Differences in Intracranial Temperature Measurements – A Systematic Analysis Between the Licox® and Hemedex® Systems

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Abstract: *Background*: Multimodality brain monitoring includes intracranial temperature (ICT) measurements. Different ICT readings have been reported from Licox® and Hemedex® systems used in the same patient with the Hummingbird® "SynergyDuo Ventricular" introducer.

Methods: To investigate the differences we report an analysis of causes for different ICT readings. In keeping with the radial brain ICT gradient model model we calculated ICTs according to the sensors' penetration depths and compared the results to clinical data from six patients.

Results: The ICT accuracy is ±0.2°C for Licox® and ±0.3°C for Hemedex® so any ICT difference ≤±0.5°C between the systems is not significant. The Hemedex®-ICT sensor is placed 15.5mm deeper than the Licox®-ICT sensor with the Hummingbird®. The calculated ΔICT from the model range from -0.7°C to -1.0°C for a 37.5°C arterial temperature, and a 22°C ambient temperature. The ΔICT ($ICT_{Licox®} – ICT_{Hemedex®}$) in six patients were -0.6°C, SD = 0.7°C, median = -0.6°C, max = 0.4°C, min = -5.7°C, range 6.1°C. 41.1% of recorded data lie within the accuracy range of ±0.5°C. 53.8% lie within a range between -0.5°C and -1.5°C, and represent the differences which can be explained by different sensor insertion depths and the model. Only 5% were outliers with ΔICT < -1.5°C.

Conclusions: This study shows that the discrepancy in ICT measurements using different sensors can be explained by (a) the ICT measurement accuracies/specifications, and (b) different insertion depths. Other causes may include (c) environmental conditions and (d) unknown factors secondary to body – and/or brain physiology.

Keywords: Intracranial temperature, brain physiology, brain monitoring, comparative study, brain injury, subarachnoid hemorrhage.

INTRODUCTION

Advanced brain monitoring is an invasive multimodality approach to investigate cerebral pathophysiology in neurocritical care. The most frequently used advanced brain monitoring parameters are intracranial pressure (ICP), cerebral partial pressure of oxygen ($p_{bt}O_2$), intracranial temperature (ICT), cerebral blood flow (CBF), and cerebral microdialysis (MD) [1-5]. These monitoring parameters are recorded with catheter based single-use sensors.

The choice of sensors and monitoring systems varies between and among users and neurosurgical units as well as between different pathologies, e.g., severe head injury (SHI) or aneurysmal subarachnoid hemorrhage (SAH) [6, 7]. To accomodate individual monitoring parameters to specific needs, protocols, or interests users combine sensors and introducing systems from different manufacturers.

Intracranial sensor placement is achieved by manufacturer-specific introducing systems which are typically bolt-based or tunneling systems. Cranial access is achieved *via* a burr hole made with a twist drill for a bolt based system or a trephine for a tunnelled sensors. Bolts provide mechanical strain relief and a bacterial barrier. Tunnelling systems allow the sensors to be inserted approximately 5-7cm underneath the galea before they enter the brain, which also provides a bacterial barrier and mechanical strain relief.

In this scenario users insert a combined intraparenchymal $p_{bt}O_2$ and ICT sensor (Licox® REF CC1.P1 sensor – manufactured by Integra, GMSmbH, Kiel-Mielkendorf, Germany) and a combined intraparenchymal CBF and ICT sensor (Bowmann Perfusion Monitor® - manufactured by Hemedex Inc®, Cambridge, MA, USA) for the same patient. Both sensors can be introduced through the same introducer system, e.g. the SynergyDuo Ventricular® (manufactured by Innerspace Medical®, Tustin, CA, USA) and identical temperature readings are expected from the two systems.

Based on customers' written or verbal feedback to the manufacturer different ICT readings have been reported from Licox® and Hemedex® systems. The reports summarize that Licox®-ICT is most often lower than Hemedex®-ICT. The difference cannot be explained by the individual ICT accuracies of each individual monitoring system.

