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Non-invasive Technology for Monitoring of Intracranial Volumetric Pulse Waves and Trends

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Introduction

The primary clinical objective after traumatic brain injury (TBI) is to prevent secondary insults including elevated ICP, a common sequel of primary injury. The concept is to prevent cerebral hypoxia by maintaining sufficient oxygen delivery to the intracranial neural tissues. This implies that cerebral blood flow (CBF), arterial oxygen saturation and haemoglobin concentration in a specific patient must be adequate. Intracranial pressure (ICP) and cerebral perfusion pressure (CPP) monitoring is recommended for severe TBI. There are several limitations of ICP and CPP monitoring: the ICP devices are invasive, distinct ICP and CPP target recommendations are uncertain and not specific for the individual patient, CPP is not equivalent to CBF and the relationship between CBF and CPP depends on the status of CBF autoregulation. Additional causes of elevated ICP include shaken baby syndrome, epidural and subdural haematomas, brain haemorrhage, meningitis, encephalitis, lead poisoning, Reye's syndrome, hypervitaminosis A, diabetic ketoacidosis, water intoxication, brain tumours, blood clots in the craniocavity, abscesses, stroke, hydrocephalus, dural synus and venous thrombosis and others. Elevated ICP is very serious pathology and may be life threatening. It requires immediate treatment and continuous monitoring. The non-invasive Vittamed 105 monitor is designed for human brain non-invasive physiological diagnosing and monitoring [1-5]. The clinical investigations of Vittamed technology show the similarity between the invasively recorded intracranial pressure (ICP) and non-invasively recorded intracranial blood volume (IBV) pulse waves, slow waves and slow trends under intensive care unit (ICU) conditions. Also the applicability of the non-invasive IBV slow wave monitoring technique for long-term non-invasive cerebrovascular autoregulation monitoring is supported by theoretical and experimental studies [6-10].

Non-invasive intracranial blood volume change monitoring method

The cause of ICP fluctuations and ICP waves ($\Delta ICP(t)$) are intracraniospinal volume (V) changes $\Delta V(t)$ (Fig. 1) [10].

Fig. 1 shows the relationship between ICP, V, cerebrospinal compliance (CSC), intracranial blood volume pulse waves $\Delta V(t)$ and ICP pulse waves $\Delta ICP(t)$. Vittamed created non-invasive ultrasonic technology for monitoring volume V changes and volume waves $\Delta V(t)$ in order to study the dynamics underlying ICP change. The dynamics of $\Delta V(t)$ have not been studied before due to the lack of non-invasive volumetric monitoring technology.

The non-invasive measurement of intracranial component volume changes is based on the time–of–flight measurement of ultrasonic wave transmission through the human head [1,4,7]. Since all intracranial components (brain tissue, cerebrospinal fluid, blood) have different acoustic properties (ultrasound speed, and frequency dependent attenuation), changes of their relative content inside the acoustic path will influence the total acoustic characteristics of intracranial media and thus the monitored parameters of the ultrasonic signal as well [4,7].

The results of mathematical simulations [4] of ultrasound pulse propagation through the human brain show the linear relationship between changes in the time-

of-flight of the ultrasound pulse with changes in blood volume within the cerebral parenchyma. Because the intracranial blood volume changes are directly related with ICP and craniospinal compliance changes, it supports the use of time-of-flight measurement to evaluate these physiological parameters.

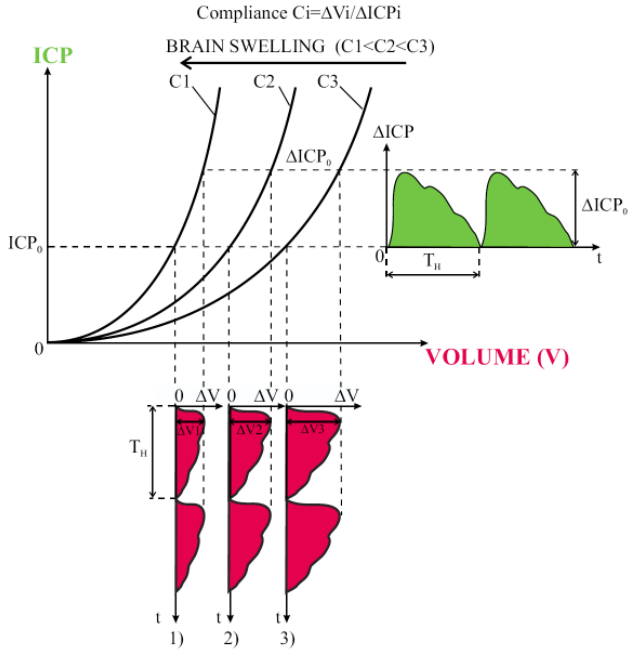

Fig. 1. Relationship between ICP, V, CSC, intracranial blood volume pulse waves ΔV(t) and ICP pulse waves ΔICP(t)

