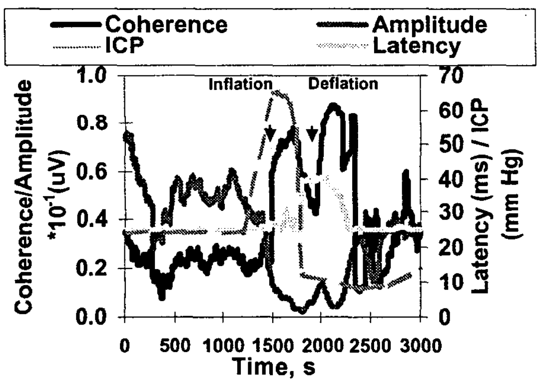

Fig. 2. Coherence, amplitude and latency are stable during the baseline period and show a noticeable change after balloon inflation

IV. DISCUSSION

Noticeable changes produced by coherence index are indicative of its usability for injury detection. Coherence tracking was compared offline to traditional amplitude and latency evaluation methods. Two false positives were rendered by coherence, which had to exceed two standards deviations to be considered positive. Amplitude had three false positives based on 50% amplitude drop, and latency had zero false positives. The average detection time for coherence was 127±57 seconds, amplitude detection time was 118±25 seconds, and latency detection time was 255±255 seconds. In addition, there might be a connection between the direction of coherence change and location of deformations in the brain shown by MRI. Extended histological and neurophysiological investigation may reveal the exact mechanism of injury.

TABLE I
COMPARISON OF COHERENCE FROM LATERAL AND CENTRAL DEFORMATION CASES

	Lateral	Central
Before Inflation (mean)	0.17±0.04	0.63±0.09
After Inflation (max)	0.84	0.09
% Change	+494%	-86%

V. CONCLUSION

We performed a series of brain herniation experiments on rats and explored the performance of autocoherence algorithm in SEP analysis. Its advantages are that it: a) requires no manual interference from the user; b) can be easily programmed for real-time analysis; and c) does not rely on comparison with baseline as all calculations are with respect to current signal. We believe that the progressive compression of the brain has a direct degrading effect on SEP morphology, which can be detected with an automatic autocoherence processing method in a comparable fashion to existing methods based on amplitude and latency tracking.

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