Physiological measurement

Intracranial pressure dynamics in clinical practice: online PC-based ICP monitoring system

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Abstract—Correct patient management involves determining the exact point on the intracranial pressure/volume (P/V) curve that corresponds to the patient; this requires calculating intracranial elastance (IE). Intracranial pressure (ICP) monitoring systems should provide the necessary information for this purpose. An ICP monitoring unit is presented that acquires ICP, systemic arterial pressure (SAP) and airway pressure (AWP). The cerebral perfusion pressure (CPP) and the mean values and the peak-to-peak values of the two of them (ICPmean, SAPmean, ICPp.p, SAPp.p) are calculated. Graphs display the temporal evolution (TE) of the ICP and SAP, as well as histograms of the ICP (%) and intracranial pulse amplitude (ICPAmplitude) with respect to the ICP or CPP during the preceding 3, 6, 12 or 24 h of monitoring. By digital filtering the ICP respiratory and cardiac components (RICP, CCICP) are calculated. Finally, the pulse amplitudes (AmP) of the ICP, CCICP and RICP are computed, as well as the average pressure per minute of SAP, CCICP, AWP and RICP. Two off-line pulse-amplitude and pulse-morphology oriented tools display the aforementioned curves, histograms and average pulses per minute, and other additional ones, in order to achieve a deeper patient monitoring study.

Keywords—Monitoring, Digital filtering, Intracranial pressure, Trigger


List of symbols

AmP = pulse amplitude
AWP = airway pressure
AWPamp = airway pressure average pulse per minute
A/D = analogue to digital
Bw = bandwidth
CCICP = intracranial pressure cardiac component
CCICPamp = intracranial pressure cardiac component pulse amplitude
CCICPamp = intracranial pressure cardiac component average pulse per minute
CPP = cerebral perfusion pressure
CSF = cerebrospinal fluid
DMA = direct memory access
ECG = electrocardiogram
Fr = sampling frequency (100 Hz)
Fs = sampling frequency (25 Hz)
FIR = finite impulse response
ICH = intracranial hypertension
ICP = intracranial pressure

ICP AmP = intracranial pressure pulse wave amplitude
ICPmean = mean intracranial pressure
ICPp.p = peak-to-peak intracranial pressure
IE = intracranial elastance
MCC = ascending mean-crossing counter
PDC = pulse detected counter
PVI = pressure–volume index
P/V = pressure/volume
RICP = intracranial pressure respiratory components
RICPamp = intracranial pressure respiratory component pulse amplitude
RICPamp = intracranial pressure respiratory component average pulse per minute
SAP = systemic arterial pressure
SAPamp = systemic arterial pulse amplitude
SAPmean = systemic arterial pressure average pulse per minute
SAPmean = mean systemic arterial pressure
SAPp.p = peak-to-peak systemic arterial pressure
Slpmean = mean slope per minute
Slpmean = mean slope threshold-crossing per minute
Slpmean = sum of the slope threshold-crossing
TE = temporal evolution curve
ThCC = Threshold-crossing counter
ThMCR = Threshold-crossing against total mean-crossing ratio

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1 Introduction

The intracranial content is composed of three elements: brain tissue, blood from the cerebral vascular bed and cerebrospinal fluid (CSF), all of which are almost incompressible; a change in any one of them would have to be compensated for by one or more changes in the other two components. Thus,

\[ V_{\text{Tissue}} + V_{\text{Blood}} + V_{\text{CSF}} = V_{\text{total intracranial}} \]

This compensatory capacity in the intracranial space constitutes a natural defense to maintain a constant total intracranial volume. For many years now, the primary clinical importance of ICP monitoring has remained unchanged and can be summarized in the following terms:

A situation of intracranial hypertension (ICH) is generated when an increase in one or more of the intracranial components cannot be compensated for. This increase in volume \((\Delta V)\) will produce an increase in pressure \((\Delta P)\), the \(\Delta P/\Delta V\) ratio being single-exponential (Langfitt, 1975) (Fig. 1), or having a constant pressure term (van Eindhoven et al., 1986). Theoretically, the patient should not be allowed to reach the asymptotic region of the P/V curve, in which a slight \(\Delta V\) would rapidly produce a severe and uncontrollable elevation of the ICP.

