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A New Method of Estimating Intracranial Elastance☆

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ABSTRACT

Objective: Current methods of calculating Intracranial Elastance Index (IEI) depend from CSF pulse-wave, whose shape may deeply change during ICP rising.
The main aim of this study was to evaluate the reliability and specificity of a novel method to calculate IEI (method C), based on the integral of the CSF pulse-wave area.
Method: Twenty ventricular infusion-tests of patients with idiopathic NPH were re-evaluated. We have compared method C with the most widely used methods to calculate IEI: a modified Szewczykowski method (diastolic ICP against CSF pulse-wave amplitude-method A) and a modified Czosnyka method (diastolic ICP against the fundamental harmonic-method B). R-squared (R^2) was calculated for each test. Means were compared through ANOVA and t-test.
Results: Mean R^2 values for methods A, B and C were 0.91 ± 0.06, 0.9 ± 0.06 and 0.96 ± 0.03, respectively. Mean R^2 values obtained through method A vs C and through method B vs C were significantly different ($p = .006$ and $p = .001$, respectively), while values obtained through method A vs B were not ($p = 1$). Analysis of ICP tracks demonstrated that 9 patients showed no different shape of the ICP wave during the infusion test, while the remaining 11 did. The mean R2 values obtained through method A vs C and through method B vs C were significantly different ($p < .001$ for both) for patients showing a different shape of the ICP wave during the infusion test.
Conclusions: Method C seems to be the most reliable method to calculate IEI, as it is independent from CSF pulse wave modifications.

Introduction

The intracranial pressure (ICP) waveform analysis is a method to assess the so called intracranial system compliance. Several clinical conditions can be accompanied by a modification of the intracranial system compliance, including head trauma and normal pressure hydrocephalus. Nonetheless, despite the several preclinical and clinical studies on this subject, the clinical value of ICP waveform analysis is still a matter of debate [1–5]. The main reason is that all the method used to assess compliance reflect intracranial system compliance but do not describe brain compliance directly [3]. Intracranial Elastance (IE) is a measure of the pressure/volume response of the intracranial system at a given level of ICP, i.e. the reciprocal of intracranial compliance. With each heartbeat, there is a pulsatile increase in cerebral blood volume, and the amplitude of cerebrospinal fluid (CSF) pressure pulsations (CSFPPAmp) is the response of the ICP to that increment of volume [6]. Szewczykowski et al. postulated that, in a patient at rest, with constant blood pressure and cardiac stroke volume, CSFPPAmp is directly proportional to IE [7]. Therefore, the relationship for each single ICP pulse wave between CSFPPAmp and its correspondent mean value provides a valid estimation of IE [8,9]. The same authors observed thatthe slope of the linear regression of the CSFPPAmp/ICP curve can be considered as a reliable index of IE (IEI) [9–11].

In healthy subjects, an ICP increase is accompanied by an elevation of the CSF pulse wave components P_2 and P_3. The CSF pulse wave initially becomes rounded and then, at higher ICP values, acquires a pyramidal shape [12,13]. If the CSF pulse wave changes its shape, the point where to measure its amplitude also changes, Czosnyka et al. proposed to calculate IEI as the slope of the linear regression between ICP and the amplitude of the fundamental (first) harmonic component, as obtained through the Fourier's spectral analysis, of 6-12 CSF pulse waves included in a given period [14]. That method was based on the assumption that the fundamental harmonic of the pulse waves accurately reflects the CSFPPAmp variations. As the authors themselves observed, the

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Table 1
Comparison of IEI values calculated with Methods A, B and C (see text for details).

Patient #	Method A IEI	Method A R^2	Method B IEI	Method B R^2	Method C IEI	Method C R^2
1	0.7	0.93	0.32	0.93	1.95	0.94
2	0.6	0.94	0.26	0.95	0.94	0.98
3	0.4	0.94	0.18	0.89	0.92	0.97
4	0.51	0.95	0.21	0.92	1	0.9
5	0.43	0.95	0.18	0.95	0.97	0.96
6	0.62	0.95	0.25	0.94	0.77	0.94
7	0.44	0.97	0.19	0.96	0.88	0.97
8	0.63	0.98	0.25	0.98	0.99	0.99
9	0.42	0.98	0.17	0.98	0.99	0.99
10	0.5	0.72	0.19	0.81	0.95	0.89
11	0.58	0.85	0.24	0.78	0.95	0.91
12	0.33	0.85	0.15	0.85	1.06	0.98
13	0.53	0.87	0.24	0.87	1.3	0.98
14	0.5	0.88	0.22	0.88	0.87	0.97
15	0.6	0.88	0.26	0.8	1.35	0.96
16	0.58	0.89	0.25	0.87	1	0.98
17	0.31	0.9	0.14	0.89	1.06	0.98
18	0.44	0.91	0.18	0.88	0.98	0.98
19	0.55	0.91	0.22	0.9	0.78	0.97
20	0.41	0.92	0.16	0.89	0.98	0.96

slope of the fundamental harmonic/pressure curve may differ from the slope of the CSFPPAmp/pressure curve, depending on the shape of each individual pulse wave. [14] Moreover, Anile et al. performed a Fourier's spectral analysis of CSF pulse wave morphology and found out that the change in the shape of the CSF pulse wave induced by ICP rising was associated with a negative phase shift of the fundamental harmonic in respect to the second harmonic [7,15]. This phase shift could be responsible for inaccuracies in estimating IEI, potentially reducing the reliability for clinical purpose of the infusion test.

