Journal of Physics: Conference Series

PAPER • OPEN ACCESS

Designing of Phantom Head Used in Optical Diagnostics of Brain Injury

To cite this article: A Aristov *et al* 2016 *J. Phys.: Conf. Ser.* **671** 012002

Designing of Phantom Head Used in Optical Diagnostics of Brain Injury

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Abstract. This article shows the results of an experimental research on properties of the materials chosen for designing of a phantom head, which is to be used in testing of a brain hematoma diagnostics device. We have conducted a comparative research of the optical properties of model materials and real head tissues

1. Introduction and terms of reference

It is important to detect intracraneal hematoma when facing brain injury. Nowadays magnetic resonance tomography and computed tomography is the basic precise instrumental method for detecting such injuries, however a possibility of undergoing tomographic screening for a patient right after obtaining an injury is practically non-existent. As a result, development of a device that would be able to immediately detect intracraneal injuries is important today. Unfortunately, sound field visualization method [1] used for gathering information on brain structure doesn't provide good results due to the intense diffusion of ultrasound in skullbones. To solve this problem there has been an approach suggested, which is based on spectroscopy in optical and near infrared wave range. The method is based on facts that molecules absorbance spectra are feature-based for a substance given, and absorbing power is tied to content of absorbing constituent in irradiated sample. The wave range used is harmless both for an operator and a sample being analyzed. Along with relevant hardware it allows to explore sites of animals and human beings without any damage to integration and bodies [2]. InfraScan has developed a device called Infrascanner model 3000 [3], this is a mobile intracraneal hematoma detector, which works in a near infrared wave range (808 nm). Published experimental research carried out on models of intracerebral bleeding, as well as clinical investigations have shows quite high diagnostic sensitivity of the device. The scannes is able to detect hematomas with a probability of 91% (in case a hematoma's maximum depth is 2.5 cm from brain cortex and with size more than 3.5 cm^3) [4, 5].

However, the device is not able to detect properties of a hematoma (dimension, depth of location, density, exact location), which are of a great diagnostic importance for further resuscitation procedures. Since diagnostics are conducted with a differential method when optical properties of symmetrical locus in exact set points on a head surface, there is a high probability to miss small or deep-seated hematomas out of sections scanned. Therefore, further development of method and device is needed, for the purpose of obtaining more perfect medical and technical characteristics.

2. Theoretical aspects of phantom head designing

We have designed a prototype of a device which allows to conduct laboratory studies aiming to search possible ways of improving diagnostic capabilities of optical method of hematoma detection [6]. The device will help to determine follows things: optimal structure of primary measuring transducer, a method to process analogue signal from photon detector, digital processing and visualization of data received from the device.

In order to model different variants of pathologies (size, location and depth of hematomas) and also minimize or take into account interfering factors on first stages of research (inhomogenous and different thickness of skull bones, different optical properties of tissues), researches need to be conducted on a model sample with known properties. This artificial research object (phantom) must have properties close to the real object. Since we use optical radiation for gathering information on an object's structure optical properties of phantom's materials have to be similar or close to the properties of the real tissues that are being simulated.

During transmission of a head, bone and brain tissues absorb the bigger part of optical radiation. Therefore, within the framework of our project we will simulate three types of tissues: bone tissue, brain tissue and hematoma. Brain tissue is a complex of big number of neurons, which are the nerve fibers surrounded by myelin sheath. Myelin sheath makes a major contribution in brain tissue's optical properties. Since myelin sheath consist of lipoprotein complexes, we suggest replacing this tissue with oil emulsion-based viscous dispersed liquid. Particularly, during the first stage of the research we used mayonnaise. Phase state of this sample in a liquid state is essential, because this way it is possible to move the subject of research (simulated "hematoma") inside the sample. Thereby, we can set its location towards optical part. A bone is one of the most important phantom environments which have quite strong modificative impact on transmitted radiation. For this reason the bone has to best meet the properties of a real object. According to comparative visual estimation of transmitted radiation intensity, and also according to the spot size of scattered radiation during transmitting of trephined human skull and samples of muddy plastics, we prefer to use fluoroplastic. Hematoma is clotted blood, that is why it is possible to simulate it with real human blood placed in a silicone clear container. By changing size of the container we can simulate size of the simulated hematoma.

3. Experimental research

We have conducted an estimation of optical properties of the chosen model materials compared to the real samples of the simulated tissues. The following bio-tissues have been conducted research on: cortical substance of a pig brain, a sample of trephined human skull, clotted and incoagulated (with addition of heparin) human blood. Polychromatic radiation source (halogen lamp) was used in the research. Intensity of transmitted and backscatter radiation that went through the study samples of materials and bio-tissues has been estimated.

Measurements have been conducted with a help of photometric sphere. Transmitted or scattered radiation from the corresponding outputs of optical sphere was recorded and fixed with Ocean Optics USB4000-IVS-NIR-ES spectrograph. Liquid and viscous samples were put into single-use thin-walled cuvets. Thickness of a sample tested in such cuvet was 2 mm. Examined fluoroplastic sheet was as thick as an average human skull bone. Below you can see comparative spectral dependence of examined samples available from experiments.