The classic clinical method to ascertain the region of the P/V curve in which a given patient is situated was proposed by Miller and Pickard (1974). It consists of a volume-pressure response (VPR) test, in which 1 cc is rapidly infused intravenicularly, provoking a brusque response in the pressure. The main inconveniences are risk of infection due to excessive manipulation; the fact that the situation of IE is known only at the instant of injection; and risk of provoking very severe and uncontrollable increases in the ICP. Using their pressure-volume index (PVI), after infusion (or extraction) of a volume of CSF from the ventricle, Marmarou et al. (1978) and Maset et al. (1987) obtained a curve representing the logarithmic expression of the exponential V/P ratio. This PVI indicates the volume necessary for a tenfold increase in the initial ICP.

To obviate the risks of intraventricular injection and make the study possible even in ICP monitoring with transcerebral transducers, two work teams studied the ICP_amp/ICP ratio. Avezaat et al. (1979) obtained the amplitude of the cardiac component of the intracranial pulse wave, determining the maximum and the minimum of the ICP wave between electrocardiogram (ECG) intervals and correlating them with the different ICP levels of the patient. Szewczykowski et al. (1977) obtained the standard deviation of ICP rather than the absolute deviation of the mean; the advantage of this is that it does not require a second signal (ECG) to obtain the data and analyse jointly the amplitude of the cardiac and respiratory components of the intracranial pulse wave.

Very briefly, the theoretical basis of both work teams is the supposition that the \(\Delta P\)'s remain constant (the amount of blood that enters the cranial cavity at each heart beat and the blood concomitantly expelled at inspiration). Under these suppositions, the IE would be

\[ IE = \frac{\Delta P}{\Delta V} = K\Delta P \]

manifestation of the homogeneous and cyclic variation in the intracranial blood volume, is directly related to the IE.

Our monitoring philosophy, which experience has shown to be practical (Garcia-Sola et al., 1989; Rubio et al., 1987), is as follows: rather than ascertaining the exact point on the P/V curve at which a given patient is situated, it is more important to be able to determine, with a high degree of sensitivity, the extent of his/her variation or movements along the curve and, obviously, towards which zone he/she is evolving. The purpose, therefore, is not to give the user a single numerical value or a single curve that provides all the information, but a set of data and curves, analogous to the monitor presented by Gaab et al. (1986), that together allow a user with a certain degree of experience to determine the status of the patient.

Differing slightly from interpretations by other authors (Czosnyka et al., 1989a), here the term \(ICP_{\text{amp}}\) refers to the result of the following computation:

\[ ICP_{\text{amp}} = \frac{1}{1000} \sum_{i=1}^{1000} |ICP_i - ICP_{\text{mean}}| \]

where \(ICP_{\text{mean}}\) is calculated for a real-time interval of 10 s. This mean value of the absolute deviations with respect to the \(ICP_{\text{mean}}\) encompasses the pulse amplitudes of the cardiac and respiratory components.

If, during the monitoring time established by the user (the preceding 3, 6, 12 or 24 h, the relationship between these \(ICP_{\text{amp}}\) values and the different levels of ICP is studied and presented in the form of a histogram, as seen in the following Section, a curve similar to that of the IE/ICP ratio is obtained; given this similarity, it is possible to determine the approximate IE of the patient. If these same \(ICP_{\text{amp}}\) values are associated, again in the form of a histogram, with the different CPP values, a curve is obtained that, together with the aforementioned curve, provides the user with a very sensitive tool for quantifying the extent to which the patient varies and in which direction.

The clinical importance is great as it is a less invasive form of assessing the variation in IE of the patient with respect to a variation in his ICH. Moreover, it is possible to detect the ICP level beyond which said Ie adopts a progressive tendency to rise, indicating that the buffer capacity of the intracranial content for the maintenance of constant volume beings to disappear.

2 Monitoring unit

Taking into account all of the above, and in response to concerns about efforts that lie on the borderline between clinical practice and research activities, our group has designed and built an ICP monitoring system which, in...