Non-invasive monitoring of ICP trends

The basic concept underlying the evaluation of non-invasive monitoring of cerebral blood volume, ICP pulse waves, respiratory waves, slow waves and trends is outlined as follows [5,7,8]:

– The intraventricular or supraventricular parenchymal acoustic path which crosses the human head is used under study The parenchymal acoustic path mainly consists of parenchymal tissue, relatively small blood vessels (arterioles, venules and capillary vessels) and a small amount of cerebrospinal fluid (CSF). The speed of ultrasound within the parenchymal acoustic path mainly depends on the blood volume inside this path. Also the attenuation of ultrasound inside this path mainly depends on the volume of parenchymal tissue inside this path.

– This path is insonated by broadband ultrasonic pulses and the time-of-flight is measured to evaluate the changes in ultrasound speed inside the parenchymal acoustic path.

– The same ultrasonic pulses and their echoes from internal surfaces of the skull are also measured to compensate the influences of the external tissue hemodynamics in real-time and *in situ*.

This method is the only existing technology for non-invasive monitoring of the volume dynamics of the cerebral parenchyma micro vessels. The non-invasive ultrasonic Vittamed monitor was tested in several intensive care units (ICU) [7–9]. The display panels of the Vittamed 105 monitor are shown in Fig. 2 a) and Fig. 2 b).

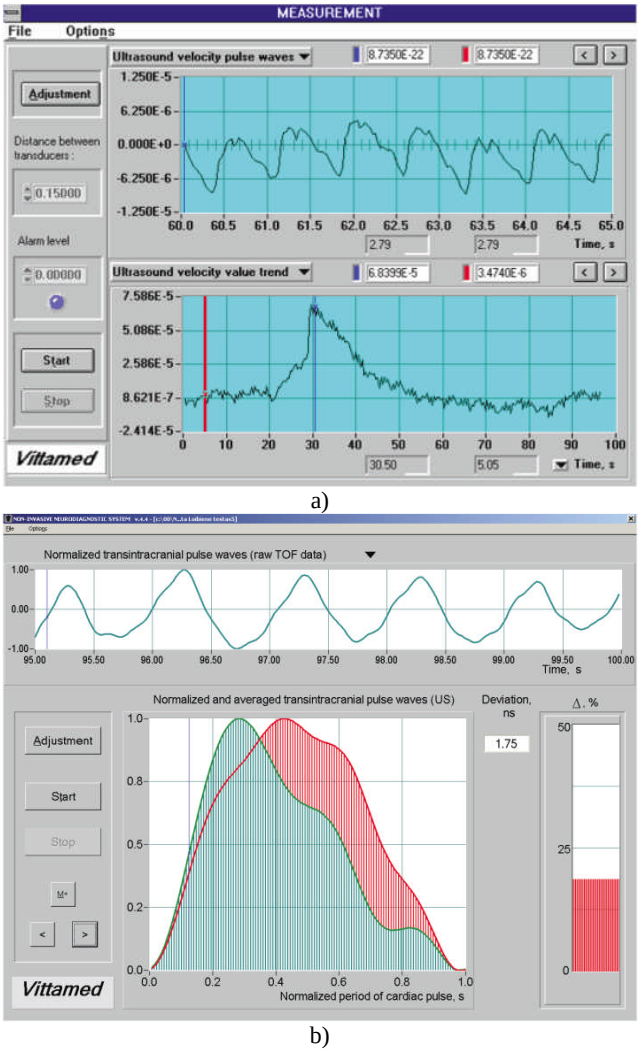

Fig. 2. The display panels of the non-invasive Vittamed 105 monitor for: a – pulse, respiratory wave and trend monitoring; b – pulse wave shape monitoring and analysis

