

Non-invasive Absolute Intracranial Pressure Measurement without Problem of Calibration: Healthy Volunteer Study

A. Ragauskas, G. Daubaris, R. Žakelis

*Telematics Science Laboratory of Kaunas University of Technology
Studentu str. 50, LT-51368 Kaunas, Lithuania, e-mail: telematics@kt.lt*

S. Rutkauskas

*Radiology Clinic of Hospital of Kaunas University of Medicine
Eiveniu str. 2, LT-50009 Kaunas, Lithuania*

G. Krutulytė, A. Kalasauskienė

*Department of Physiotherapy and Applied Physiology of Academy of Physical Education
Sporto str. 6, LT-44221 Kaunas, Lithuania*

Introduction

Intracranial pressure (ICP) is a fundamental physiological parameter with the same importance as arterial blood pressure (ABP) because the brain blood flow is driven by $CPP = ABP - ICP$. Here CPP is cerebral perfusion pressure.

Non-invasive absolute ABP measurement method invented and developed by S. Riva-Rocci, J. Erlanger (Nobel Prize in 1944) and others [1-4] is available from 1904. Non-invasive absolute ICP measurement is still not available for clinical practice after more than 100 years.

An objective is to develop an innovative non-invasive absolute ICP meter which does not need calibration of the system "individual patient - non-invasive absolute ICP meter" and to perform healthy volunteer and traumatic brain injury (TBI) patient studies in order to prove the clinical value of innovative non-invasive absolute ICP meter.

State of the art

Non-invasive techniques for the measurement of ICP were reported as early as 1966 in newborns and infants. Because these techniques rely on an open fontanelle, they are not applicable in older children and adults. Other methods of non-invasive ICP measurement attempt to find the biophysical objects or physiological characteristics that would be related or correlated to the ICP and that could be measured or monitored non-invasively. Some of the proposed non-invasive technologies are based on dielectric properties of cranium or intracraniospinal structures. Most of proposed approaches are based on ultrasonic measurements through the associated physiological parameters such as skull diameter, blood flow parameters in intracranial or intraocular vessels, pulsations of cerebral

ventricles, acoustic properties of the cranium or skull bones or transintracranial parenchymal acoustic path, brain tissue resonance parameters, etc. Very promising for absolute ICP measurement is dynamic magnetic resonance imaging (MRI) technique. Other approaches include tympanic membrane displacement, ophthalmodynamometry, quantitative pupillometry, otoacoustic emission, pulsatility of the ocular circulation, retinal vein pressure correlation with ICP, prediction of ICP based on transcranial Doppler (TCD) and ABP simultaneous measurements [5-12].

However, there are a few common problems making impossible the introduction of the proposed methods into clinical application:

1. Biophysical object: which biophysical parameter of what object in the human cerebrospinal system could be a stable in time and a repeatable function f of absolute ICP, i.e., $f(aICP)$?

2. Functional dependence $f(aICP)$: is that function linear and independent of such influential factors as ABP, cerebrovascular autoregulation (CA) impairment, anatomical and physiological individuality of the patient, etc.?

3. General individual calibration problem: how to calibrate non-invasively the system "individual patient - non-invasive ICP meter"?

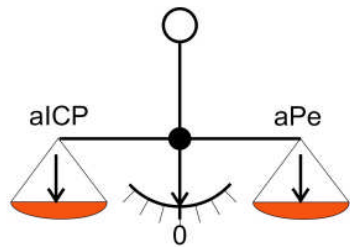
Current technology development efforts and clinical studies failed to solve these general problems.

Non-invasive absolute ICP measurement method

Calibration is a metrological term. By definition a calibration is determination of the correct value of measuring instrument by comparison with a "golden standard", i. e., measurement instrument which is much more accurate than the instrument under calibration. Non-

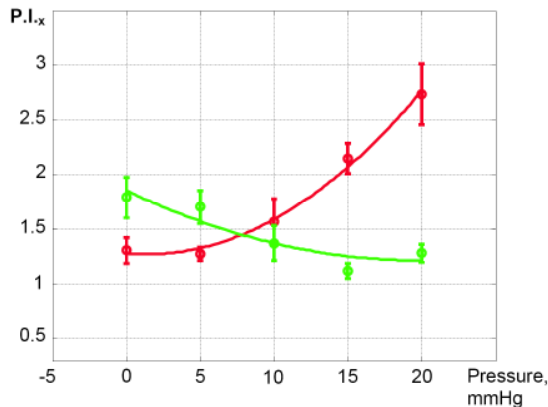
invasive absolute ICP "golden standard" does not exist. Therefore the non-invasive calibration of the system "individual patient-non-invasive ICP meter" is impossible. This is the main reason why it is impossible to apply the existing approaches to non-invasive ICP measurement for creation of reliable non-invasive absolute ICP meter.