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It becomes important to factor in various monitoring conditions when comparing lCT measurements from independent monitoring systems. We here report (a) an analysis of potential root causes for different ICT between the systems, and (b) present recorded clinical data to explain and clarify the observed differences.

MATERIAL AND METHODS

Sensors' Specifications

The Licox®-ICT accuracy is specified at ±0.2°C at body temperature [8]. The Hemedex®-ICT accuracy is specified at ±0.3°C between 25°C and 46°C [9]. Under these premises any ICT difference between Licox® and Hemedex® of less than or equal to ±0.5°C is not significant because of the specified ICT accuracies of both monitoring systems.

Applied Physiology - Radial Brain ICT Gradient Model

ICT rises with increasing depth from the brain surface towards the center of the brain, which is illustrated in Fig. (**1**). It is not a global but a local variable which also depends on distance from the brain surface, i.e.: ICT sensor insertion depth, arterial blood temperature, ambient temperature, and other variables and constants. This relationship can be expressed by the following formula [10]:

$$ICT(r)=T_a+T_m-(h\Delta(T_a+T_m-T_e))/(K+h\Delta)\cdot\exp(-r/\Delta) \quad (1)$$

r = radial distance from brain's surface (ICT sensor insertion depth below dura level)

(a) T_a=37.5°C

(b) T_m=0.35°C

(c) h=3mW/cm^2/°C

(d) T_e=22°C

(e) K=5,03mW/cm/°C

(f) Δ = 0.36cm

The formula is derived from the physical model, in which brain temperature has two sources: 1. Arterial blood with a temperature of $\mathbf{T_a}$ (a), which represents body core temperature. 2. Brain metabolism with a temperature of $\mathbf{T_m}$ (b). A patient's head is exposed to an ambient temperature of $\mathbf{T_e}$ (d) which causes cooling. This heat transfer is expressed as **h** (c). Brain tissue will conduct heat from its center towards its surface with a heat conductivity of **K** (e).

Based on the underlying physiological model cortical CBF acts as a local "shielding" against cerebral heat loss [10]. To account for this phenomenon a "characteristic shielding length" $\mathbf{\Delta}$ (f) is needed in this equation. In the human adult brain this "characteristic shielding length" was found to be 3.6 mm = 0.36 cm [10].

ICT SENSORS, BOLT INTRODUCER AND INSERTION DEPTHS

Fig. (**2**) shows a Licox® CC1.P1 sensor inserted into the blue port and a Hemedex® sensor inserted into the white port of the Hummingbird® "SynergyDuo Ventricular" bolt [11]. The lengths of the ICT sensing areas of a Licox® CC1.P1 sensor is 4.5 ± 0.5 mm and for the Hemedex® it is approximately 1 mm. In combination with a Hummingbird® "SynergyDuo Ventricular" bolt introducer this will result in

- A *theoretical* measurement area from the dura level to a penetration depth of 5mm for the Licox® CC1.P1 sensor.
- An insertion depth of 19.7mm for the Hemedex® sensor.

With this particular sensors/introducer combination it is *essential* to note that the proximal two thirds of the Licox® sensor ICT sensing area will not have a direct sensor/brain tissue interface because it is located in the distal Hummingbird® introducer section. The Hummingbird® introducer provides a thermal isolation for the proximal two thirds of the ICT sensing area and prevents proximal cooling of the sensor. Only the direct sensor/brain tissue interface area will transfer the heat into the ICT sensing area. The heat is now conducted towards the proximal part of the ICT sensing area. Consequently we must take the ICT