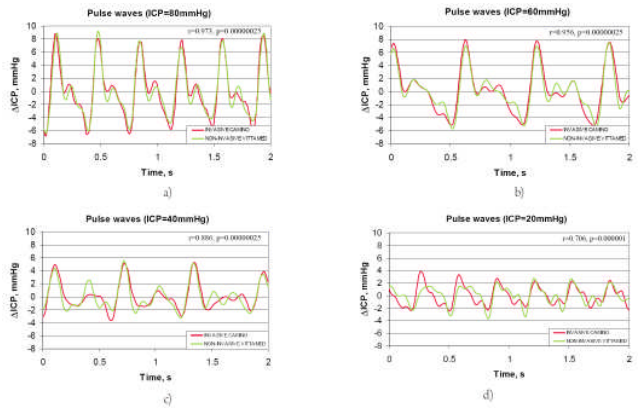

Fig. 3. Simultaneous invasive and non-invasive of ICP pulse waves monitoring: a – ICP=80 mmHg, b – ICP=60 mmHg, c – ICP=40 mmHg, d – ICP=20 mmHg

Simultaneous invasive ICP monitoring (Camino V420 or Codman ICP Express) with the non-invasive Vittamed monitor was performed on ICU coma patients with severe, closed head injuries. The clinical results of simultaneous ICP pulse wave monitoring and long - term trend monitoring (1 h ... 3 h) are illustrated in Fig. 5 –Fig. 9. Here non-invasively measured transintracranial

ultrasound speed data are converted into absolute ICP values using invasive ICP monitoring data for such a conversion.

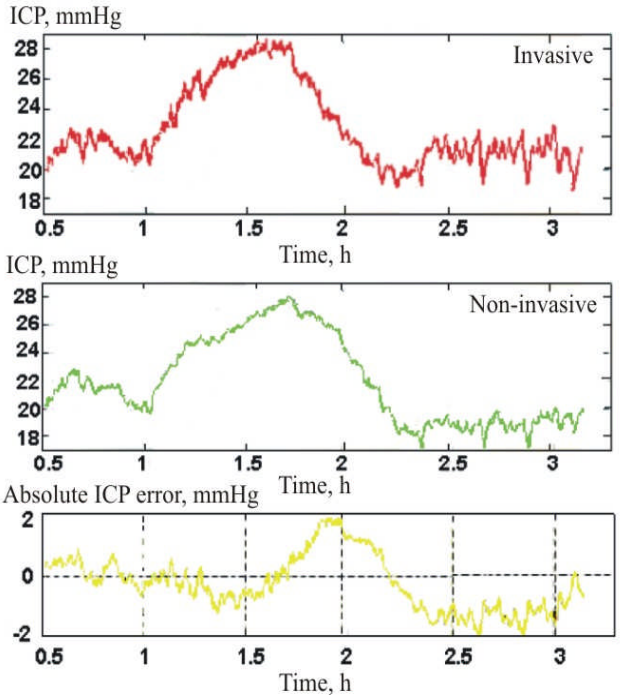

Fig. 4. Simultaneous invasive and non-invasive of ICP long – term monitoring: red line – invasive (Camino V420) ICP recording; green line – simultaneous non-invasive recording (Vittamed); yellow line – absolute invasive / non-invasive ICP data difference (mmHg). These represent the absolute ICP monitoring errors of both invasive and non-invasive devices.

