PROCEEDINGS OF THE LATVIAN ACADEMY OF SCIENCES. Section B,
Vol. 75 (2021), No. 5 (734), pp. 371–378.

DOI: 10.2478/prolas-2021-0054

CEREBRAL OXIMETRY MEASUREMENTS RESULTS DEPENDING ON A PRECLINICAL SKULL PHANTOM MODEL

Roberts Leibuss[1,2,#], Arnija Reihmane[1,3], Lāsma Baltace[4], Kārlis Baltacis[4], Sabīne Štelmahere[2], Vineta Zemīte[4], Yuri Dekhtyar[4], and Pēteris Stradiņš[1,2]

[1] Pauls Stradiņš Clinical University Hospital, 13 Pilsoņu Str., Rīga, LV-1002, LATVIA

[2] Rīga Stradiņš University, 16 Dzirciema Str., Rīga, LV-1007, LATVIA

[3] University of Latvia, 19 Raiņa Blvd 19, Rīga, LV-1586, LATVIA

[4] Rīga Technical University, 1 Kaļķu Str., Rīga, LV-1658, LATVIA

[#] Corresponding author, roberts.leibuss@gmail.com

Contributed by Pēteris Stradiņš

It is more common to perform non-invasive examination during general anaesthesia to ensure effective perioperative patient care. To achieve these results, researchers and clinicians are seeking out different technologies and developing new equipment. One such apparatus is a cerebral oximeter, which is used during cardiac surgery with cardiopulmonary bypass for neuroprotection management for reducing risk of postoperative neurological injury (cerebral stroke, neurocognitive dysfunction, and cerebral haemorrhage). A cerebral oximeter performs non-invasive transcutaneous measurements using near infrared radiation to assess the oxygenation of tissues. The objective of the study was to determine if the angle and thickness of a patient's skull affects measurements. Intralipid water solution, gelatine, and ink were used to make six phantoms with skull thickness ranging from 6 to 11 mm. All phantoms were bent from a 0 to 20 degrees angle. The cerebral oximeter SOMETICS INVOS 5100C was used to perform regional oximetry measurements. For skull thickness of 11 mm, the rSO2 was 45.8% (SD 0.96); for skull thickness of 10 mm, the rSO2 was 45.25% (SD 2.22); for skull thickness of 9 mm, the rSO2 was 32% (SD 1.63); for skull thickness of 8 mm, the rSO2 was 17% (SD 1.83); for skull thickness of 7 mm, the rSO2 was 15% (SD 0); for skull thickness of 6 mm, the rSO2 was 15% (SD 0). No significant changes were observed regarding the angle of the skull phantom. The thickness of the bone layer of the skull phantom affected the regional oximetry results, whereas the angle of the skull did not affect it.

Keywords: *cerebral perfusion, spectrophotometry, cardiac surgery, cardiopulmonary bypass, neuroprotection, neurocognitive dysfunction, neurologic injury.*

INTRODUCTION

Nowadays it is more common to perform non-invasive exams and obtain quick results to ensure and increase effective patient care during general anaesthesia. To achieve these goals, different technologies are being sought out and new equipment is being developed. One such apparatus is a cerebral oximeter. It performs transcutaneous measurements to assess the oxygenation of tissues in the frontal cortex, which is the most oxygenated area of the brain. The measurements are performed using near infrared radiation (700–1000 nm). This infrared radiation spreads through the skin, subcutaneous fat, skull, dissipating in the muscles and brain below. Infrared radiation is absorbed by oxygen-containing substances with varying concentrations, such as haemoglobin in the blood or myoglobin in the muscles, as well as tissues with relatively constant concentrations, such as melanin in the skin. These measurements mainly reflect changes in the oxygen content of haemoglobin in tissues and are necessary to observe the changing balance between oxygen supply and consumption. (Frost *et al*., 2012)

The first studies on different absorption of infrared radiation in different tissues were published in 1977 (Tosh and Patteril, 2016). Following these studies, this research direction developed rapidly and revealed that there were different oxyhaemoglobin and deoxyhemoglobin absorption ranges at different wavelengths. These studies enabled the production and sale of the first cerebral oximeter in 1990 (Bsis-Vandervliet, 1999). This technology is used as an indicator for various cardiovascular, neurological, and other complex surgical procedures as an early warning of changes in oxygen content in the brain, or as a trend monitor to follow changes in oxygen content over time.