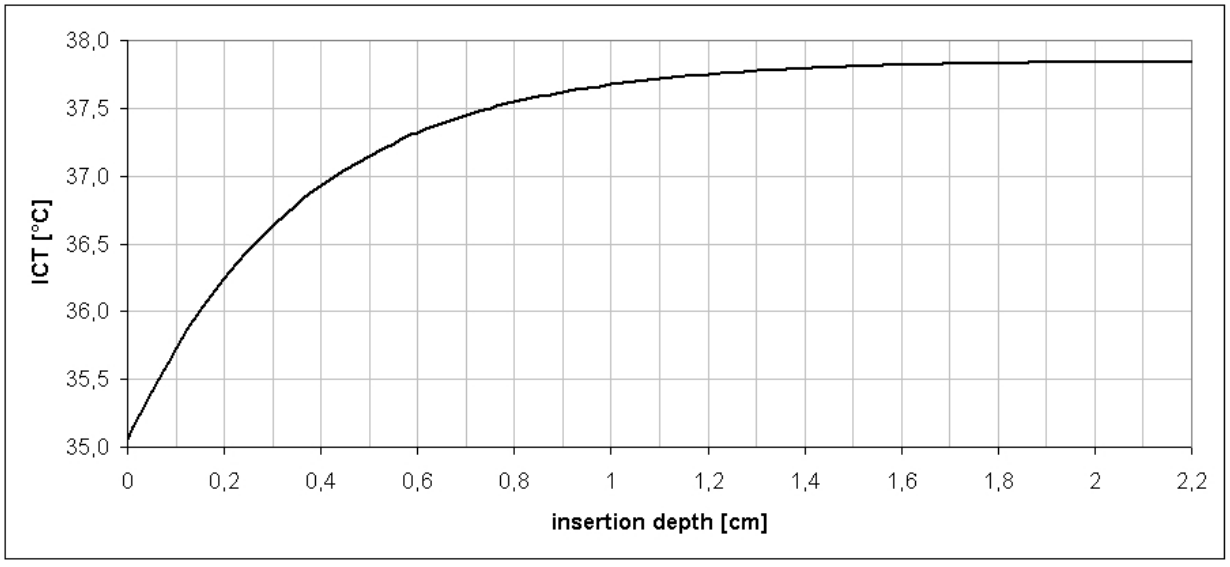


Fig. (1). Relationship between insertion depth and ICT according to the radial brain ICT gradient model.

