

Complex Analysis of Intracranial Hypertension in Traumatic Brain Injury using Approximate Entropy

Hornero R.¹, Abásolo D.E.¹, Aboy M.^{2,3}, McNames J.³, Goldstein B.⁴

¹E.T.S.I. Telecomunicación – Universidad de Valladolid, Spain

²E.T.S.I-Telecomunicación – Universidad de Vigo, Spain

³BSP Laboratory, Electrical and Computer Engineering – Portland State University, USA

⁴Complex Systems Lab, Pediatrics – Oregon Health & Science University, USA
robhor@tel.uva.es

1 Introduction

Traumatic brain injury (TBI) is the leading cause of death and disability in children in the United States [1]. Elevated intracranial pressure (ICP) following TBI often results in secondary injury due to decreased cerebral perfusion pressure (CPP) and cerebral ischemia.

We measured changes in the intracranial pressure complexity (ICP), estimated by the approximate entropy (*ApEn*), as patients progressed from a stable state of normal ICP (<20-25 mmHg) to intracranial hypertension (ICH; ICP > 25 mmHg). The results show that the degree of irregularity and complexity of ICP coincides with episodes of ICH in TBI.

2 Materials and Methods

This study included 33 episodes of ICH in eleven patients with significant head injuries who were admitted to the pediatric intensive care unit at Doernbecher Children's Hospital. ICP was monitored continuously using a ventricular catheter or parenchymal fiber-optic pressure transducer (Integra NeuroCare, Integra LifeSciences, Plainsboro, NJ). The ICP monitor was connected to a Philips Merlin patient monitor (Philips, Best, Netherlands) which sampled the ICP and ABP signals at 125 Hz. An HPUX workstation automatically acquired these signals through a serial data network, and they were stored in files on CD-ROM.

We used the following criteria to identify acute episodes of intracranial hypertension: (1) the difference between the minimum value in the ICH region and the maximum value in the stable region > 10 mmHg, (2) the minimum value in the ICH region > 20 mmHg, and (3) the maximum value in the stable < 25 mmHg. This detection criterion was implemented in an automatic algorithm for off-line detection of ICH episodes.

Approximate Entropy (*ApEn*) is a family of parameters and statistics quantifying regularity in time-series [2]. It measures the logarithmic likelihood that runs of patterns that are close remain close on subsequent incremental comparisons. It assigns a non-negative number to a time series, with larger values corresponding to more complexity or irregularity in the data. It has two user-specified parameters: a run length m and a tolerance window r . It is important to consider $ApEn(m, r) - ApEn(m, r, N)$, where N is the number of points of the time series – as a *family* of parameters: comparisons between time series segments can only be made with the same values of m and r .

Prior to *ApEn* estimation, the ICP signals were filtered to eliminate the low frequency components (baseline trend) and remove the mean pressure (DC component). We used a highpass equiripple FIR filter with a cutoff frequency of 0.5 Hz. Each filtered ICP signal was windowed into frames of 10 seconds in duration. *ApEn* was estimated for each frame. We used normalized parameters of $m = 1$ and $r = 20\%$ of the frame time series standard deviation (SD) [3]. These input parameters produce good statistical reproducibility for *ApEn* for time series of length $n \geq 60$ [2].

3 Results and Discussion

The estimated approximate entropy was lower in the critical region than during the ICH period in 28/33 episodes ($p < 0.001$). Fig. 1 shows a plot of the normalized approximate entropy for each of the 33 episodes and the median *ApEn* across all the episodes.

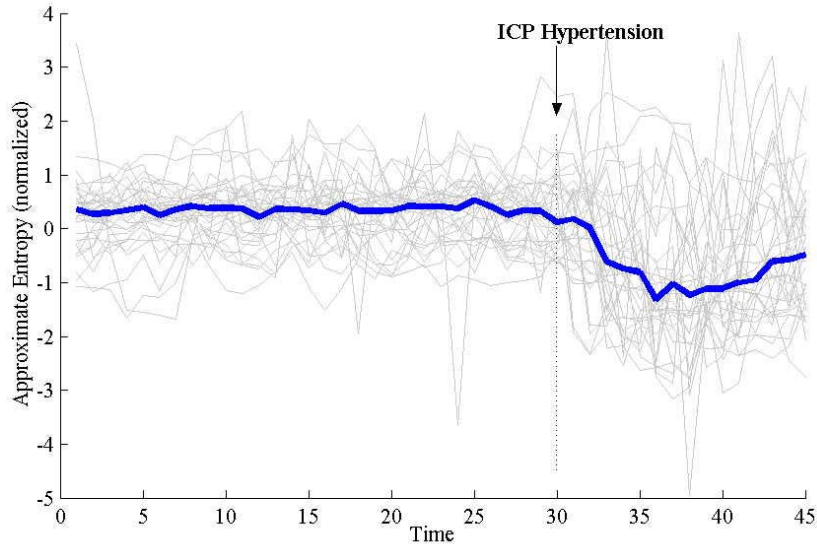


Fig. 1. *ApEn* (normalized) for each of the 33 episodes and median *ApEn* across all ICH episodes

Fig. 1 shows that the estimate *ApEn* decreases as patients progressed from a stable state of normal ICP to a state of ICH. This decrease in complexity and variability in physiologic signals is directly related to severity of disease. Severe traumatic brain injury (TBI) results in decreased variability of physiologic oscillators indicative of decomplexification of organ systems.

4 Conclusions

We estimated changes in ICP complexity as severe head injury patients progressed from a stable state of normal ICP to acute intracranial hypertension. Since it is not possible to directly measure the complexity of individual organ systems, approximate measures must be used. We used approximate entropy as an estimate of ICP complexity. We conclude that decreased complexity of ICP coincides with episodes of acute intracranial hypertension in TBI.

References

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