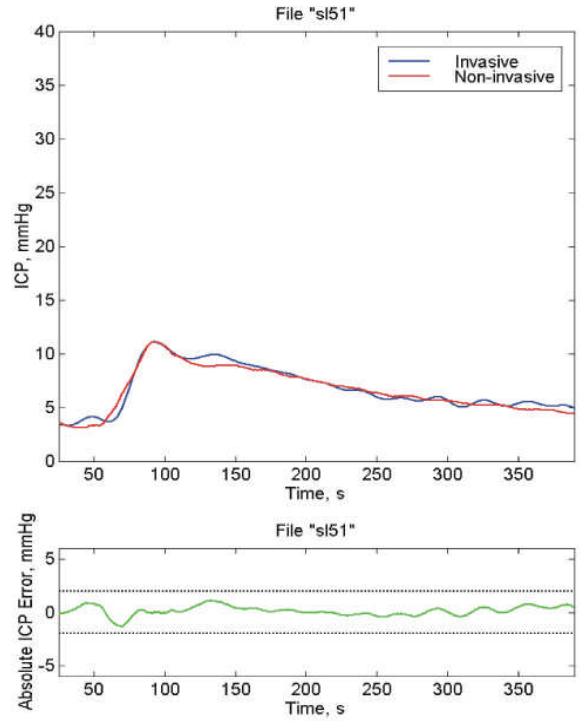

Fig. 5. Simultaneous invasive and non-invasive of ICP long – term monitoring

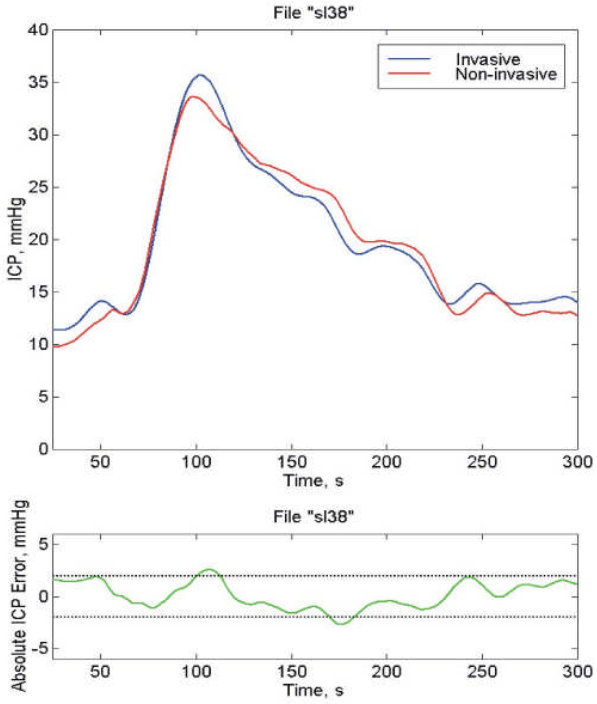

Fig. 6. Simultaneous invasive and non-invasive of ICP long – term monitoring

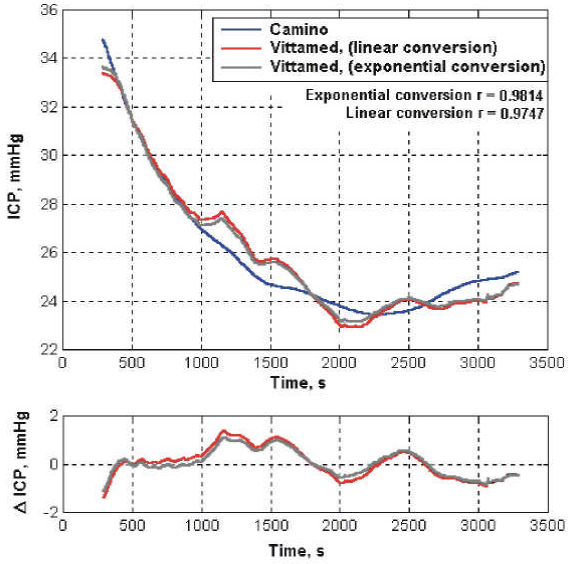

Fig. 7. Simultaneous invasive and non-invasive of ICP long – term monitoring

The non-invasive ICP indices were calculated from the ultrasound time-of-flight data using linear conversion after real-time and *in situ* compensation of the influence of the external tissue and skull bones on the measured time-of-flight data. A linear relationship was demonstrated in patients with head injuries between the measured ultrasound speed in the cerebral parenchymal acoustic path and ICP. The test range was clinically relevant and covered a range from ICP =0 mmHg up to ICP = 50 mmHg. This linear relationship covers the critical treatment level of ICP, believed to be approximately 20 mmHg.

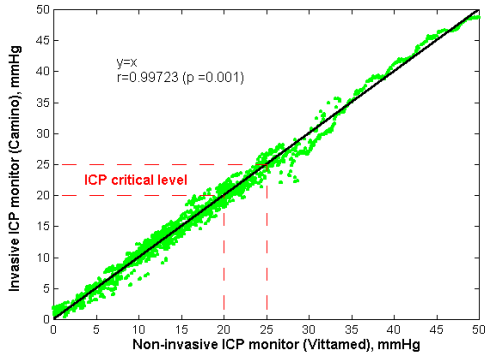

Fig. 8. Readings from invasive ICP monitor plotted against readings of non-invasive ICP monitor (18 patients with TBI)

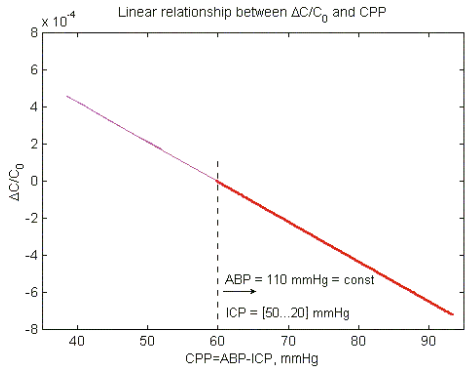

Fig. 9. Relationship between non-invasively measured ultrasound speed data and CPP

Conclusion

New Vittamed 105 has been created and clinically tested. The clinical investigations of new technology show the similarity between the invasively recorded intracranial pressure (ICP) and non-invasively recorded intracranial blood volume (IBV) pulse waves, slow waves and slow trends under intensive care unit (ICU) conditions.