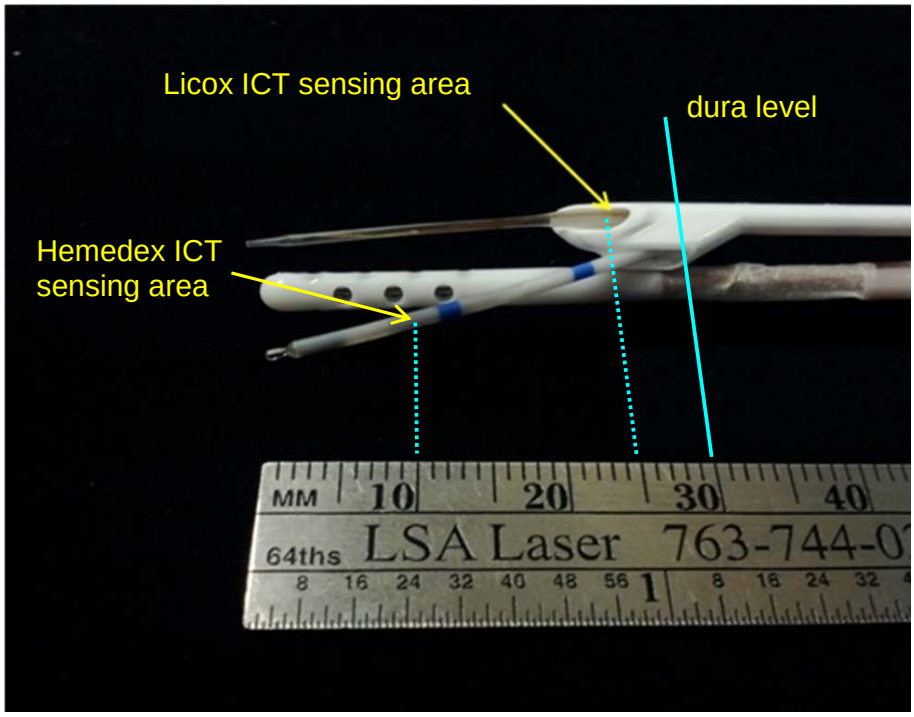


Fig. (2). Licox® REF CC1.P1 combined oxygen and ICT sensor and Hemedex® combined intraparenchymal CBF and ICT sensor inserted into a Hummingbird® SynergyDuo Ventricular® bolt introducer. The ruler is shown to appreciate the dura level and the different insertion depths of the sensors*. This will result in a *theoretical* measurement area from the dura level to a penetration depth of 5mm for the a Licox® CC1.P1 sensor although the *effective* measurement area covers 1.5mm (from 3.5mm below dura level to a penetration depth of 5mm, see text for details). The insertion depth for the Hemedex® sensor is 19.7mm with an ICT sensing area of 1mm.

*Please note that this is a photo taken through a microscope which enables stereoscopic vision and accounts for the perspective shown.

measurement at the distal third of the ICT sensing area. This will reduce the *effective* length of the Licox® ICT sensing area from 5mm to 1.5mm. Therefore we must assume that this will result in an *effective* measurement area from 3.5mm below dura level to a penetration depth of 5mm.

In summary, according to the above mentioned considerations, the Hemedex®-ICT sensor is on average placed 15.5 mm deeper into the brain than the Licox®-ICT sensor when the Hummingbird® "SynergyDuo Ventricular" bolt is used.

To confirm our calculated differences we analyzed continuously recorded data samples in a series of 6 critically ill patients provided to Integra, GMSmbH by an ICU which uses the above described sensors/introducer combination and compared those results with the results calculated from the model. Simultaneous ICT measurements were recorded with the two above described sensors in four severe TBI patients and two patients after aneurysmal SAH.

RESULTS

Radial Brain ICT Gradient Model Application - Calculated Differences Between Licox®-ICT and Hemedex®-ICT

In keeping with the radial brain ICT gradient model one expects different ICTs when the two sensors are used with the Hummingbird® "SynergyDuo Ventricular" bolt because of the different insertion depths.

Fig. (**3**) shows the calculated ICT as a function of insertion depth. The insertion depths of both sensors are highlighted. It also shows the ICT difference between the two sensors, which is calculated as: $\Delta ICT = ICT_{Licox}{}^{®} - ICT_{Hemedex}{}^{®}$. The calculated ΔICT ranges from -0.7°C to -1.0°C for Ta=37.5°C, Te=22°C, Tm=0.35°C, Δ=0.36cm, h=3mW/cm^2/°C, and K=5,03mW/cm/°C. We have chosen Ta and Te for what we consider average/normal ICU conditions.

Comparison with Clinical Data Sample

The ICT differences ($\Delta ICT = ICT_{Licox}{}^{®} - ICT_{Hemedex}{}^{®}$) calculated from the recorded ICT data of all six patients are shown in Fig. (**4**). The mean ΔICT = -0.6°C, SD = 0.7°C, median = -0.6°C, max = 0.4°C, min = -5.7°C, range 6.1°C.

