ANALYSIS OF CHANGES IN THE ICP SIGNAL PRIOR TO CRITICAL INCREASES

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Abstract—Sudden increases in intracranial pressure (ICP) are extremely serious and can be life-threatening. Up to the present moment, effective methods have been studied to return the ICP to normal levels after a rapid increase has occurred. This study analyzes different characteristics of the ICP signal just prior to the occurrence of an increase, and compares it with the characteristics of the signal during a regular episode. The results show that there are statistically significant changes in the ICP signal prior to an ICP increase. This results may be further used to try to predict increases in ICP, so they can be more rapidly and effectively treated.

Keywords—Intracranial pressure, percussion wave.

I. Introduction

Sudden increases in ICP are extremely serious and can be life-threatening if not treated rapidly enough. Even though several methods have proven effective in bringing the ICP back to a normal level after a critical increase has occurred, the ability to predict such increases would allow physicians to react more efficiently, considerably decreasing the amount of damage caused to the brain.

My hypothesis was that detectable changes take place in the ICP signal during the transition from normal ICP levels to raised ICP levels. The purpose of this study is to carry out a comparative analysis of the ICP waveform during regular episodes and the recorded signal just prior to an elevation of ICP, and identify those characteristics that are indicative of a rapid ICP increase.

The methods discussed in this paper are based on the analysis of the ICP signal using metrics at the beat level, such as percussion-to-percussion interbeat interval, peak amplitude, peak-to-valley distance, and percussion wave slopes. These metrics may detect signals changes more accurately than coarse metrics, such as the signal mean or variance.

II. Methodology

A. Data Acquisition

The ICP signals used in this study were recorded from eleven different patients at the Pediatrics Intensive Care Unit of the Doernbecher Children’s Hospital (OHSU). The ICP signal was monitored continuously and sampled at a rate of 125 Hz. Six-hour periods of the signal were recorded on CD-ROM.

B. Detection of ICP increases

In order to determine which ICP increases were relevant to our study, the raw ICP signal was filtered using a low-pass filter with cutoff frequency of 0.125 Hz. Then, we selected three-minute-long portions of our filtered signal that met the following criteria: (1) The difference between the maximum value in the first thirty seconds and the minimum value in the last thirty seconds of the three-minute segments was at least 10 mmHg, and (2) the minimum value in the last thirty seconds was at least 20 mmHg.

C. Signal Characterization

After detecting the significant ICP increases, five nonoverlapping thirty second segments preceding the ICP increase by an amount of at least ninety seconds were compared to the thirty second segment immediately prior to the increase. The five first segments corresponded to portions of the data representing regular episodes of ICP signal, whereas the sixth segment was considered to belong to the transition region from a state where the ICP levels are normal, to a state of increased ICP. The different segments were labelled as shown in Fig. 2.

The different metrics used to characterize the ICP signal were the amplitude, the beat-to-beat interval, the peak-to-valley distance, and the percussion wave slopes.
Fig. 2. Illustration of the division of the ICP signal into six segments. Segments 1 through 5 represent regular episodes of ICP, segment 6 represents a transition from normal to increased levels of ICP. Each segment corresponds to a thirty-second-long portion of the ICP time series.

Fig. 3. Illustration of the different metrics used for the characterization of the ICP signal. The beat-to-beat interval measures the time elapsing from the peak of one P wave to the next. The peak-to-valley distance measures the difference in amplitude between the maximum and the minimum values of the P wave.

D. Statistical Analysis

After the five metrics were recorded for all six segments in every ICP rise detected, we calculated the mean and variance of each metric for every individual segment. For each ICP rise, we compared the mean and variance of the different metrics in the six different segments. We recorded a change whenever the mean or variance of each metric were greater in segment 6 (transition ICP) than those in segments 1 through 5 normal ICP) simultaneously, or whenever they were less in segment 6 than in segments 1 through 5 simultaneously.

For our analysis, we assumed that the metric values in the different segments were independent. We recorded the number of times that a change was detected, and we performed a sign test. For each metric, we recorded as +’s those ICP increases where a change was detected, and we recorded as -’s the rest of the ICP increases. According to our assumption of independence between the segments, the probability of getting a + or a - was 0.5, respectively. Our null hypothesis was that all segments were drawn from the same distribution, that is, that there was statistically no significant difference between the transition ICP segment (segment 6) and the regular ICP segments (segments 1 through 5).

The number of times when a change was detected was recorded, together with the corresponding p-values, for each of the metrics. The results are summarized in Table 1.

III. RESULTS AND DISCUSSION

Twenty-three significant rises in ICP were found in seven different patients using our spike detection criteria. The results of the statistical changes in these ICP elevations are recorded in Table 1.

For some of the metrics, there was only a small number of cases out of the twenty-three spikes where a change was detected. Those metrics appear with high p-values, and they are unusable for ICP increase prediction. A few of the metrics, however, presented consistent changes. The most remarkable ones were the mean of the peak amplitudes and the mean of the peak-to-valley distances, with p-values under 0.05.

Those metrics where the p-value is under 0.05 show a consistent change in the ICP waveform prior to the occurrence of an increase. It is necessary to further analyze whether or not these metrics are selective enough, that is, how often an increase in ICP occurs whenever a change in these metrics is found. Once a selective metric has been identified, the problem of ICP increase prediction can be addressed. This can be the subject of further studies.

IV. CONCLUSION

The results of this study show that there are detectable changes in the characteristics of the ICP waveform during a
regular episode, and immediately prior to an ICP increase. The most consistent of these changes are those associated with the mean value of the peak amplitude and the mean of the peak-to-valley distance in the percussion wave of the ICP. These results may be used to develop real-time ICP critical increase prediction algorithms, which will allow physicians to take preventive measures, reducing the risk of brain injury or, in some cases, death.

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