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The study of the spectral characteristics of biological tissues for optimization of surgical lamp parameters

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Abstract. During surgery, it is important for the surgeon to determine the optimal lighting conditions for contrast imaging of the operated objects. The paper analyzes various parameters of a controlled colour-dynamic surgical lamp based on a powerful led when contrasting individual organs and tissues of model animals, as well as optical parameters of the organs themselves. The results will allow developing a library of colours and lighting settings for a wide range of surgical operations.

1. Introduction

The outcome of surgery depends on many objective and subjective factors. Knowledge and skills of the surgical team may be ineffective in the absence of the necessary light conditions in the operating room. Using standard surgical light is impractical for operations on different structures, tissues, organs, etc. Inaccurate characteristics of the light flux entering the operating field make the colour rendering from the object less distinguishable and structured, create more highlights or shadows. The correct definition of light and colour balance is especially important for extensive surgical interventions and operations on internal organs [1–6]. The surgeon should adequately assess the degree of tissue damage, the presence, volume of necrosis or tumour process [7], etc.

From a surgeon's assessment of the operating field will depend on the prognosis of the disease and outcome of treatment for the patient. Excessively high brightness or insufficient lighting causes rapid fatigue of medical personnel and causes stress during surgery. Proper lighting with perfectly selected brightness and colour mode helps the surgical team to adequately assess the condition and viability of tissues, the spread of the pathological process and choose rational tactics of surgical treatment of the patient.

The optimal light balance can be provided by modern led lamps. LED is a device which emits light by flowing a current to the p-n junction [8,9]. LEDs with variable colour and brightness characteristics of the light make it possible to combine the light colour mode for each type of tissue, which have their own density, as well as the degree of absorption and reflections of light.



The aim of this work is to Study the spectral characteristics of biological tissues for the automatic selection of the characteristics of the surgical lighting of the lamp and generation of libraries of illumination for certain structures of a biological object.

2. Materials and methods

Experimental measurements were carried out using a specially designed controlled colour-dynamic surgical light based on the powerful RGBW LED Phlatlight CBM-360 Luminus Inc. The main nodes of the prototype are developed by Submicron Heterostructures for Microelectronics, Research & Engineering Center, Russian Academy of Science (St. Petersburg). The prototype of the colour-dynamic surgical light has the following characteristics: the output luminous flux up to 4000 lm, the illumination of the area 200x200 mm up to 25000 lx (in white light), with uniform color distribution ~ 5% and intensity not worse than 15%; the range of white light is 1200-2500K with a general colour rendering index of 70-90. The white colour at the source can be obtained by classical RGB mixing, and phosphors are used for the blue source. The software of this luminaire allows changing the intensity of LEDs current. The range of wavelengths used in the surgical light is 350-740 nm, which eliminates harmful UV and IR radiation, which in other traditional sources is excluded by filters. Management of light parameters of the surgical light during the research was carried out from a remote computer using the developed software associated with the illuminator over the radio interface Bluetooth class 2 with a range of up to 30 m. The spectral characteristic of the emitted light was controlled by a mobile spectrometer MK350.

OL 770-LED High-speed LED Test and Measurement system (Optronic Laboratories, Inc., USA) includes supplementary device OL 700-71 was used to measure optical parameters of tissues.

In laboratory conditions, on the basis of Orel State University named after I.S. Turgenev, with the help of a surgical light, animal studies were carried out. Experimental studies were performed on clinically healthy male rats $n = 5$ of the Wistar line (6 months old [10,11]) in accordance with the principles of good laboratory practice of GLP (according to GOST 33647-2015). The work was approved by the ethical committee of "Orel State University named after I.S. Turgenev" (record of the meeting No. 10 of October 16, 2018). The animals were kept in controlled quarantine, temperature, humidity, and purity conditions for 2 weeks. During the study, the rats were anaesthetized with Zolilet 100 (Vibrac, France), respectively, at standard dosages.

3. Experimental measurements

The experiment was conducted in two stages. The first stage consisted of the selection of the spectral characteristics with the colour-dynamic surgical light, the second stage was the study of optical parameters of the object with the OL 770-LED High-speed LED Test and Measurement system.

The first stage. Biological objects were placed on a special fixing platform. Studies were carried out on the skin area after preliminary depilation, subcutaneous fat, muscle tissues of the abdominal cavity organs (pancreas, bladder, kidney, liver, spleen.). After the end of the study, the animals were withdrawn from the experiment in accordance with the rules for conducting the experiments.

A colour-dynamic surgical light was installed above the operating table at a distance of 70 cm, which ensured the creation of a uniform light spot of at least 20x20 cm size (Figure 1). During the research in the software, the parameters of each LED were changed. Based on the subjective visual assessment of the operating team, the optimal illumination of the operating field was selected for each site of the study. The spectral characteristic of the emitted light was controlled by a mobile spectrometer.