The objective of the study was to determine whether the angle between an incident light beam and infrared detector location, as well as the thickness of skull bone, influence the results of measurements of cerebral oximetry. The objectives of the study were to develop a skull phantom, to perform cerebral oximetry measurements depending on the geometric properties of the skull phantom, to analyse the results obtained to assess how the phantom skull thickness and curvature affect the measurements of cerebral oximetry results, and to draw conclusions about the effects of the skull phantom on the oximetry measurements, to make recommendations for the use of the obtained results and further research.

MATERIALS AND METHODS

Clinical research has made it possible to both evaluate different factors that influence the results of cerebral oximetry, and to compare different cerebral oximeters. At the same time, however, it is impossible for them to be completely objective as there are several physiological and other factors that influence the possible outcome.

A human skull phantom can be used for the accomplishment of this goal by creating the qualities of absorption and scattering of infrared radiation in a replica of a human head. This can be achieved by adding a substance or small particles to the base material of the skull phantom, which would then provide the necessary absorption and scattering properties. Studies have shown that several factors, such as the number of layers a skull phantom has (Kleiser *et al.*, 2016), the necessity to replace human blood with an equivalent and the pigment melanin, which is found in skin, influence the skull's optical properties.

For the purpose of measuring the cerebral oxygenation, a cerebral oximeter SOMETICS INVOS 5100C was used. A cerebral oximeter is a device that is used to determine rSO^2, fluctuations in haemoglobin volume and indirectly also the blood flow of the brain, as well as the amount of oxygen consumed by muscles. It shows the dynamic balance between oxygen delivery and consumption in capillary, venule, and arteriole pools. The device operates on the principle that near infrared radiation of 700–1000 nm is able to penetrate the skin, subcutaneous tissue, skull, and the brain, where it is either absorbed or scattered. Weakening of the infrared signal can be caused by oxygen absorption in tissues with variable (haemoglobin, myoglobin) or constant (melanin) oxygen concentration, as well as different cell structures, such as the nucleus (Steppan and Hogue, 2014). INVOS 5100 is constructed of photodiodes that emit two 730–810 nm near infrared radiation waves — the head tissue absorption and scattering coefficients, that correspond to these wavelengths (Roggan *et al.*, 1999; Correia *et al.*, 2009) (Table 1) and of two photodetectors that are 30–40 mm away from the photodiodes and pick up the transmitted signal, an illustration of which can be seen in Figure 1. To determine the regional oxygen saturation, it is needed to compare the results of the two photodetectors. According to the information provided by the manufacturer, the oxygen saturation can be determined up to a depth of 5 cm.

The device calculates the regional oxygen saturation by the absorption rate of near infrared radiation in both venous and arterial blood at a proportion of 3 : 1, which gives real-time data on oxygen delivery and its balance or disbalance, as well as shows the residual oxygen left in veins or what is left after all the basic life supporting organs have been supplied with it. The algorithm of this device presumes that all tissues have the same scattering coefficient.

This device can be used with four different disposable cerebral oximetry sensors, which all vary in size and design, but all use the same wavelength, intensity, and distance between photodiodes and photodetectors. In this study, paediatric sensors were used, which were placed directly onto the phantom.

While taking the measurements it must be noted that the device only measures regional oxygen saturation in the 15–95% range. The manufacturer also notes that the measurement repeatability for the device including sensors is 1% of the *in vitro* measurement value. In cases when the oxygen saturation is low, the device shows a notification "Poor

Table 1. Head tissue absorption and reduced scattering coefficients

	Absorption coefficient μa, cm^{-1}	Absorption coefficient μa, cm^{-1}	Reduced scattering coefficient μs', cm^{-1}	Reduced scattering coefficient μs', cm^{-1}
Tissue	730 nm	810nm	730 nm	810nm
Skin	0.17	0.18	23.5	22.5
Skull	0.33	0.38	22	19
Brain	0.25	0.25	23.5	20.0
Blood	11	19	11	19

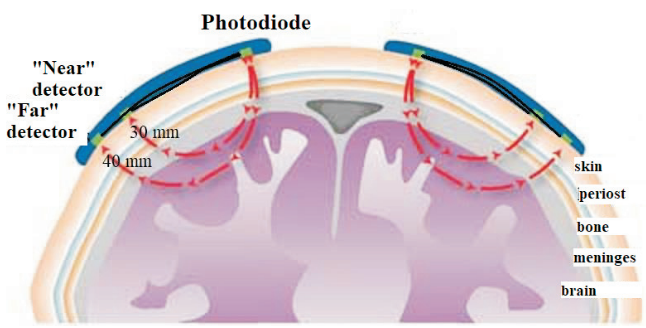

Fig. 1. Placement of sensors on head-device INVOS 5100 ("Covidean").

signal quality” (Steppan and Hogue, 2014), “Low rSO_2” or “15%”. In cases where the oxygen saturation is high, the device shows a notification “Poor signal quality” or “95%”. The device also has a signal strength indicator that shows the intensity of the signal, which depends on different physiological factors and is susceptible to possible interruptions from near-by devices. This factor is used only as an indicator.

