Optimization of Spectral Characteristics of the Controlled Color-Dynamic Surgical Light Source for Visualization of Organs and Tissues of Laboratory Animals

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Abstract**—Modern LED light sources have many advantages for operational lighting. They make it possible to choose the optimal type of lighting for the surgeon during operations on certain organs and systems. The study was aimed at experimental selection of lighting parameters for various organs in vivo in normal and pathological conditions using a controlled color-dynamic LED lamp. The results showed that specific spectral parameters of lighting are necessary for certain types of organs and tissues; color and light balance adjusting improves the contrast visualization of individual tissues relative to each other. This work is the initial stage of creation of a special atlas of light source parameters for visualization of organs and tissues during surgical interventions with the use of controlled color-dynamic surgical light source.**

Keywords—surgical lighting, contrast visualization of biological tissues, controlled semiconductor light sources, LEDs, color dynamic parameters, biomedical optical imaging

I. Introduction

Optimum operating lighting is a precondition for any surgical procedure. For a successful operation, the surgeon needs to clearly distinguish between anatomical structures, correctly assess the condition of organs and tissues and identify pathological changes, differentiate vascular structures and nerve bundles [1]–[5]. To ensure the required level of the surgical field illumination, operating LED lamps have been actively used recently [6]–[9]. The widely used surgical LED lights provide clear white light close to daylight, creating a feeling of comfort. Such luminaires are energy-efficient and long-life, as well as they have greater portability compared to traditional halogen light sources due to a small size. In addition, halogen light sources have certain spectral characteristics, which require the use of additional filters if it is necessary to change the spectral composition of light. LED lamps can solve this problem by mixing light from multiple sources. [10]. The ability to combine colors enhances the perception of the surgical field by the surgeon and improves the visibility of certain anatomical structures and tissues. In addition, proper selection of spectral composition can reduce psycho-emotional stress and prevent rapid fatigue of the operating team.

The spectral characteristics of tissues depend on their functional state [11]–[13]. The pathological appearance of atypical chromophores, changes in the structure of cells and the percentage of hemoglobin derivatives affect the optical properties of tissues, including visible light range. Pathological tissues acquire changes that can be visually distinguished using amplification or attenuation of a certain color component of the lighting. Mostly, recent research of tunable surgical lighting is aimed at studying the parameters of a single organ in vitro without taking into account that any organ is an integral anatomical and functional part of the general body system. J. Shen, and others picked up the optimal illumination for vessels imaging in the isolated sheep heart [14]. Kurabuchi et al. conducted a comparative analysis of the optimized and conventional light sources based on computer simulation and the study of blood flow in the rat caecum, experimentally confirming the efficiency of spectrally tunable light source lighting [15]. The diagnostic value of a spectrally tunable light source was confirmed by in vivo study, which showed the improvement of retinal lesions visualization in diabetic retinopathy [16].

The study was supported by the Ministry of Science and Higher Education of the Russian Federation (grant 14.604.21.0187 of 26.09.2017, unique ID: RFMEFI60417X0187).

For the widespread implementation of tunable surgical lamps in clinical practice, additional research is needed to find spectrally optimal light source emission spectra when lighting various organs, taking into account their anatomical position relative to other organs and systems.

Thus, the aim of this work was experimental research of spectral parameters of combined LED lighting of laboratory animals, which were considered optimal for visual perception by a surgeon, for further creation of a library of spectral lighting combinations.

II. Materials and Equipment

The study was conducted using controlled color dynamic surgical light source [9] based on the powerful RGBW Phlatlight CBM-360 Luminus Inc. The luminaire contains four crystals of a big area and a heat-conducting case with a temperature sensor. In-put power of this LED can reach 100 W, and luminous fl ux in the white light synthesis mode can exceed 4000 lm.

A color-dynamic surgical light source 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 study, the power controlled LEDs (Red 630 nm, Green 525 nm, Blue 460 nm, White 6500 K) were changed using special software. 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 experimental setup and reproducible colors are shown in Figure 1.

Fig. 1. The experimental setup and reproducible colors

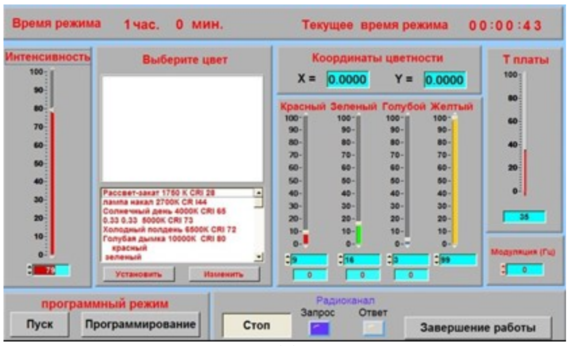
The animal studies were carried out with the help of a surgical light in laboratory conditions at Orel State University named after I.S. Turgenev.