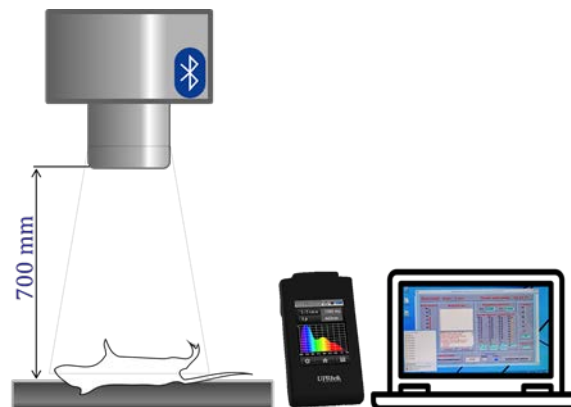


Figure 1. Experimental setup.

When each individual organ was illuminated, the spectral components of the light source were changed to increase the contrast of the visualization of the tissue. To select the optimal colour of illumination providing contrast imaging, the reflectance spectra $R(\lambda)$.

The second stage. Pieces of the biological object were placed on slides the size of $77 * 26 * 1 \text{ mm}^3$. Glasses with objects were placed in the prefix OL770-71 so that the incident light fell on the fabric (glass outside), this is necessary to reduce the impact on the reflection spectra of the slide, which in our case is only the carrier. Eleven types of biological tissues were selected for the study: pancreas, liver, spleen, skin, heart, brain, muscle, kidney, subcutaneous fat, bladder, and lung. After the end of the experimental part, a graphical construction of the reflection and absorption spectra from the tissues was carried out.

4. Results

The choice of optimal illumination of the operating field depending on the field of work was made empirically. An example of lighting adjustment in the program is shown in figure 2.



Figure 2. Colour temperature of the light spot when the skin is illuminated.

The chosen type of lighting has an optimal brightness for this type of fabric and a uniform level of illumination. There is a lack of shadow and a decrease in the glare from the surface of the serous membrane, the minimum direct and reflected brilliance. There is a clear distinction between the anatomical structure and vascular pattern of the tissue, natural folds and channels of the abdominal cavity are clearly visible. The boundaries of the organs and vascular structures covered by the peritoneum acquire a good brightness contrast. There is a lack of emotional irritation and eye discomfort.

The operating field, represented by the peritoneum (serous membrane), in this chromaticity of lighting has a comfortable visual perception.

In general, the spectral evaluation of the operating field is subjective in view of the fact that the assessment of illumination in the visualization of biological tissues is due to the individual features of the visual perception of the surgeon. The results of preliminary studies allow us to draw conclusions about the advisability of using a surgical light with dynamically controlled light and colour parameters to achieve maximum resolution and optimal contrast imaging of individual anatomical structures and tissues during surgical manipulations.

Preliminary studies of spectral characteristics of biological cultures and tissues using the adapted complex OL-770 showed significant differentiation of biological tissues by optical characteristics. The last sentence confirms the prospects of using different lighting for the visualization of certain tissues. Figures 3 show the obtained reflection spectra.