The cerebral oximeter registers a result once every 5–6 seconds. All the measurements are taken in normal mode, which is meant for uninterrupted patient monitoring. It must be noted that all of the aforementioned factors are considered in the process.

As a trial-run for measuring cerebral oximetry whilst observing the possible influence of the skull’s curvature and thickness on the results, a pumpkin (Fig. 2) was used, as it is composed of different layers varying from hard to soft, which bears similarity to the skull and the brain. Sparkling water was used as an equivalent to blood — it provides both absorption and scattering qualities. It was concluded that a pumpkin is a poor replica of the optical qualities of the human skull, leading to the decision to create a more complex skull phantom with more accurate absorption and scattering properties.

Currently two approaches to creating a phantom skull can be distinguished — skull phantoms created with nanoparticles and intralipid solution and skull phantoms that are made with epoxy resin and other polymers that allow the layers to quickly dry and harden, resulting in a durable product. The latter approach also provides the possibility of differently shaped skull phantoms to be made. Skull phantoms made of epoxy resin also retain their optical properties for up to a year (Wrobel *et al*., 2015).

Different solutions are used for providing the properties of absorption in a skull phantom, such as intralipid solution or nanoparticles (TiO_2, SiO_2, etc.). Intralipid solution concentrations used in this study were based on literature reviews (Aernouts *et al*., 2014).

A decision was made to make a liquid skull phantom based on a previously approved method, where the scattering properties would be provided using intralipid water solution and ink that would be used as the absorbent, while gelatine would act as a binder. As the infrared radiation sensor of the cerebral oximeter emits light that scatters and absorbs in the human brain tissue up to 5 cm deep and in an approximately 5 cm wide range, the skull phantom must be at least 6 × 6 × 6 cm large.

To determine what ink concentration is required to provide the quality of absorption in deionised water, spectrophotometry measurements and absorption coefficient calculations were made. rSO2 measurements were taken when making the intralipid phantom to determine if the measured and the calculated concentrations match the concentration that the device can measure.

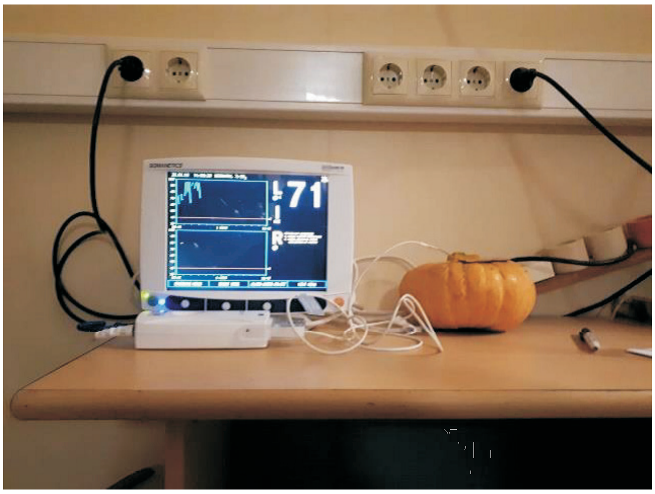

Fig. 2. Pumpkin used as a skull phantom.

A spectrophotometer was used to measure the concentration of a dissolved substance in liquid by measuring the light that is absorbed (the number of photons). Transmission measurements were made with a spectrophotometer Cecil CE1021 that allows measurements at a wavelength 200–1100 nm, 8 nm frequency strip and 1 nm precision. Reusable 10 × 10 mm 3500 µl quartz cuvettes that are meant for wavelength 320–2500 nm were used when working with the device.

As the skull phantom was made of ink and deionised water solution, it was necessary to find solution concentrations that would fit correspondingly to the tissue absorption coefficients.