Experimental studies were performed in male mice (n = 3; 6 months old) in accordance with GLP (according to GOST 33647-2015). The work was approved by the ethical committee of Orel State University named after I.S. Turgenev (protocol 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 mice were anesthetized with Zoletil 100 (Vibrac, France) at standard dosages.

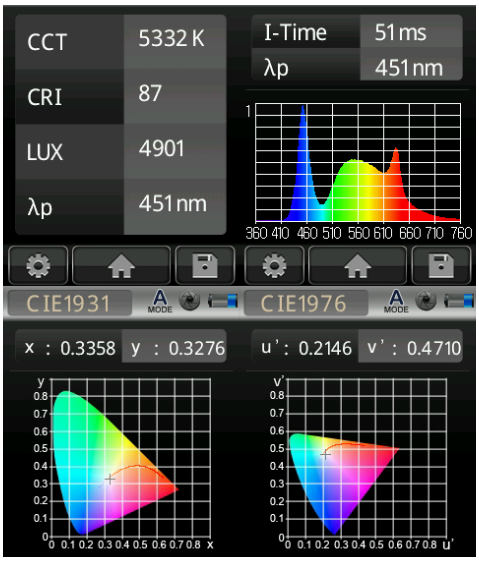
The surgeon and the operating team visually evaluated the color mixing parameters, as well as the contrast of the organs relative to each other. The selection of the spectral characteristics for optimal illumination of organs and tissues was based on the following criteria: 1) uniformity of illumination; 2) illuminance; 3) lack of glare and blinding; 4) lack of shadow; 5) lack of direct and reflected fading; 6) a clear distinction between the anatomical structures of tissue and small details, the absence of their fusion; 7) brightness contrast of formations; 8) lack of emotional irritation; 9) lack of visual discomfort and fatigue. Lighting parameters (illumination (E_v) and chromaticity coordinates x and y of lamp) was measured with an MK350 spectrometer. The studies were carried out at the muscles of the anterior abdominal wall, the total area of open abdominal cavity, the liver in normal condition and pathology (modeled hepatocarcinoma), the stomach, intestines, pancreas in normal condition and pathology (modeled ischemia), kidneys, heart, and lungs.

III. Results and Description

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



(a)



(b)

Fig. 2. Example of lighting adjustment in the program (a) and chromaticity coordinates on the color chart (b)

Examples of the certain organs spectra corrected in the software during the examination are shown in Figure 3.

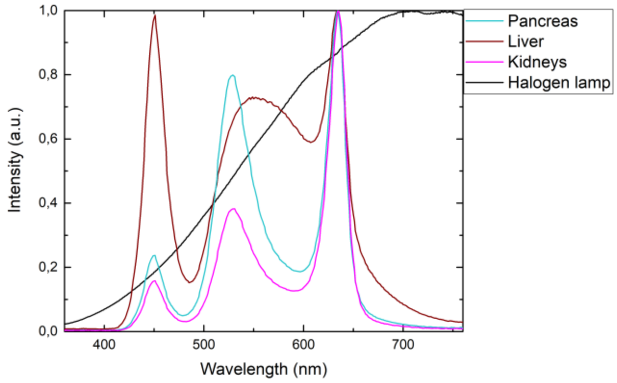


Fig. 3. The optimal spectra for pancreas, liver and kidney in comparison with halogen lamp

The illumination (E_v) and chromaticity coordinates x and y of lamp measured by a spectrometer during the examination of various animal organs are presented in Table 1.

TABLE I. THE ILLUMINATION AND CHROMATICITY COORDINATES

Place of study	E_v, lx	x	y
Muscles of the anterior abdominal wall	9000	0,3592	0,3448
Abdominal cavity	2000	0,3988	0,4026
Stomach and small intestine	2300	0,4373	0,4316
Liver	15000	0,4194	0,3959
Kidney	5700	0,4311	0,4258
Tumor in the liver	1500	0,3328	0,3259
Pancreas	15500	0,3711	0,4210
Ischemic pancreas	7100	0,3705	0,3647
Lungs	4000	0,4325	0,4167
Heart	5000	0,4172	0,3894

Using the indicated parameters, determined by the surgeon and the operating team as optimal, the muscle layer of the anterior abdominal wall was illuminated uniformly, with a sufficient level of illumination and brightness. Different muscle groups did not have the effect of visual fusion and did not cause discomfort during examination. White-yellow colored connective tissue formations, aponeurosis and fascia contrasted well with the pink-red muscle layer. Nervous and vascular formations, especially small arterial and venous branches, were clearly visualized. There were no unwanted shadows and glares from muscle tissue that impeded visual perception.