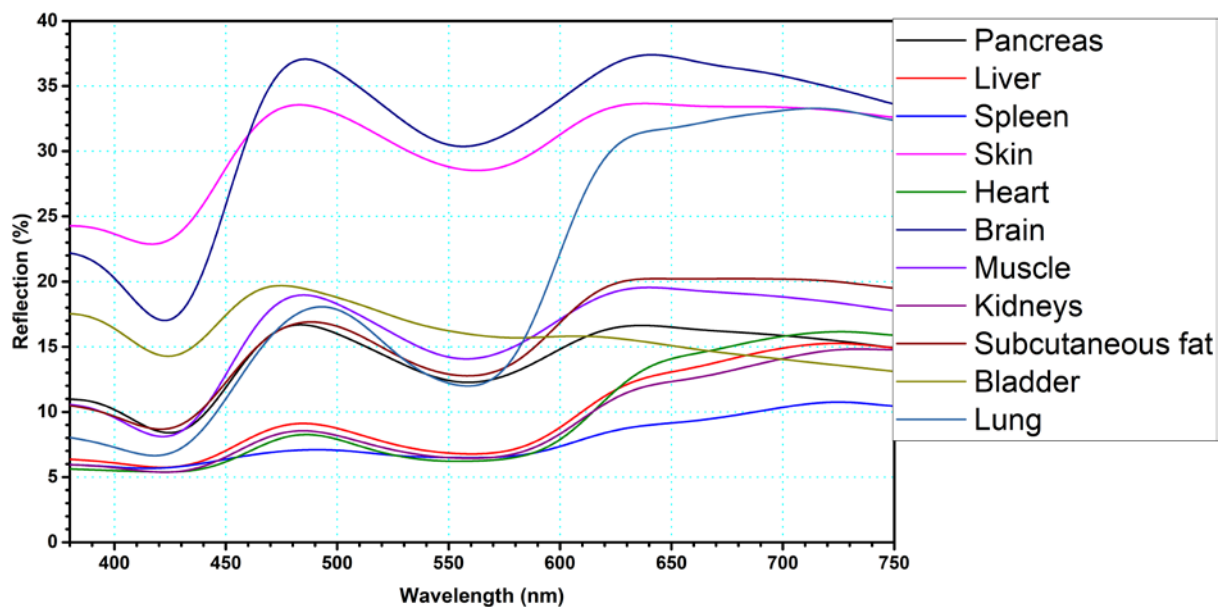


Figure 3. Reflection spectra from tissues and organs.

As can be seen from the curves, the tissues have very different reflective properties in the blue-green part of the spectrum (400 ÷ 550 nm). This result suggests the possibility of increasing visual contrast in properly selected lighting.

Comparing the reflection spectra with the experimentally obtained data from the mk350 spectrometer, it was observed that compensating for the dips in the reflection spectra in a certain area, it is possible to obtain a more contrasting operating field. For example, figure 4 shows the reflection spectra from a broadband lamp and from controlled colour-dynamic surgical light fixed by a spectrometer for the pancreas, skin and muscle.

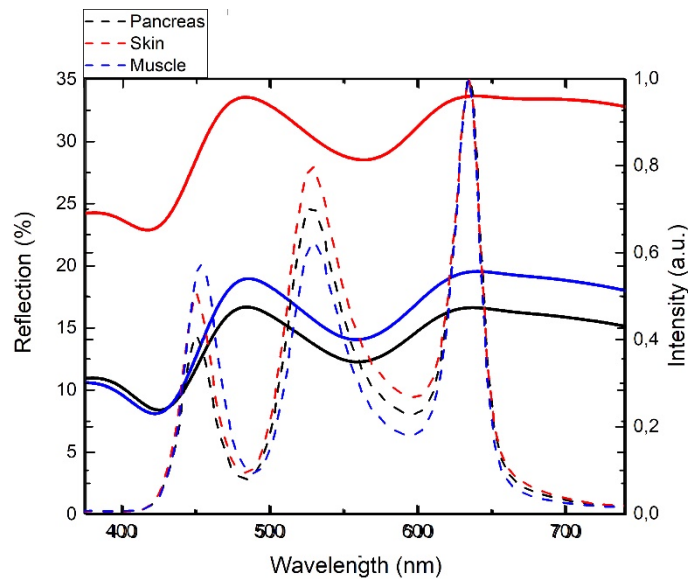


Figure 4. Reflection spectra from a broadband lamp and from controlled colour-dynamic surgical light from rat pancreas, skin and brain. The Solid line is the diffuse reflection spectrum from a broadband lamp, the dashed line is the spectra of the experimental lamp obtained from the spectrometer.

Experimentally selected colour settings on the lamp are in good agreement with the spectra of reflection. In areas where there is a predominance in the blue and green spectrum of reflection, the program exhibited values so as to reduce this parameter and make a more contrast and bright image. On the contrary, in those places where there are gaps in the reflection spectrum, the parameters of surgical lighting are chosen so that they enhance the contrast of a certain biological object and darken the area around.

Based on the analysis of the data, it was concluded that the contrast criteria for the surgical illuminator. With greater tissue reflectivity, the study area is better expressed and contrasted, in the presence of the absorption component of the spectrum, there are less differentiated area and darker tissue.

5. Conclusions

The results of this work show that the use of dynamic control of light and colour parameters of the illumination of the operating field has the potential for contrasting visualization and a differential approach to the illumination of specific anatomical structures in the course of surgical manipulations.

At present, data are being collected on an extended range of biological objects, including in vivo, in order to develop optimal operating illumination algorithms for surgical interventions on various organ systems. However, it is assumed that the visualization of anatomical structures is influenced by a number of factors, such as the state and type of changes in tissues, the phase development of pathological processes, their reaction to ongoing treatment, blood filling of the tissue, the presence of other liquids, etc. There is a need to conduct studies to study the contribution of each factor to the visualization of biological tissues for a correct interpretation of the intraoperative situation and further development of this direction within the framework of the concept of "Optical Imaging".

The studies of the spectral characteristics of biological tissues using the OL 770-LED High-speed LED Test and Measurement system showed the differentiation of biological tissues by optical characteristics. Comparison with light spectra, which were obtained experimentally, confirms the prospects of using different lighting for the visualization of certain tissues. All spectral characteristics of biological tissues and light spectra obtained in the course of a comprehensive study will form the basis for the development of algorithms for controlling the operation of a controlled semiconductor colour-dynamic surgical light.

Acknowledgements

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