Measurements were taken for a reference point cuvette in the spectrophotometer at transmission wavelength 730 nm. Then, deionised water and the smallest possible amount of ink were mixed and filled in a cuvette, which was then placed in the spectrophotometer. Measurements were taken again at the same wavelength. Then the cuvette was rinsed with deionised water, the next suspension concentration mixed, and the process was repeated until all solution concentrations had been measured. All measurements were repeated at least twice. For the creation of the final version of the skull phantom, the intralipid solution was added to deionised water in a transparent PET bowl so that the scattering rate would be adequate for blood, depending on which ink (Forpus F060421) was added. INVOS cerebral oximeter sensors were then placed and fixated on the bowl’s sides with tape to ensure the registration of the measurements. The ink concentration was then gradually increased and measured with the phantom on a scale.

Transmission measurements at wavelength 810 nm were taken to determine the absorption coefficient µa.

Soy oil (Heuschen & Schrouff) and lecithin (Lecithin 1200 mg, UAB EVD, Baltics) was used as the intralipid and combined in pre-set proportions (Ohmae *et al*., 2018). The prepared solution was warmed in a water bath at 60 °C for approximately 10 min until lecithin had visually completely dissolved. Then it was filled in a sterile syringe and kept in a refrigerator at 2–6 °C and heated to 35 °C before use.

The brain part of the phantom skull was constructed by adding gelatine to part of the deionised water, such that it would correspond to 20% of the deionised water's complete weight. Then it was heated in a water bath at 35 °C until completely dissolved. Then the rest of the water was added, creating a homogenous solution, to which the predetermined amount of ink and intralipid solution were added, after which it was heated and stirred continuously. Then the liquid was poured into a mould. The prepared solution was cooled in the refrigerator at 2–6 °C until it had completely hardened. Measurements were then taken with a cerebral oximeter to determine the values before adding another layer on top of the previous one. By simulating a brain part with an even layer, it was possible to better evaluate the skull phantom's thickness and angle effect on rSO_2 values, and in addition the environment of a very close-knitted capillary net was mimicked.

The subsequent bone and skin layers were prepared using the same method and placed on top of the brain layer of the skull phantom.

The intralipid skull phantom was elastic and allowed for elastic deformation up to a 20° angle. Layer thickness was controlled by using previously known or calculated data, and after the phantom had dried — also by measuring them, as layers can visually differ (Fig. 3).

Two other phantoms without scattering and absorbing properties were also produced in order to better understand the algorithm used by the device to take measurements. Neither of the cases produced any oximetry result values, and notification of a mistake was shown on the device. In total, six skull phantoms were made with skull thickness 6–11 mm.

RESULTS

Absorption measurements were initially performed to create a skull phantom and provide absorption for infrared radiation similar to that of human tissues. The experiment used wavelengths corresponding to those applied by the INVOS 5100 cerebral oximeter at 730 and 810 nm. The results of the measurements, which is the transmission in this case, and the calculated results, which are the absorption factor, are summarised in Table 2.

Fig. 3. Different layers of a skull phantom.

Table 1 demonstrates how the regression equation and the corresponding curve was developed to evaluate the relationship between absorption and ink concentration. Knowing that this dependency needs to be linear, a straight line was constructed. The determination factor R^2 was also used to assess the strength of the correlation (Fig. 4).

Figure 4 and Table 2 show that the ratio of the absorption factor and ink concentration in deionised water is linear. A higher ink concentration in deionised water increased absorption. Blood has an absorption coefficient of 11 cm^{-1} (730 nm) and 19 cm^{-1} (810 nm), and thus the required concentration of ink in the solution was 18.78% (730 nm) and 19.70% (810 nm).

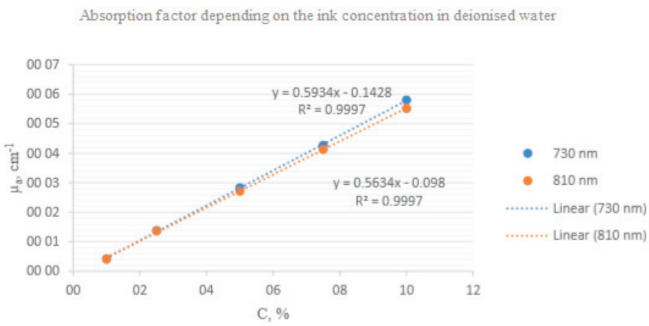

Fig. 4. Absorption of near-beam radiation at wavelength 730 and 810 nm depending on the ink concentration in deionised water.