The only solution [13-15] of non-invasive absolute ICP meter's calibration problem is to apply for aICP measurement the direct comparison of aICP and absolute extracranial pressure aPe by the natural physiological "scales", preliminary balanced by human anatomy (Fig. 1 a).

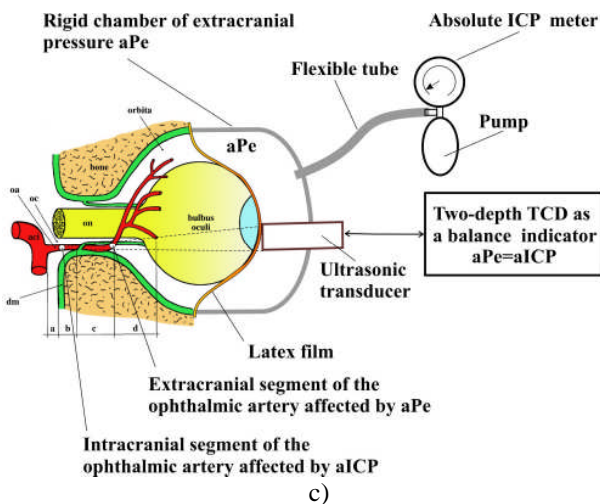


Balance of "scales" when $aPe=aICP$

a)



b)



c)

Fig. 1. Innovative non-invasive method for absolute ICP (aICP) measurement: (a) preliminary balanced "scales" as an aICP measurement instrument without calibration problem, (b) illustration of the balance of pulsatility indexes PI in intracranial (green) and extracranial (red) segments of the ophthalmic artery - the PI(Pe) curves has the crossing point when $aPe=aICP=8.0\text{mmHg}$ in this case,(c) structure of proposed non-invasive aICP meter

Proposed method is based on the same methodology as non-invasive ABP meter. In non-invasive ABP meter the external pressure is applied to the arteria brachialis in order to occlude the artery. Occlusion is the balance point between systolic ABP absolute value and external pressure value. A stethoscope is usually used as the indicator of such balance .

Proposed non-invasive aICP measurement method [13-15] is based on "reinvention" of non-invasive ABP meter using different artery and different balance indicator:

1. The ophthalmic artery (OA) is used as a natural pressure sensor and the natural "scales" in order to balance aICP with aPe. Intracranial segment of OA is compressed by aICP. Extracranial segment of OA is compressed by the extracranial pressure aPe which is easily applied to the tissues surrounding the eye ball (Fig. 1 c)) in order to increase the intraorbital pressure.

2. Two-depth transcranial Doppler device (TCD) is used for the indication of balance $aICP=aPe$. Two-depth TCD simultaneously measures blood flow parameters in the intracranial and extracranial segments of the ophthalmic artery and compares that parameters in order to identify the balance $aICP=aPe$.

3. In the case of balance $aICP=aPe$ it is easy to measure accurately aPe. Estimation of aPe means the estimation of absolute value of intracranial pressure aICP.

Proposed aICP measurement method is based on the assumption that every intracranial artery can be used as an ICP measurement transducer which transforms ICP into the artery diameter deformation and, as a consequence, into the artery blood flow parameters' change. But the only OA has intracranial and extracranial segments with the negligible difference in anatomy. Both segments of OA are divided by the dura mater inside optic nerve canal.

In order to solve the problem of individual calibration of the system "individual patient - non-invasive absolute ICP meter" balancing of aICP with aPe in two segments of the same arterial vessel - ophthalmic artery (OA) is proposed. The mean value of OA blood flow, its systolic and diastolic values, pulsatility indexes are almost the same in both OA segments in the point of balance $aICP=aPe$. As a result of that all individual influential factors (ABP, cerebrovascular autoregulation impairment, individual pathophysiological state of patient, individual diameter and anatomy of OA, hydrodynamic resistance of eye ball vessels, etc.) do not influence the balance $aICP=aPe$ and, as a consequence, such natural "scales" does not need calibration.

Healthy volunteer study

Thirty one young adults (31 M, age 22 ± 3) with no known neurological problems participated in the study. The non-standard pulsatility indexes PIx were used for the pressure balance $Pe = ICP$ indication.

In order to compare aICP values measured using proposed method on the group of healthy volunteers with already published [16,17] MRI study data we performed the measurements in supine and upright (sitting) body positions.

Typical dependence of PIx on the TCD measurement depth is shown in Fig. 2.