During abdominal cavity study a diverse gamut of shades was observed due to the different colors of the organs covered by the serous membrane. When the selected optimal spectral composition was used, the peritoneum was visualized as transparent, smooth and shiny; a network of pink capillaries was clearly defined. When examining the entire area, the serous membrane had no glare, direct and reflected luster, as well as did not cause the effect of visual fatigue and irritation. The connective tissue structures were yellowish-white in color; the vessels were contrastingly distinguishable from the surrounding tissues. The stomach of white-yellow color was clearly seen among other organs of the abdominal cavity upper floor, the shape and degree of its filling were clearly distinguishable. The serous membrane of the small intestine contrasted with the visible surface of the stomach, had a yellowish-pink color and a shiny smooth surface, while peristalsis was clearly defined. Mesenchymal vessels and lymph formations from the main trunks to the final branches were brightly visible along the intestinal tube. According to the parameters of the source, clear visualization of the stomach structure requires a stronger illumination of the surface and the amplification of the red radiative component of the source.

The indicated optimal spectral parameters for the liver provided a solid red-brown color of the organ; the lobes of the liver and the ligamentous apparatus were well distinguished. Due to the regulation of the color balance of the surgical lamp, natural impressions of the liver and its granular structure were determined. The liver tissue did not have undesirable glare and fading, did not cause a blinding effect. Such spectral composition of the radiation allowed to see a clear difference in the texture of liver and kidneys , as well as providing a good visual differentiation of the elements of the hepatoduodenal ligament.

To examine the mouse liver with hepatocarcinoma, the lighting parameters were selected in the way which allowed to show up the tumor in the general structure. Conglomerates of tumor nodes in the right hypochondrium, individual white nodes on the surface of the liver, metastatic foci throughout the peritoneum were determined during laparotomy. For a clear visualization of the primary focus boundaries, less intensive illumination of the common surface was required, as well as the predominance of the yellow radiative component of the source. Despite the fact that the peak wavelength was close to the parameters of the liver, the overall spectrum of illumination has changed.

After separation of the leaves of the gastrocolic ligament, the pancreas of whitish color, with a shiny serous membrane, was well defined using the selected combination of spectral parameters for organs and structures of the retroperitoneal space. The blood vessels, as well as the bends and lobular structure of the gland, were contrasted. Shadows and glare interfering with the surgeon's perception of the organ were not observed. In the study of ischemic pancreas, an adjustment was made relative to healthy tissue. Since blood flow in the organ is reduced during ischemia, structural imaging required a lower intensity of the red and green sources, which led to a shift in the peak wave of the total radiation.

The combination of light source parameters for visualizing organs through the median sternal section of the chest cavity made it possible to clearly determine the boundaries and evaluate the structure of the lungs. The selected combination of spectra allowed to evaluate the surface of the lungs as grainy pink and to visualize the lobes and blood vessels well. During the choosing of lighting parameters for the heart, the possibility of clear visualization of its blood vessels and vascular bundle was evaluated.

IV. Consclusion

It was revealed that it is necessary to use a specific version of illumination for emphasizing different organs in the general system. Parenchymal tissues and tumor formations (pancreas and liver), which absorb a lot of light, require an increase in light intensity. In contrast with organs covered by the peritoneum, such parameters cause an undesirable shine. For better visualization of vascular network, as well as for organs with strong blood supply, it is necessary to prevail the intensity of red light source among other parameters. On the contrary, for differentiating blood-filled organs from ligaments and glands, it is preferable to increase the intensity of green and yellow light sources.

Moreover, in vivo studies allowed to establish light balance so it is possible to visualize the relationship of each organ with surrounding systems and organs, identify areas of pathological changes and uniform formations around the main focus during oncogenesis.

This work serves as an initial stage in the development of a special atlas of spectral visualization of internal organs for surgical interventions using a controlled color-dynamic surgical light source with a correlation of the radiation spectrum. The parameters were selected as comfortable for the particular operating team, which introduces subjectivity in the assessment of lighting of organs and tissues. In the future, it is planned to expand and improve the library of parameters with more in vivo measurements in healthy and pathologically altered organs and tissues. It will form the basis for creating lighting modes to improve and optimize visualization and assessment of the condition of organs and tissues during the surgery, as well as reduce the visual and emotional stress of the operating team. For further research, it is planned to enlist other surgical teams to create a base of expert assessments, as well as to develop a method for objectifying the selection of optimal lighting characteristics based on the reflectivity of organs and systems.

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