Therefore, none of the above mentioned methods of estimating IE seemed to guarantee that its results were not altered by changes in CSF pulse wave morphology.

Indeed, Foltz hypothesized that a progressively higher CSF pulse pressure could be considered as an index of intracranial compliance loss and that CSF pulsatility could be related to the mathematical formula of power [16]. This formula calculates the power involved in bringing a volume of moving fluid of known mass, travelling at a known velocity to a condition of rest and can be applied on CSF pulse pressure waves. The wave power can be approximated as the integral of the surface delimited by the wave itself. This method considers the single CSF wave as a whole, whatever its shape. This means that it should be far less sensitive to the changes of CSF pulse wave morphology (induced by ICP rising). On this basis, we have tried to use the integral of each single CSF pulse wave surface as a parameter to estimate the IEI and have compared this method with the most widely used methods to calculate IEI. The main potential clinical benefit of our study could be the evaluation of patients with suspected normal pressure hydrocephalus, in order to better understand the relationship between intracranial system compliance and shunt responsiveness.

Materials and methods

This study includes 20 ventricular infusion tests we had performed on patients with idiopathic normal pressure hydrocephalus between December 2005 and December 2006 (Table 1).

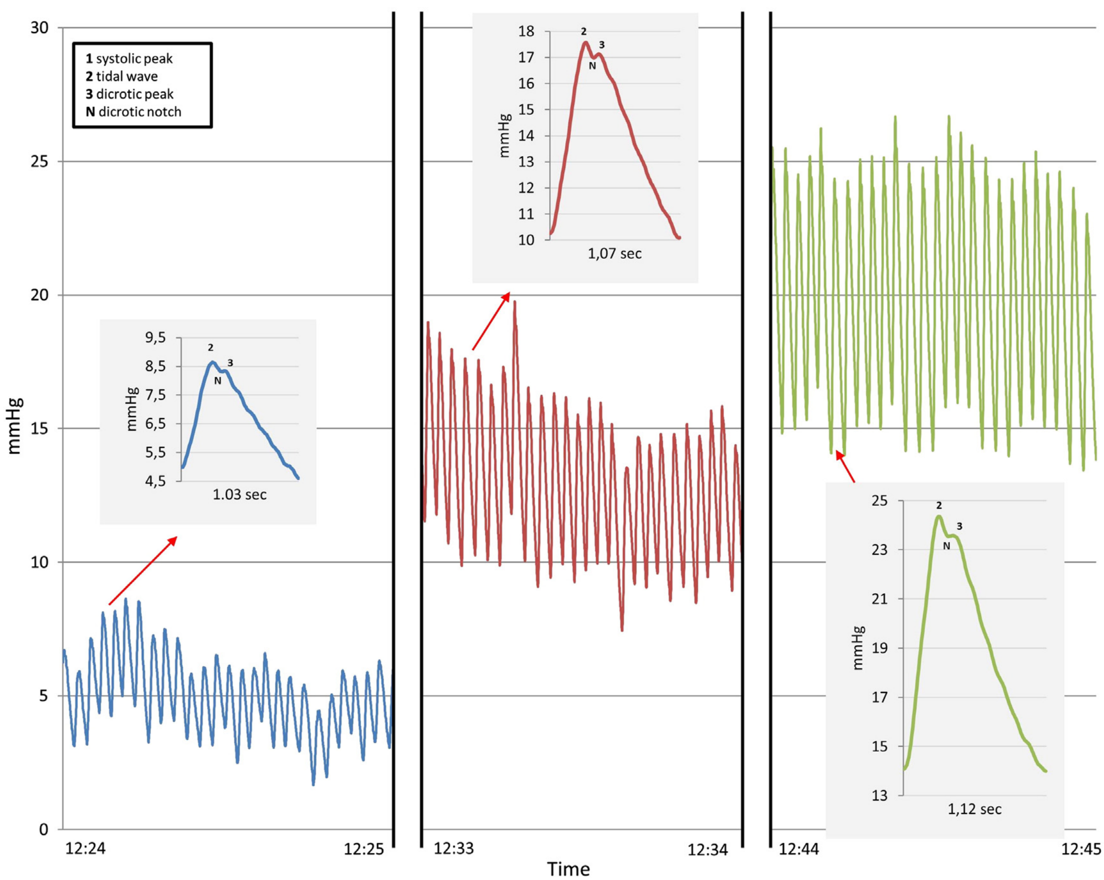

Fig. 1. Example of ICP waves during the intraventricular infusion test. In this patient, the CSF pulse wave morphology remains constant during the infusion test.