Table 2. Ink concentration in deionised water and corresponding absorption factors at 730 and 810 nm

Concentration, %	730 nm			810 nm		
	Transmission, %	Transmission	Absorption coefficient μ_a, cm^{-1}	Transmission, %	Transmission	Absorption coefficient μ_a, cm^{-1}
1.0	65.7	0.657	0.420	65.9	0.659	0.417
2.5	25.0	0.25	1.386	25.5	0.255	1.366
5.0	5.9	0.059	2.830	6.6	0.066	2.718
7.5	1.4	0.014	4.269	1.6	0.016	4.135
10.0	0.3	0.003	5.809	0.4	0.004	5.521

Phantom oxygen concentration measurements with the INVOS 5100C were performed at different skull thickness from 6 to 11 mm, thus creating six different phantoms. The concentration was also measured before each layer was applied, to assess relative changes. When the ink concentration was lower than 18.6% and higher than 18.9%, a notification "Poor signal quality" was shown. The values of the measurements are given in Table 3. An additional 1 mm filter of PET plastic was used for the brain part measurements. From each phantom of different thickness, measurements were performed at 4 points and the standard deviation (SD) was calculated (Table 4).

Table 3 clearly illustrates how rapidly the measurements change depending on the ink concentration in water and demonstrates that the only attainable results were within the range of 18.6% to 18.9%, which correspond to the previously determined ink concentration in the solution of 18.78% at 730 nm. Thus, it can be concluded that an ink concentration of 18.6% to 18.9% corresponds to that of the blood absorption coefficient. It can also be concluded that an increased ink concentration leads to lower rSO_2 values.

The results from Table 4 indicate that enlarged skull thickness increases the oximetry value.

In order to determine the impact of the angle of the curve of the skull phantom on the results of the regional oxygen content measurements, all six of the above mentioned phantoms were bent from 0 to 20 degrees (Fig. 5).

Table 3. rSO_2 measurement results based on ink concentration in deionised water

No.	Concentration, %	rSO_2, %	rSO_2, %	rSO_2, %	$rSO_{2median}$, %	Standard deviation
1	18.767	PSQ	PSQ	PSQ	–	–
2	18.717	PSQ	15	15	15.0	0.0
3	18.712	15	15	15	15.0	0.0
4	18.707	15	17	15	15.7	1.2
5	18.702	15	21	20	18.7	3.2
6	18.697	23	24	23	23.3	0.6
7	18.692	23	27	31	27.0	4.0
8	18.687	38	47	45	43.3	4.7
9	18.682	62	56	60	59.3	3.1
10	18.677	72	60	66	66.0	6.0
11	18.672	95	95	95	95.0	0.0
12	18.667	95	95	95	95.0	0.0
13	18.617	PSQ	PSQ	PSQ	–	–

PSQ, poor signal quality

Table 4. rSO_2 measurement results based on skull thickness.

No.	Layer	Skull thickness, mm	rSO_2, %	rSO_2, %	rSO_2, %	rSO_2, %	rSO_{2vid}, %	SD
1	Brain	0	54	53	57	56	55.0	1.83
	Brain and skull	11	54	56	55	56	55.3	0.96
	Brain, skull and skin	11	46	45	47	45	45.8	0.96
2	Brain	0	51	52	57	62	55.5	5.07
	Brain and skull	10	51	52	56	54	53.3	2.22
	Brain, skull and skin	10	46	43	48	44	45.3	2.22
3	Brain	0	52	55	48	53	52	2.94
	Brain and skull	9	35	36	33	36	35	1.41
	Brain, skull and skin	9	32	34	32	30	32	1.63
4	Brain	0	58	45	52	67	55.5	9.33
	Brain and skull	8	21	16	23	20	20	2.94
	Brain, skull and skin	8	19	15	16	18	17	1.83
5	Brain	0	46	52	56	50	51	4.16
	Brain and skull	7	15	15	15	15	15	0
	Brain, skull and skin	7	15	PSQ	15	15	15	0
6	Brain	0	53	55	49	54	52.8	2.63
	Brain and skull	6	PSQ	15	PSQ	15	15.0	0
	Brain, skull and skin	6	15	PSQ	15	PSQ	15.0	0

