Innovative Light Therapy: 1. Biological Effectiveness of Polychromatic Polarized Light Transmitted through Interference, Absorption and Fullerene Filters

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Abstract: On the formalin test model, we studied the effect of polychromatic polarized light of the BIOPTRON device equipped with interference filters (red, blue, green) on pain and non-painful behavioral reactions of laboratory animals with a locus of tonic/inflammatory pain. The study (the same for all light variants) was performed on adult white laboratory mice-males weighing 27-32 g. The pain center was caused by subcutaneous injection of 0.3 μL of 5% formalin solution in the dorsum of the left hind limb. The intensity of the pain was judged by the duration of the pain reaction (licking of the pain locus) for consecutive 10 minutes and for the entire observation period (60 minutes). The light source was the BIOPTRON-compact, equipped with a halogen lamp and a Brewster polarizer. Light was applied to the pain locus immediately after formalin injection for 10 minutes. The distance from the filter to the skin surface was 5 cm, and the diameter of the light spot was reduced to 5 mm. The control was a group of animals with a similar pain effect, but without light application. Processing of experimental data was carried out on a computer using special programs. It was found that polychromatic light obtained after conversion by interference filters as monochromatic red, blue or green statistically significantly \((p < 0.001; p < 0.05; p < 0.05)\) reduced the pain. The duration of the pain response during 60 minutes of observation reduced to 341 ± 93 s (red filter), 435.4 ± 37.1 s (blue filter) or 343.6 ± 65.8 s (green filter) versus 566.2 ± 47 s in the control (without light application). If the duration of the pain response in the control was taken as 100%, then after 10 minutes of exposure to the pain area with monochromatic polarized light obtained after conversion by interference filters, the pain was 60%, 77% and 61%, respectively. Based on these data, the red and green filters turned out to be the most effective, and the least—blue. The duration of the pain response in the group that received a 10-minute exposure to the locus of pain by light passing through the fullerene filter was 56.5% of the magnitude of the similar reaction in the control (without light application). There were found no significant differences between the analgesic effects of interference and absorption filters of the corresponding color. Application of red filters gave 40% of analgesia (interference) and 46% (absorption). For the corresponding pair of blue filters, pain relief was 23 and 31%, and green—39 and 36%. Analgesia from the fullerene filter when applying it to the pain locus was 43.5%. In case of application different variants of light for clinical purposes, it is advisable to take into account both the manifestations of their biological effectiveness, proven on the pain model, and additional features determined by the original wave ranges, polarization and light power density.

Key words: Polychromatic polarized light, Bioptron device, pain, formalin test, analgesia, interference filter, absorption filter, fullerene filter.

1. Introduction

After the advent of lasers, it seemed that all problems associated with the use of light for medicinal purposes were solved automatically [1-3]. And if surgeons enthusiastically mastered the “light knife”, therapists were faced with the need to understand the mechanisms for obtaining the desired therapeutic effects. Initially, low-intensity laser light seemed a panacea for the relief of many pathological syndromes. However, subsequent studies have shown that polarization is not the only variable that can cause the biological effect of light [4]. We had to pay...
attention to the power density, wave range, coherence and interruption frequency of the light flux. On the other hand, the need to take into account the characteristics of a biological object (response threshold, application zone, exposure, dose, etc.) became clear. Advent of the new technology that creates polarized polychromatic light (Bioptron devices) or multi-range LED light, as well as new options for optical filters (including interference and fullerene), has expanded the number of types of modified light and complicated orientation for the doctor in their capabilities. Studies of the mechanisms of action of light at all levels, often carried out using disparate methods, still provide fragmentary answers that do not answer the basic question: how and why do different types of the light act.

A way out can be found if the research is carried out using a single technology, i.e. choose a standardized model of experience, the same type of pathology, a unified methodology for assessing results. These requirements correspond to the formalin model of pain [5, 6], which we used as the basis for assessing the analgesic efficacy of light based on the dynamics of animal behavioral reactions. These studies, for the first time, objectively proved that polarized poly- and monochromatic light can reliably reduce the pain response if it is applied to the locus of pain or acupuncture point [7-18]. Differences in the effect are revealed depending on the characteristics of the wave ranges and light sources. However, a complete list of types of light, which could potentially cause a similar biological reaction, has not yet been covered. The mechanisms of action of isolated light ranges have not been sufficiently studied, especially in connection with the consideration of the radiation power density.

Interaction of the electromagnetic waves, including visible light, is called interference, which presents a redistribution of their intensity as a result of the several light waves overlapping each other.