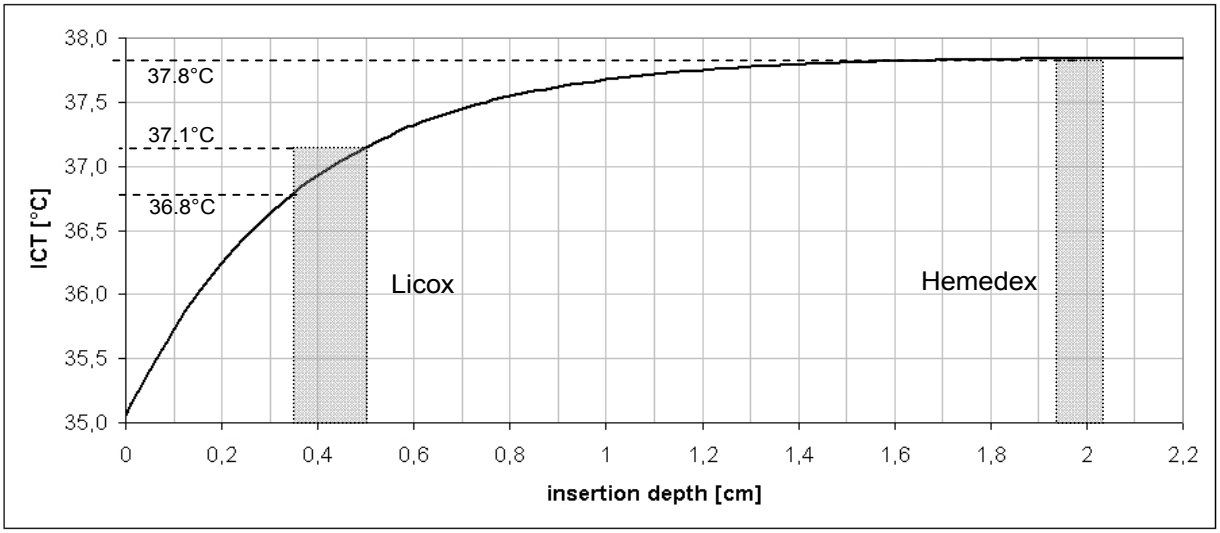
The relative frequencies of the measured ΔICTs from all six patients are illustrated in Fig. (**5**) using temperature intervals with a class width of 0.5°C. The distribution of recorded patient data can be summarized as follows:

1. 41.1% lie within a range of ±0.5°C.

   These ΔICTs (14.4% + 26.7%) are likely caused by the specified ICT measurement accuracies of the Licox® and the Hemedex® sensors.

2. 53.8% lie within a range between -0.5°C and -1.5°C.

   These ΔICTs (46.6% between -1.0°C and -0.5°C, and 7.2% between -1.0°C and -1.5°C) represent the clinical observations brought forth to the



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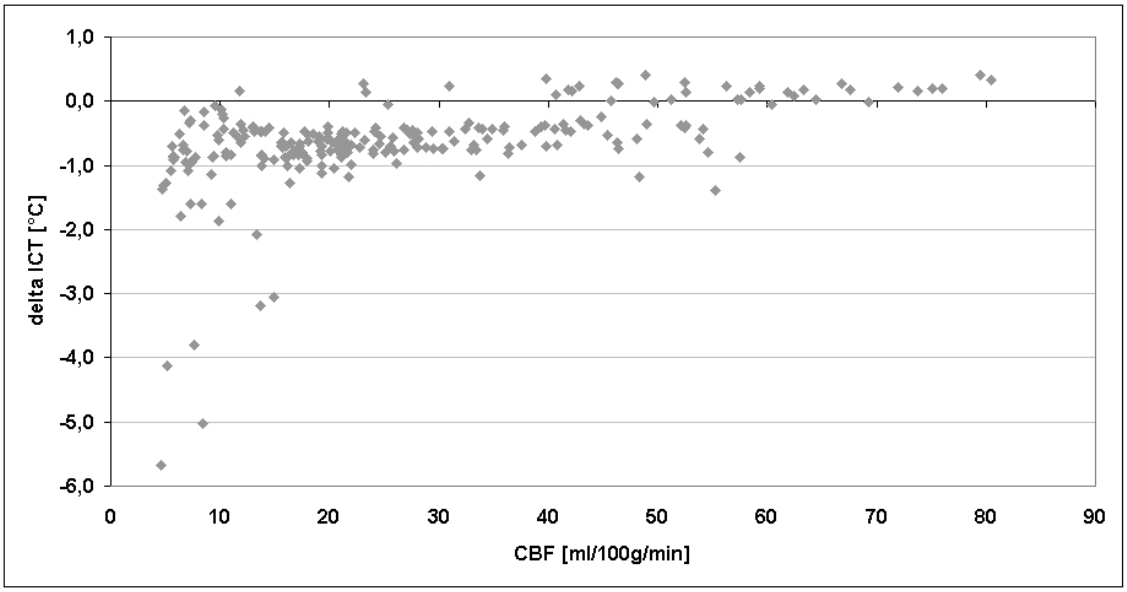