PSQ, poor signal quality

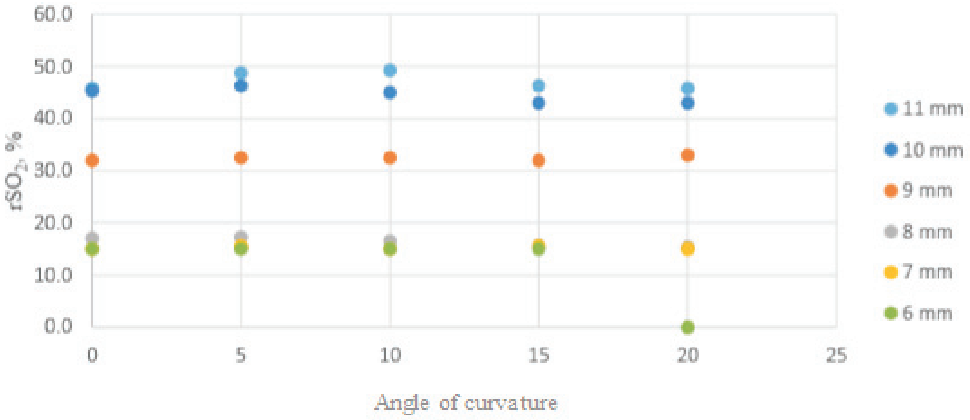

Fig. 5. rSO_2 measurement results depending on the curve of the skull phantom.

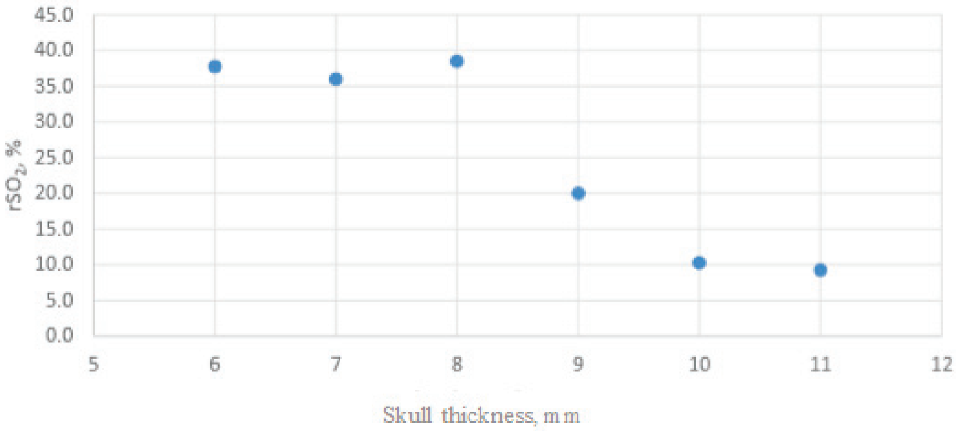

Fig. 6. Difference of measurement results between the brain layer and the phantom.

There were no significant changes in the oximetry values compared to the original values.

DISCUSSION

One of the oxygen concentration measurement limitations is caused by the phantom manufacturing technology, as only the brain layer can be controlled. Measurements were performed for both the liquid-shaped brain layer and after hardening. Given that no significant changes in measurement values were observed, the values for the phantom were recorded in a solid state. Theoretically, if the preconditioning process is constant at all times and the phantom is uniform, all measurement values should be similar and comply with the normal distribution. Given that the total number of measurements was small ($n = 24$), the Shapiro-Wilk normalcy test was used to test normality. This test compares data from a sample to a normal distribution that has the same mean and variance and examines whether the sample is taken from a population with a normal distribution. That is, the deviation from a normally divided population at a certain probability is compared. The original hypothesis, H_0, was that the data corresponded to a normal distribution. Calculations were made using the *Shapiro-Wilk Test Calculator* online tool (Shapiro Wilk test…). The probability of data being taken from normal distribution was 0.265. Given that p-value > 0.05, the hypothesis that the data is derived from normal distribution cannot be rejected. In addition, Shapiro-Wilk statistic (W) was 0.950, which at a significance level of 95% indicate that the distribution is normal, as $W \in (0.9169; 1.0000)$.

The standard deviation reflects sufficiently well the potential error resulting from the production of the phantom, which was high. However, given that the process of making a phantom is complex and includes many sources of uncertainty, such as weight, the precision of a pipette, and the oximetry device itself, inhomogeneity of raw materials and other, such precision is acceptable. The same uncertainty may be attributed to the accuracy of the production of bone and skin layers, as the same method of manufacturing is applied.

It was expected that an increase in thickness should lead to a decrease in the reported oxygen concentration due to the weakening of the signal, but practically the reverse situation was observed. However, this can be explained by the manufacturer's oximetry value calculation algorithm, which is based on the Beer-Lambert Law.

By graphically displaying the difference between the measured oxygenation of the brain through the PET filter and the phantom (Fig. 6), it was revealed that the difference between values increased as the slice thickness increased.