This phenomenon is characterized by alternating in space maxima and minima of light intensity (interference pattern). Since the phenomenon of interference directly depends on the wavelength, for the light containing various spectral components (white light), they are separated. An interference filter lets the red part of the spectrum of the incoming radiation pass and reflects the remaining parts of the spectrum due to the phenomenon of multipath interference in thin dielectric films (Fig. 1). Compared to absorption filters, for example, from the “Bioptron-Color Therapy” set, interference filters have lower losses in the useful transmission zone and higher efficiency in the suppression zone. They

Fig. 1 The scheme for creating poly- and monochromatic polarized light flux by applying absorption (a), interference (b) and fullerene (c) filters.

1—polarizer of polychromatic light (the Brewster system of the Bioptron device); 2—polarized polychromatic light flux; 3—arrows indicating the direction of polarization; 4—red absorption filter whose components absorb non-red parts of the spectrum but transmit red light; 5—monochromatic light flux converted by the filter (red-infrared); 6—interference films; 7—interference filter, whose components transmit only red light; 8—fullerene filter that absorbs violet-blue light and twice reduces green-yellow bands of light; 9—converted polychromatic (red and infra-red and partially green and yellow) light flux with toroidal polarization.
practically do not absorb light energy. Absorption filters heat, absorbing part of the light flux, and interference filters practically do not heat. At the same time, the production of interference filters is much cheaper. Despite a number of the listed advantages, the biological effectiveness of the interference filters is practically not studied.

The fullerene filter is characterized by the light quanta, passing through it, receiving a change in their trajectory and a redistribution of their location in the light flux [19]. The UV and blue part of the spectrum is absorbed in the same way as in the absorption filter, yellow-green is approximately halved, and red-infrared remains unchanged. In this case, the quantum flux in the mentioned range becomes structured and propagates in the form of toroid (energy packets).

The aim of this work was to experimentally check whether the polarized light of the BIOPTRON device equipped with an interference filter (red, blue, green) affects pain and non-painful behavioral reactions of laboratory animals with a locus of tonic/inflammatory pain (formalin test). We also compared the efficiency of polarized light (PL) transmitted through the interference, absorption, or fullerene filters.

2. Materials and Methods

2.1 Animals

The experiments were performed on adult white male mice weighing 27-32 g. All experiments were carried out in accordance with the ethical recommendations of the International Pain Association. The animals were kept in the vivarium of A.A. Bogomoletz Institute of Physiology, NAS of Ukraine (Kyiv) in conditions of controlled temperature (18-200 °C) and 12-hour light day. All animals had free access to water and food (special granulated food). The day before the experiment, the mice were placed one by one in plastic cells and adapted to the experimental conditions.

Each mouse was used only in one experiment and at the end it was put to sleep by a lethal dose of urethane (intraperitoneally). To reduce the effect of circadian rhythms on the nociceptive sensitivity of animals [20], all experiments were conducted at the same time of the light part of the day (from 10 to 13 hours).
PL to the locus of pain. BIOPTRON-compact device was the PL source with a polychromatic filter (produced by Bioptron AG, Zepter, Switzerland), radiating a linearly polarized (up to 95%), incoherent, low-energy (40 mW/cm²) light with a wavelength range of 480-3,400 nm in the visible and near infrared spectrum [21]. At the output of the Bioptron device, we installed one of three interference or absorption filters: red, blue, or green, as well as a fullerene filter (0.3% fullerene in polymethyl methacrylate, PMMA). The distance from the light filter to the illuminated surface of the skin was 5 cm. The light spot diameter of the device was 40 mm, but for these experiments we used a diaphragm with a hole of 5 mm. After the 10 minutes session, we recorded the beginning and the end of each cycle of the above pain and non-painful behavioral reactions during 60 min of observation.

We measured power density of the light flux of the BIOPTRON-compact device with interference, absorption, and fullerene filters (Table 1). They revealed that the highest power density was observed in the light passing through the red filter, regardless of the type of the filter. Interference filters have less power absorption; therefore, accordingly, the power density of their light is higher than that of sorption ones. Illuminance, which is directly proportional to the light intensity of the light source, for each of the filters, was not proportional to light power density. All filters significantly reduced illuminance, while for green this difference was the smallest, and for blue it was the largest. The fullerene filter combines the middle and red wave ranges, while maintaining a sufficient power density and providing high illuminance.

### 2.4 Statistical Analysis

With the help of a special computer program, we calculated the duration of pain and non-painful behavioral reactions for every consecutive 10-minute intervals of time and for the entire observation period (60 min). Experimental data are presented as mean ± SEM. Reliability of the difference between the groups was determined by the Student’s test (t-test). The difference was considered statistically significant at $p < 0.05$.