Fig. (4). ICT differences ($\Delta ICT = ICT_{Licox}^{®} - ICT_{Hemedex}^{®}$) calculated from the recorded ICT data of all six patients. The mean ΔICT = -0.6°C, SD = 0.7°C, median = -0.6°C, max = 0.4°C, min = -5.7°C, range = 6.1°C (see text for details).

manufacturers and they represent the differences which can be explained on the basis of the different sensor insertion depths.

It is noteworthy that the calculated ICT difference of -0.7°C to -1.0°C, based on our model, is contained in the largest section (46.6%) of the recorded patient data! This supports the conclusion that the theoretical model is applicable to and can be confirmed by experimental clinical data.

3. 5% outliers with ΔICT < -1.5°C.

These ΔICTs (2.1% between -1.5°C and -2.0°C and 2.9% with ΔICT < -2.0°C) are in keeping with variabilities in clinically recorded data and they are negligible. We speculate that these values could represent data obtained with Licox® ICT probes positioned in a very superficial cortical location.

DISCUSSION

This study shows that the clinical observation - a discrepancy in ICT measurements using different sensors - can be largely explained on the basis of (a) the ICT measurement accuracies/specifications, and (b) different insertion depths. Other causes may include (c) environmental conditions and (d) unknown factors secondary to body – and/or brain physiology. To the best of our knowledge this is the first clinical paper to report on differences between two independent ICT monitoring systems.