Looking at Figure 3 from a clinical point of view, it can be estimated that in a case where the skull is less than 8 mm, the equipment shows reliable regional oxygen saturation values. This is essential to consider if the equipment is used for making oxygenation measurements of other tissues. From the phantom development process, it can be concluded that the equipment is highly sensitive to a narrow range of absorption changes, as well as to the target tissues of radiation. It should be noted that it may show false results when measuring in other areas of the body.

The angle of curvature of the phantom may theoretically affect the measurement results because the length of the path between the source and the two sensors change. The phantom could be curved to an angle of 20-degree angle until it starts to crack, which could correspond to the curve of the human skull. A change in values of rSO2 was not observed during the arc to this angle.

There are other studies that measure the oximetry on skull phantoms but have differences in the technology and layers in the phantom manufacturing process. Due to this, the results obtained with the oximeters vary and possible shortcomings have been noted in some studies (Dullenkopf *et al.*, 2003; Hyttel-Sorensen, Testing…) where oxygen concentration values were higher than in our study.

It is difficult to compare our results with cerebral oximetry results in human participants in other studies because of human skull variability and inability to standardise parameters. However, in a study where cerebral oxygenation was measured with INVOS 5100C, the results obtained were higher than in our study (Kleiser *et al.*, 2018; Hyttel-Sorensen, 2013), which may indicate possible clinical inaccuracy of our study.

The present study resulted in practical experiments that were done for the first time using a solid optical skull equivalent phantom and commercially available equipment. Experiments showed that it is possible to actually simulate the optical properties of tissue and that it is possible to continue the on-going study and to analyse other potential causes of measurement errors. The following recommendations for further studies may be:

- For further development of an optical phantom, it would be necessary to validate the optical properties using experimental methods;
- The INVOS 5100 algorithm of the machine used takes into account different absorption of oxyhemoglobin and deoxyhemoglobin, there is a need to apply other absorbent substances or a combination of substances with different absorption values at wavelengths of 730 and 810 nm instead of ink;
- Additional experiments should be performed using other equipment, because a specific algorithm exists for a particular device. Because of this, the phantom used in this study may not be suitable for testing other equipment;
- The total number of measurements is limited by the time consumption to manufacture a phantom, it would be necessary to make more phantoms and repeat the measurements to increase replication;
- Bending the phantom may alter its optical properties as a result of mechanical influences. Therefore, it would be necessary to make and measure phantoms at different angles;
- Produce phantom skull layers of less than 1 mm thickness;
- It is necessary to perform additional measurements of skull thickness exceeding 11 mm to determine the threshold at which the machine will stop displaying measurement values.

CONCLUSION

The thickness of the bone layer of the phantom skull affects the regional oximetry results, but the angle of the skull does not affect it.

REFERENCES

Aernouts, B., Beers, R., Watte, R., Lammertyn, J., Saeys, W. (2014). Dependent scattering in Intralipid® phantoms in the 600–1850 nm range. *Optics Express*, **22** (5), 6086–6098.

Bsis-Vandervliet, J. (1999). Discovery of the near-infrared window into the body and the early development of near-infrared spectroscopy. *J. Biomed Opt.*, **4** (4), 392–396.

Correia, T., Gibson, A., Hebden, J. (2009). Identification of the optimal wavelengths in optical topography using photon density measurement functions. *Proc. SPIE (Society of Photo-Optical Instrumentation Engineers),*, **7187**, 718718.

Dullenkopf, A, Frey, B, Baenziger, O, Gerber, A, Weiss, M. (2003). Measurement of cerebral oxygenation state in anaesthetized children using the INVOS 5100 cerebral oximeter. *Paediatr. Anaesth.*, **13** (5), 384–391.

Frost, E., A. M. (2012). Cerebral oximetry: A replacement for pulse oximetry? *Middle East J. Anaesthesiol.*, **21**(6), 807–813.

Hyttel-Sorensen, S. Testing and calibrating a prototype NIRS oximeter for use a part of the intervention in a randomised clinical trial. https://www.rigshospitalet.dk/english/departments/juliane-marie-centre/department-of-neonatology/research/SafeboosC-II/Documents/testing-and-calibrating-a-prototype-nirs- oxymeter.pdf (accessed 30.10.2019].

Hyttel-Sorensen, S., Kleiser, S., Wolf, M., Greisen, G. (2013). Calibration of a prototype NIRS oximeter against two commercial devices on a blood-lipid phantom. *Biomed. Opt. Express.*, **4** (9), 1662–1672.

Kleiser, S., Nasseri, N., Andresen, B., Greisen, G., Wolf, M. (2016). Comparison of tissue oximeters on a liquid phantom with adjustable optical properties. *Biomed. Opt. Express*, **7** (8), 2973–2992.