In the case when $P_e = 0$ mmHg and the healthy volunteer's body is in supine position the typical aICP value is close to 10 mmHg [16,17]. In that case P_{Ix} values are different in extracranial and intracranial segments of OA (Fig. 2 a)). It is shown in Fig. 2 a) that the standard deviation SD of measured P_{Ix} in both OA segments is less than 0.025. The difference of P_{Ix} in both segments is equal to 0.28 when aICP = 10 mmHg. In that case SD expressed in mmHg is equal to 0.71 mmHg and the uncertainty (U) of proposed non-invasive absolute ICP measurement device is $U = 2SD = \pm 1.42$ mmHg. That $U = \pm 1.42$ mmHg is even less than nominal uncertainty ± 2.0 mmHg of invasive ICP meters.

In the case when $aP_e = 10$ mmHg and aICP = 10 mmHg the values of P_{Ix} in both OA segments are approximately the same (Fig. 2 b)).

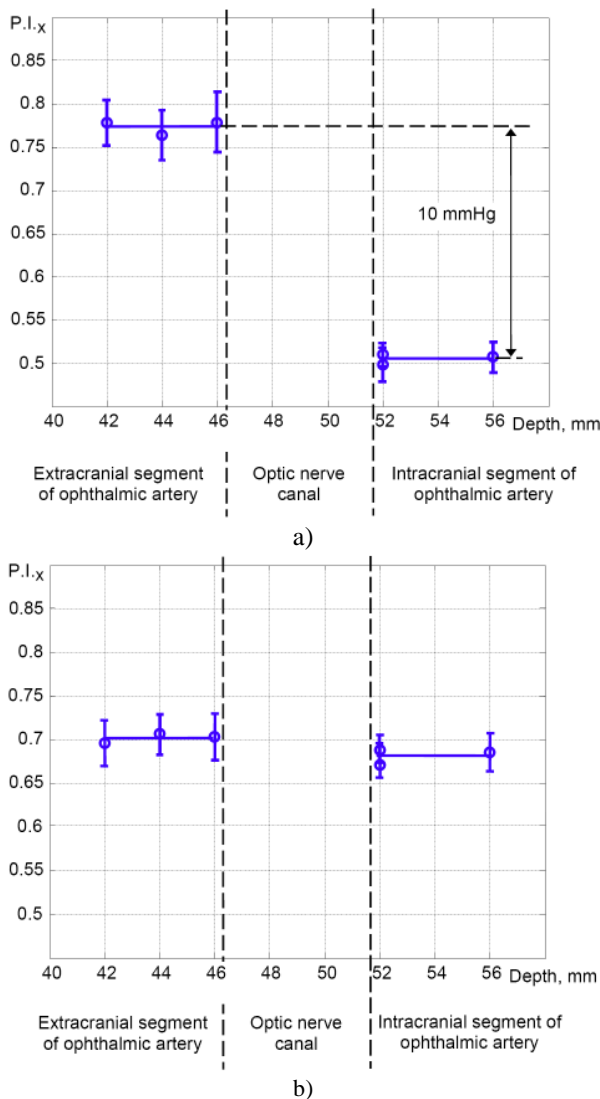


Fig. 2. Typical dependence of the ophthalmic artery P_{Ix} on the TCD measurement depth in supine body position of the healthy volunteer (aICP close to 10 mmHg): a) $P_e = 0$ mmHg, b) $P_e = 10$ mmHg

The distributions of aICP measured by phase contrast MRI [16,17] for the groups of eight and twenty three healthy volunteers in supine body position are shown in Fig. 3.

The distribution of aICP measured for the group of thirty one healthy volunteer (supine body position) by proposed ultrasonic method is shown in Fig. 4.

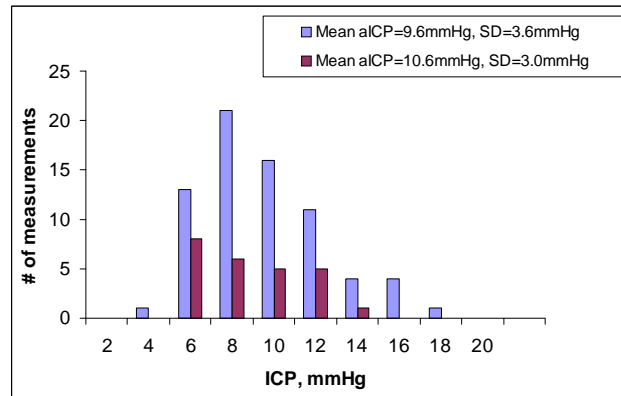


Fig. 3. The distributions of aICP measured by phase contrast MRI [16,17] for the groups of eight (red) and twenty three healthy volunteers (blue) in supine body position