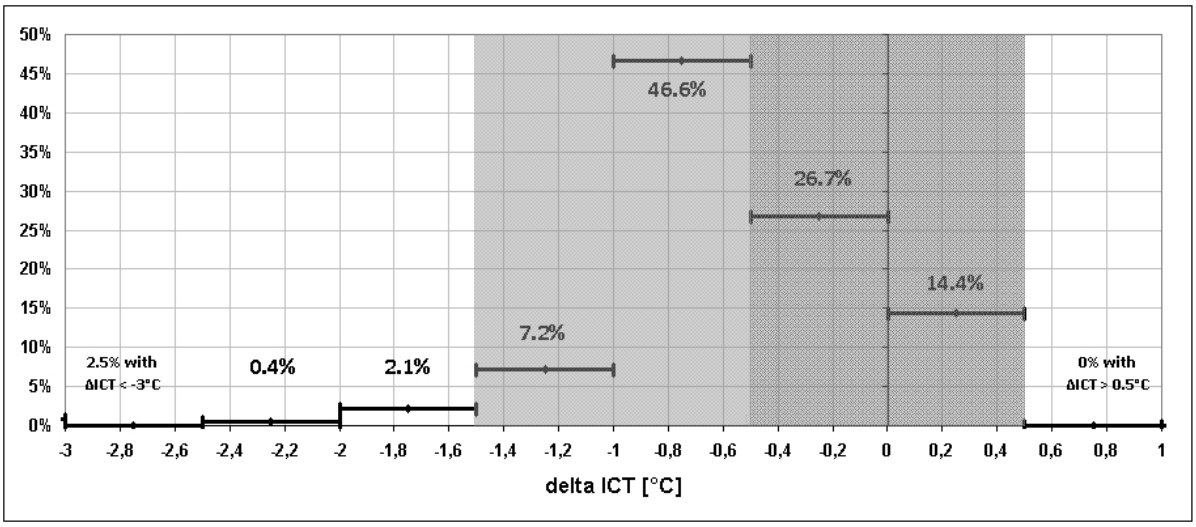

Fig. (5). Relative frequencies of the ICT differences (ΔICT= $ICT_{Licox}^{®}$ – $ICT_{Hemedex}^{®}$) calculated from the recorded ICT data of all six patients using temperature intervals with a class width of 0.5°C. 41.1% (dark shaded area) are within the technical specifications/measurement accuracies of the sensors. 53.8% (light shaded area) represent the ICT differences which can be explained on the basis of the different sensor insertion depths. The remaining 5% are outliers (see text for details).

The ICT measurement accuracies/specifications are system-related features and range from ±0.2°C for the Licox® sensor and ±0.3°C for the Hemedex® sensor. These cannot be corrected for and account for a relative deviation of 1.3% (0.5°C/37.5°C) if we consider a maximum specification-related disagreement of 0.5°C. Other authors and we consider this magnitude clinically acceptable [12].

Based on our analysis almost half of the reported ICT differences can be explained on the basis of different insertion depths. Our study also confirms the clinical validity of the formula by Zhu *et al.* [10]. This study and our results do not confirm previous results by Fountas *et al* (5), although the presence of a radial ICT gradient has been confirmed previously [13]. In their study six ICT measurements were taken at 1cm distance intervals upon retraction of an intraventricular temperature probe from the lateral ventricle [5]. For the 5 intraparenchymal areas they do not report significant ICT differences. (38.2°C at 1cm; 38.4°C at 2cm; 38.3°C at 3cm; 38.3°C at 4cm; 37.9°C at 5cm). It must be noted, however, that they did not reach the superficial cortical locations which were subject to our investigation.

The physiological model and this study also show that superficial ICT sensor placement harbours the risk of large measurement variation. A previous study has reported that: "Cerebral temperatures were generally insensitive to surface conditions (air temperature and evaporation rate), which affected only the most superficial level of the cerebrum (< or =1.5mm)" [14]. If the Licox® ICT sensor is used with its designed bolt its insertion depth reaches down to 10mm, which reduces ΔICT considerably. As stated above two thirds of the Licox® ICT sensor do not have a tissue/sensor interface. We feel that is appropriate to conclude that the superficial Licox ICT sensor location, which is achieved with this particular sensor and introducer combination is not desirable for clinical practise.

External, i.e. environment-specific factors may also cause measurement differences and these factors include exposition to light and heat sources, proximity to electrical fields. This is stated in the Licox® operations manual [15]. We did not find published data about contributions and/or magnitudes of these confounding variables.

It is conceivable that advanced brain monitoring in mechanically ventilated, critically ill patient is subject to numerous confounding factors which may influence recordings of invasively monitored neurophysiologic parameters to an unknown degree. Internal, i.e. patient-specific factors include CBF-heterogeneity and impairment or loss of cerebrovascular autoregulation may render the model partially or entirely invalid for a given patient or recording interval. In this context treatment-specific factors should also be listed, e.g. pharmacologic effects, head/body positioning, effects of surgery, and ventilation. Once again the retrieved literature is sparse and we found only one study which reports "that cooling of the upper airway can directly influence human brain temperature" [16]. In a critical appraisal of these factors it must be said that one expects both ICT sensors to trend in an equal direction. We hope that this paper will generate more formal research on this topic.

Last but not least we wish to point out the limitations of our study. First the number of patients is limited. In response to this it is noted that the data are virtually uniformly applicable to the model and confirms the predictions. As with all clinical data our study has outliers, which can be explained on the basis of applied physiology. In addition our results are confirmed by albeit few previous studies.