References

1. **Ragauskas A., Daubaris G.** Method and apparatus for non – invasively deriving and indicating of dynamic characteristics of the human and animal intracranial media. US Patent 5,388,583, 1995, European Patent EP0717606B1. 1999.
2. **Ragauskas A., Daubaris G.** Method and apparatus for non – invasively deriving and indicating of dynamic characteristics of the human and animal intracranial media. US Patent 6,387,051. 2002.
3. **Chambers I. R., Daubaris G., Jarzemskas E., Fountas K., Kvascevicius R., Ragauskas A., Rocka A., Robinson J. S., Sitkauskas A.** The clinical application of non-invasive intracranial blood volume pulse wave monitoring // Physiol. Meas. – 2005. – 26. – P. 1019–1032.
4. **Petkus V., Ragauskas A., Jurkonis J.** Investigation of intracranial media ultrasonic monitoring model // Ultrasonics. – 2002. – 40. – P. 827–831.
5. **Ragauskas A., Daubaris G., Petkus V., Chomskis R.** Ultrasonic non-invasive intracranial wave monitor // Ultragarsas. – 2002. – 4(45). – P. 34–39.
6. **Ragauskas A., Daubaris G., Ragaisis V., Petkus V., Andrasunas V.** Assesment of cerebrovascular autoregulation non-invasive monitoring in the cases of traumatic brain injuries // Matavimai. – 2002. – 3(23). – P. 21–24 (in Lithuanian).
7. **Ragauskas A., Daubaris G., Ragaisis V., Petkus V.** Implementation of non-invasive brain physiological monitoring concepts // Medical Engineering and Physics. – 2003. – 25. – P. 67–678.
8. **Ragauskas A., Daubaris G., Petkus V.** Innovative technologies of head injury physiological monitoring // Ultragarsas. – 2000. – 37. – P. 51–57.
9. **Rocka S., Sitkauskas A., Kvascevicius R., Jarzemskas E., Rocka V., Ragauskas A., Daubaris G., Robinson J.** Assessment of ultrasonic pulse waves in patients with diagnosing brain death // Acta medica Lithuania. – 2002. – T2. –N3. – P. 130-135.
10. **Marmarou A.** Keynote lecture. Intracranial Pressure and Brain Monitoring XII Symposium. – Hong-Kong, 2004.

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New non-invasive ultrasonic technology and Vittamed 105 monitor for monitoring of intracranial volumetric trends and pulse wave has been created and clinically tested. The clinical investigations of new technology show the similarity between the invasively recorded intracranial pressure (ICP) and non-invasively recorded intracranial blood volume (IBV) pulse waves, slow waves and slow trends under intensive care unit (ICU) conditions. Ill. 9, bibl. 10 (in English; summaries in English, Russian and Lithuanian).

А. Рагаускас, Г. Даубарис, В. Петкус, Р. Райшутис, Р. Хомскис, Р. Шлитерис, В. Декснис, Й. Гузайтис, Г. Ленгвинас, А. Ругайтис. Неинвазивная технология мониторинга интракраниальных объёмных волн пульса и трендов // Электроника и электротехника. – Каунас: Технология, 2008. – № 6(86). – С. 51–54.

Создана новая ультразвуковая технология для мониторинга интракраниальных пульсаций и трендов, а также новый Vittamed 105 монитор. Клинические исследования в условиях отдела реанимации показали хорошее совпадение между инвазионным и неинвазионным методами зарегистрированными пульсовыми волнами и трендами внутричерепного давления. Ил. 9, библ. 10 (на английском языке; рефераты на английском, русском и литовском яз.).

A. Ragauskas, G. Daubaris, V. Petkus, R. Raišutis, R. Chomskis, R. Šliteris, V. Deksnys, J. Guzaitis, G. Lengvinas, A. Rugaitis. Neinvazinė intrakranijinių tūrinių pulsinių bangų ir trendų stebėsenos technologija // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 6(86). – P. 51–54.

Sukurta nauja neinvazinė ultragarsinė technologija ir Vittamed 105 monitorius, skirtas intrakranijinių tūrinių trendų ir pulsinių bangų stebėsenai. Naujos technologijos klinikiniai tyrimai neurochirurginės reanimacijos sąlygomis parodė, kad invaziškai ir neinvaziškai registruoti galvospūdžio trendai bei invaziškai ir neinvaziškai registruotos intrakranijinės pulsinės bangos. Il. 9, bibl. 10 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).