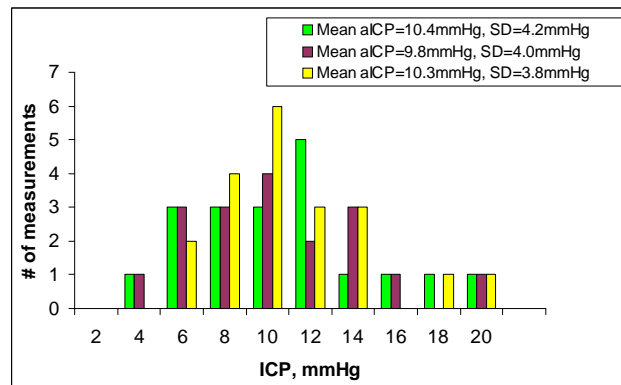


Fig. 4. The distribution of aICP measured for the group of thirty one healthy volunteer (supine body position) by proposed ultrasonic method using three different TCD signal analysis methods

Conclusion

The achieved agreement between mean aICP and SD for the independently studied three groups of healthy volunteers is an evidence that phase contrast MRI [16,17] and proposed ultrasonic method [13-15] of non-invasive absolute ICP measurement are free from systematic errors and do not need the calibration of the system "individual patient - non-invasive ICP meter".

New non-invasive absolute ICP measurement TCD technique shows the uncertainty of absolute ICP measurement $U=2SD=\pm 1.42$ mmHg which is close to the uncertainty of invasive ICP meters.

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An objective is to develop an innovative non-invasive absolute ICP meter which does not need calibration of the system “individual patient - non-invasive absolute ICP meter” and to perform healthy volunteer studies in order to prove the clinical value of innovative non-invasive absolute ICP meter. The achieved agreement between mean aICP and SD for the independently studied three groups of healthy volunteers is an evidence that phase contrast MRI method and proposed ultrasonic method of non-invasive absolute ICP measurement are free from systematic errors and do not need the calibration of the system “individual patient - non-invasive ICP meter”. III. 4, bibl. 17 (in English; summaries in English, Russian and Lithuanian).

A. Рагаускас, Г. Даубарис, Р. Жакелис, С. Руткаускас, Г. Крутулите, А. Каласаускене. Неинвазивное измерение абсолютного внутричерепного давления: студия здоровых людей // Электроника и электротехника. – Каунас: Технологія, 2009. – № 7(95). – P. 103–106.

Поставленные цели были создание и развитие неинвазивного прибора для измерения абсолютного внутричерепного давления который не требовал бы индивидуальной калибровки для системы “индивидуальный пациент – неинвазивный измеритель абсолютного внутричерепного давления”, а также произвести студию здоровых людей с целью выяснить клиническую информативность такого инновативного прибора. Полученные результаты измерения абсолютного внутричерепного давления двумя независимыми способами включая фазового контраста магнитной резонансной визуализации, а также предложенным методом, подтверждают то, что обе способы имеют незначительные систематические погрешности измерения абсолютного внутричерепного давления, то есть не требуют индивидуальной калибровки для системы “индивидуальный пациент – неинвазивный измеритель абсолютного внутричерепного давления”. Ил. 4, библи. 17 (на английском языке; рефераты на английском, русском и литовском яз.).

A. Ragauskas, G. Daubaris, R. Žakelis, S. Rutkauskas, G. Krutulytė, A. Kalasauskienė. Neinvazinis absoliutinio intrakranijinio slėgio matavimo metodas: sveikų savanorių studija // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 7(95). – P. 103–106.

Tikslas yra sukurti ir išstbulinti neinvazinį absoliučiojo intrakranijinio slėgio matavimo įrenginį, kuris nereikalautų individualaus sistemos „individualus pacientas – neinvazinis absoliučiojo intrakranijinio slėgio matavimo įrenginys“ kalibravimo, ir atlikti tokio įrenginio tyrimus su sveikais savanoriais, kad pagrįsti tokio inovacinio įrenginio klinikinę reikšmę. Gautas matavimo rezultatų vidutinės intrakranijinio slėgio vertės ir standartinės deviacijos sutapimas, palyginti su nepriklausomu sveikų savanorių tyrimo fazinio kontrasto magnetinio rezonanso metodu rezultatais, liudija, kad taikant tiek fazinio kontrasto magnetinio rezonanso metodą, tiek pasiūlytąjį inovacinį metodą reikšmingų sisteminių absoliučiojo intrakranijinio slėgio matavimo paklaidų nebūna, todėl abiem atvejais sistemos „individualus pacientas – neinvazinis absoliučiojo intrakranijinio slėgio matavimo įrenginys“ kalibruoti nereikia. II. 4, bibl. 17 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).