Kleiser, S., Ostojic, D., Andresen, B., Nasseri, N., Isler, H., Scholkmann, F., Karen, T., Greisen, T., Wolf, H. (2018). Comparison of tissue oximeters on a liquid phantom with adjustable optical properties: An extension. *Biomed. Opt. Express*, **9** (1), 86–101.

Ohmae, E., Yoshizawa, N., Yoshimoto, K., Hayashi, M., Wada, H., Mimura, T., Suzuki, H., Homma S., Zuzuki N., Ogura H. et al. (2018). Stable tissue-simulating phantoms with various water and lipid contents for diffuse optical spectroscopy. *Biomed. Opt. Express*, **9** (11), 5792–5808.

Operators manual INVOS system, model 5100C. http://www.wemed1.com/downloads/dl/file/id/7947/product/10495/manual_for_mo_s_5100c.pdf (accessed 20.01.2019).

Roggan, A., Friebel, M., Dorschel, K., Hahn, A., Muller, G. J. (1999). Optical properties of circulating human blood on the wavelength range 400–250 nm. *J. Biomed. Opt*., **4** (1), 36–46.

Shapiro-Wilk test calculator. http://www.statskingdom.com/320ShapiroWilk.html?fbclid=IwAR0W3Sn9ZkABYv4bOdlh9wGlFqYDWWE0Zj-CduvjFoSgyWMeTHE-uSHPdOA (accessed 24.10.2019).

Steppan, J., Hogue, C., W. Cerebral and tissue oximetry. (2014). *Best. Pract. Res. Clin.* Anaesthesiol., **28** (4), 429–439.

Tosh, W., Patteril, M. (2016). Cerebral oximetry. *Brit. J. Anaesth Education*, **16** (12), 417–421.

Wrobel, M. S., Popov, A. P., Bykov, A. V., Kinnunen, M., Jedrzejewska-Szczerska, M., Tuchin, V. V. (2015). Multi-layered tissue head phantoms for noninvasive optical diagnostics. *J. Innov. Opt. Health Sci*., **8** (3), 1541005.

Received 17 September 2020
Accepted in the final form 5 June 2021

CEREBRĀLĀS OKSIMETRIJAS MĒRĪJUMU REZULTĀTI ATKARĪBĀ NO GALVASKAUSA FANTOMA PIRMSKLĪNISKĀ MODEĻA

Mūsdienās biežāk tiek izmantoti neinvazīvi izmeklējumi, kuri pacientiem spēj nodrošināt efektīvu aprūpi. Lai nodrošinātu pacienta perioperatīvās aprūpes augstu kvalitāti, pētnieki meklē dažādas tehnoloģijas un izstrādā jaunas iekārtas. Viena no tām ir cerebrālais oksimetrs. Ar to veic transkutānus mērījumus, izmantojot inftrasarkano starojumu, lai novērtētu audu oksigenāciju. Pētījuma mērķis bija noteikt, vai galvaskausa fantoma leņķis un biezums ietekmē cerebrālā oksimetra mērījumus. Tika izmantots intralipīda ūdens šķīdums, želatīns un tinte, lai izgatavotu sešus fantomus ar galvaskausa biezumu no 6 līdz 11 mm. Mērījumi katram fantomam tika veikti četros punktos. Visi seši fantomi tika izliekti no 0 līdz 20 grādu leņķim, lai noteiktu galvaskausa fantoma izliekuma leņķa ietekmi uz reģionālo oksigenāciju. Lai veiktu reģionālās oksimetrijas mērījumus, tika izmantots cerebrālās oksimetrijas instruments SOMETICS INVOS 5100C. Galvaskausa biezumam 11 mm rSO2 bija 45,8% (SD 0,96); galvaskausa biezumam 10 mm rSO2 bija 45,25% (SD 2,22); galvaskausa biezumam 9 mm rSO2 bija 32% (SD 1,63); galvaskausa biezumam 8 mm rSO2 bija 17% (SD 1,83); galvaskausa biezumam 7 mm rSO2 bija 15% (SD 0); galvaskausa biezumam 6 mm rSO2 bija 15% (SD 0). Mērot oksimetrijas atkarību no galvaskausa izliekuma leņķa, būtiskas izmaiņas oksimetrijas vērtībās netika novērotas. Fantoma galvaskausa kaulu slāņa biezums ietekmēja reģionālo okismetriju, taču galvaskausa leņķis to neietekmēja.