Figure 1 shows the spectra of radiation transmitted through the brain and the environment which was selected for simulating the brain in a phantom.

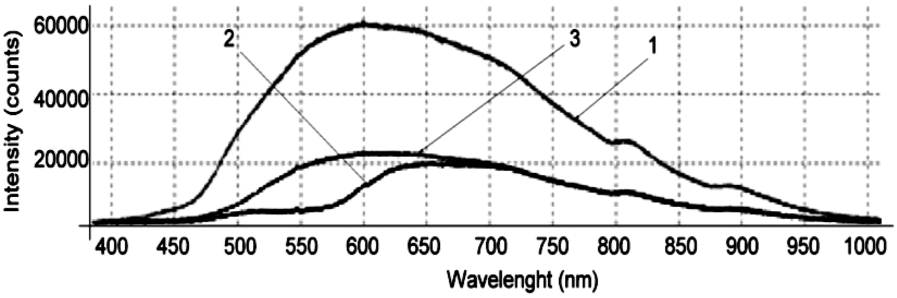

Figure 1. The spectra of radiation transmitted through objects: 1 - the spectrum of the radiation source without an object, 2 - after the radiation transmitted through the brain, 3 - after the radiation transmitted through the mayonnaise.

The graphs show that absorbance spectra of the examined environments best match at wavelengths of 650 nm to 900nm. This is proved by the graph of the intensity of the transmitted radiation (figure 2). Both samples of the same thickness transmit about 30% of radiation in this area. Unfortunately, spectral characteristics of the spectrometer we used did not allow us to examine longer waves.

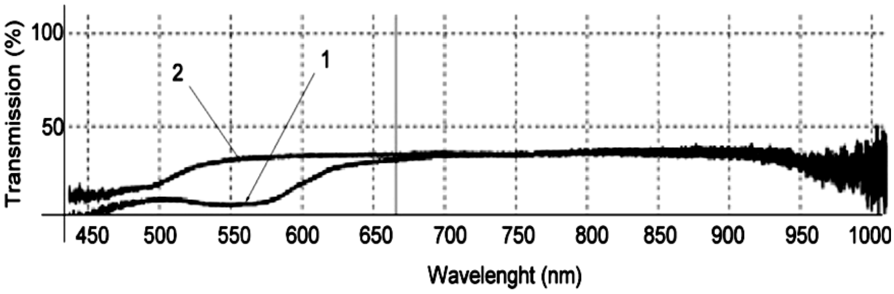

Figure 2. Graphs of the intensity of radiation transmitted through objects: 1 - brain, 2 - mayonnaise. Thickness of a layer transmitted is 2 mm.

A similar comparative research was conducted with a bone tissue and fluoroplast (figure 3). Examination of a skull bone is a specific in some way as a skull has significant differences in thickness and structure all over its surface, so the absorption intensity for the object is changed largely for each segment. We used fluoroplastic plate as thick as an average skull bone. Measurements were held on a trephined parietal bone (60×60 mm). Intensity of radiation transmitted through the bone was being changed by 2 times depending on a certain part of the bone. Therefore, we chose a part of it that would be approximately of the same thickness as fluoroplastic plate.

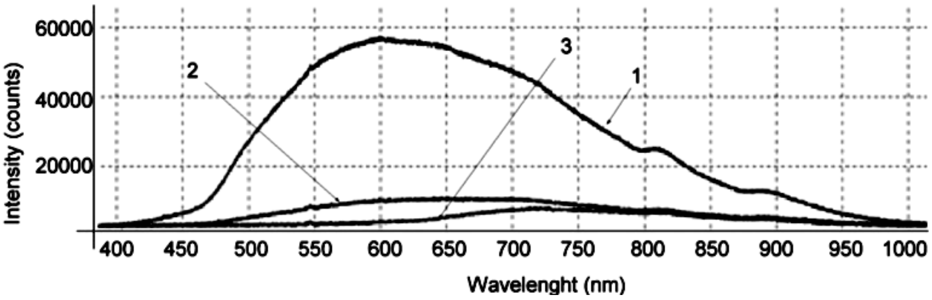

Figure 3. The spectra of radiation transmitted through objects: 1 - the spectrum of the radiation source without an object, 2 - after transmitting through a fluoroplastic plate, 3 - after transmitting through a bone.

The graph shows that spectral characteristics of these samples best match at wavelengths of 750 nm to 900nm. This is the most noticeable on the intensity curves of the transmitted radiation (figure 4). As we can see from the graphs, dispersion of parameters of the bone and fluoroplastic plate is about 5% in the range of 750 nm to 900 nm.