Second we do not know the individual patient's arterial temperature and the ambient temperature. This could result in a deviation of the predicted from the measured data. This deviation can occur in both directions both larger and smaller. The formula presented is able to accomodate individual patient-specific and environmental variations and it would be desirable to confirm its applicability with a

different data set. This could include a study in which sensor depths are varied to further investigate the relationship between sensor depth and ΔICT.

CONFLICT OF INTEREST

Erhard Lang is a member of the Integra Speakers Bureau and consults Integra for complaints received with the use of Licox products. Jens Bracht is the technical director of and an employee of Integra, GMSmbH in Kiel.

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Declared none.

REFERENCES

[1] Leal-Noval SR, Munoz-Gomez M, Arellano-Orden V, *et al*. Impact of age of transfused blood on cerebral oxygenation in male patients with severe traumatic brain injury. Crit Care Med 2008; 36(4): 1290-6.

[2] Jaeger M, Soehle M, Schuhmann MU, Winkler D, Meixensberger J. Correlation of continuously monitored regional cerebral blood flow and brain tissue oxygen. Acta Neurochir (Wien) 2005; 147(1): 51-6; discussion 6.

[3] Al-Rawi PG, Tseng MY, Richards HK, *et al*. Hypertonic saline in patients with poor-grade subarachnoid hemorrhage improves cerebral blood flow, brain tissue oxygen, and pH. Stroke 2010; 41(1): 122-8.

[4] Lang EW, Lagopoulos J, Griffith J, *et al*. Cerebral vasomotor reactivity testing in head injury: the link between pressure and flow. J Neurol Neurosurg Psychiatry 2003; 74(8): 1053-9.

[5] Fountas KN, Kapsalaki EZ, Feltes CH, Smisson HF, 3rd, Johnston KW, Robinson JS, Jr. Intracranial temperature: is it different throughout the brain? Neurocrit Care 2004; 1(2): 195-9.

[6] Figaji AA, Zwane E, Kogels M, *et al*. The effect of blood transfusion on brain oxygenation in children with severe traumatic brain injury. Pediatr Crit Care Med 2010; 11(3): 325-31.

[7] Helbok R, Madineni RC, Schmidt MJ, *et al*. Intracerebral monitoring of silent infarcts after subarachnoid hemorrhage. Neurocrit Care 2011; 14(2): 162-7.

[8] Directions for use: Licox IP2.P Booklet_Rev00_2011-06-30, 2011.

[9] Product Information, Bowman Perfusion Monitor H4400-0017 Rev B. Available at: http://www.hemedex.com/BPM_Specifications.htm

[10] Zhu M, Ackerman JJ, Sukstanskii AL, Yablonskiy DA. How the body controls brain temperature: the temperature shielding effect of cerebral blood flow. J Appl Physiol 2006; 101(5): 1481-8.

[11] Instructions for use, Hummingbird bolt introducer "SynergyDuo Ventricular", P/N 50399 Rev. B Available at: www.innerspacemedical.com

[12] Alessandri B, Hoelper BM, Behr R, Kempski O. Accuracy and stability of temperature probes for intracranial application. J Neurosci Methods 2004; 139(2): 161-5.

[13] Mellergard P. Intracerebral temperature in neurosurgical patients: intracerebral temperature gradients and relationships to consciousness level. Surg Neurol 1995; 43(1): 91-5.

[14] Nelson DA, Nunneley SA. Brain temperature and limits on transcranial cooling in humans: quantitative modeling results. Eur J Appl Physiol Occup Physiol 1998; 78(4): 353-9.

[15] Operations Manual Licox CMP Brain Monitoring System. rev 04_US/2010-01-20, 2010.

[16] Mariak Z, White MD, Lewko J, Lyson T, Piekarski P. Direct cooling of the human brain by heat loss from the upper respiratory tract. J Appl Physiol 1999; 87(5): 1609-13.

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