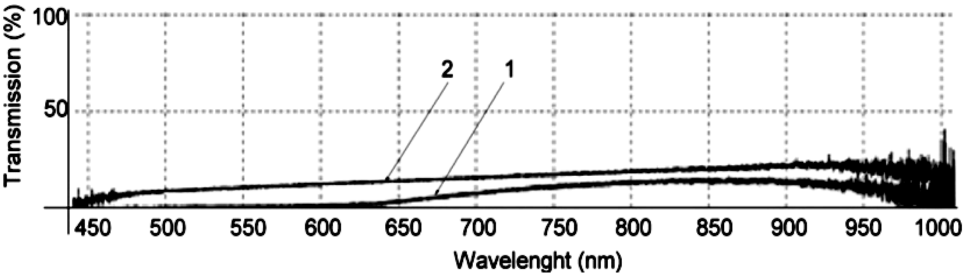

Figure 4. Graphs of the intensity of radiation transmitted through samples: 1 - bone, 2 - fluoroplastic.

During the examination of samples of clotted and incoagulated blood (figure 5) we discovered that waves shorter than 600 nm are absorbed by both clotted and incoagulated blood. On 650 nm spectral field we can see the biggest difference in the intensity of absorption by samples of clotted and incoagulated blood (figure 6). On this range the difference is 15-18%. On the range of 800-900 nm we can see the smalls difference in the spectral characteristics of these samples.

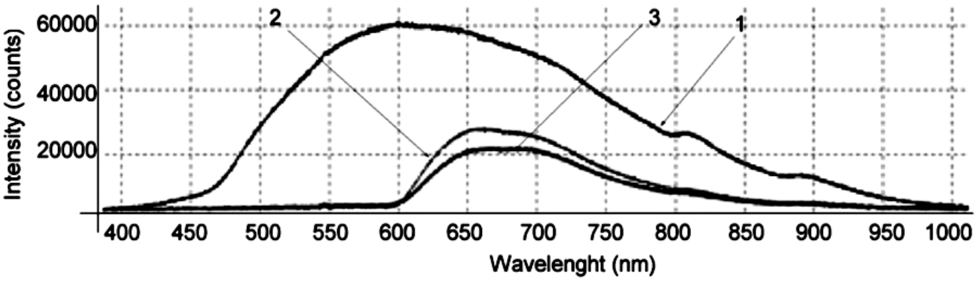

Figure5. The spectra of radiation transmitted through objects. 1 - without objects, 2 - incoagulated blood, 3 - clotted blood.

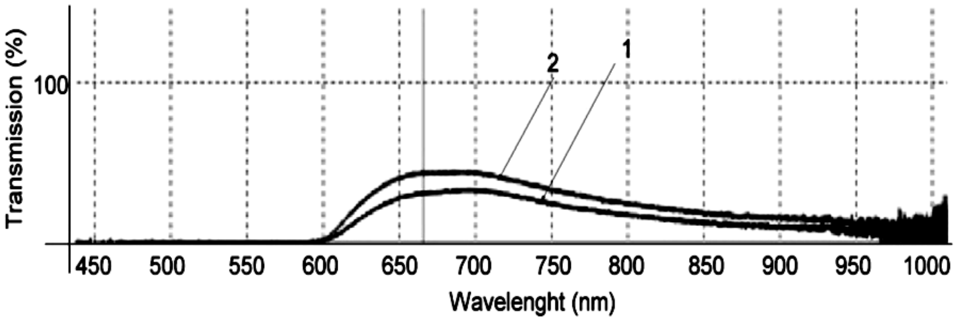

Figure 6. Graphs of intensity of radiation transmitted through samples. 1 - clotted blood, 2 - incoagulated blood. Thickness of a layer transmitted is 2 mm.

4. Results and conclusions

We can draw some conclusions based on the results of our experimental investigations. Thus, due to the large difference of spectral characteristics of clotted and incoagulated blood, two-wave spectroscopy in red (650 nm) and in near infrared (800 nm) spectral range is the most specific for detecting a hematoma. It is possible to detect a brain region with a hematoma near it more precisely by conducting a comparative analysis of the two wave ranges mention above. Estimation of optical characteristics of a pig's cortical substance and 70% oil emulsion (mayonnaise) has proved almost full match of their spectral characteristics in 650-850 nm spectral range. Thus, oil emulsion of a certain concentration can fully simulate brain tissue during optical investigations in this wave range. Notably, emulsion has certain goods on solid phantoms due to the possibility to easily move diagnosable object in liquid fluid, and, as a result, to obtain a phantom with new properties. Examination of optical properties of fluoroplastic plate as a skull bone in a head phantom has shown similarities of their spectral characteristics in 750-850 nm wave range. Significant reduction of transmission through skull bone in the range lower than 630 nm can be explained by the presence of tissues filled with blood in the skull bone. This property of a material can be created only with a help of composite materials with addition of proper absorption filler.

Altogether, the results of experimental investigations we conducted have proved the possibility of using artificial materials we selected for designing phantom head for future optical researches.

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