### 3. Results

#### 3.1 Influence of the Polarized Light Transmitted through a Red, Blue, and Green Interference Filter on Painful Behavioral Reactions

The analgesic effect of the BIOPTRON-compact PL, equipped with a red, blue or green interference filter, was investigated using a somatic pain model (formalin test). It was found that PL, passing through all three filters, weakens the pain response in animals with a locus of inflammatory pain caused by a chemical factor. This is clearly seen when comparing

| Table 1: Power density and illuminance of the BIOPTRON-compact light, which has passed through filters with various physical properties. |
|--------------------------|-----------------|-----------------|
| Type of the filter       | Light power density, mW/cm² | Light luxmetry, lux |
| Without any filter (halogen lamp) | 57.6           | 9,910           |
| Interference red filter  | 46.0            | 660             |
| Interference green filter | 34.9           | 2,020           |
| Interference light-blue filter | 32.7       | 510             |
| Absorption red filter (Bioptron-compact color set) | 49.3 | 1,270 |
| Absorption green filter (Bioptron-compact color set) | 23.8 | 2,450 |
| Absorption light-blue filter (Bioptron-compact color set) | 17.3 | 410 |
| PMMA-based fullerene filter | 40.3         | 4,240           |

All measurements were performed after the filter. The distance between the device and the sensor was 5 cm. The measurements of power density were made by the device of the Company OPHIR NOVA II; luxmetry—by light meter 401025 of the Company EXTECH instruments.
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Fig. 2  Dynamics (a) and total duration (b) of the pain response caused by formalin injection after a 10-minute application of the BIOPTRON-compact device light with a red, blue or green interference filter to the locus of pain in comparison with the control (without light application).

Numbers above the columns are the duration of pain for 60 minutes of observation (s).

Table 2  Duration of the painful behavioral reaction for 60 min of observation in the control and three experimental groups (average values for each group).

| Groups of animals         | Duration of painful reaction | % from the control |
|---------------------------|------------------------------|--------------------|
| Control (placebo)         | 566.2 ± 47                   | 100                |
| Red interference filter   | 341 ± 93***                  | 60                 |
| Blue interference filter  | 435.4 ± 37.1**               | 77                 |
| Green interference filter | 343.6 ± 65.8***              | 61                 |

Significance of differences with the control: ** p < 0.05; *** p < 0.001.

Comparing total values of the pain response duration for 60 minutes of observation (Fig. 2b, Table 2), it was found that in all three experimental groups the pain was statistically significantly weaker than in the control. Duration of the pain response for 60 minutes of observation in groups where animals immediately after creating the pain locus received a session of polarized light transmitted through interference filters made 60% (red light), 77% (blue light) and 61% (green light) from the values in the control group (without light application). Red and green light did not differ in efficiency, and the blue was significantly weaker than the red and green.

3.2 Effect of the Polarized Light Transmitted through a Red, Blue, and Green Interference Filter on the Non-painful Behavioral Reactions

In animals with an artificially created locus of tonic pain (formalin test), we also studied non-painful
behavioral reactions along with pain ones: sleeping, grooming (washing), motor activity (running) and eating behavior. The results of measuring the duration of non-painful behavioral reactions without polarized light application (control) and after a 10-minute exposure of the pain area to the BIOPTRON-compact device with a red, blue or green interference filter are shown in Fig. 3 and in Table 3.

In the group where the PL of the BIOPTRON-compact device with a red interference filter was used, the duration of sleeping, washing and running did not significantly differ from similar reactions in the control group. That is, red interference light suppressed pain, but did not significantly alter the natural behavior of animals. Blue light reduced the duration of sleep (1.8 times), but 2.4 times increased grooming and 1.6 times increased running time, i.e. despite a decrease in pain, the animals became more agitated. Green light increased the duration of sleep (1.4 times) and the duration of grooming (2.3 times), but did not affect the mobility and eating behavior of the animals.

3.3 Comparison of the Biological Effectiveness of Polarized Light Transmitted through Interference and Absorption Filters of the Same Color

Thus, our experimental data showed that the PL of the BIOPTRON-compact device equipped with a red, blue or green interference filter statistically reliably relieves pain. Earlier on a similar experimental model, we studied the effects of light passing through absorption filters of the same color, as well as through...
Fig. 4 Duration of the pain reaction in the experimental groups receiving a 10-minute exposure to the locus of pain by BIOPTRON-compact device light with a fullerene, interference and absorption filter (three colors) in comparison with the control (without light application).

1—control group; 2—fullerene filter; 3—interference filters (red, light-blue, green); 4—absorption filters (red, light-blue, green).

The numbers above the columns are the duration of pain in % of the control group, taken as 100%.

a fullerene filter. It has been proven that such light also has an analgesic effect. It was of interest to compare the efficiency of interference filters with absorption filters of the same color and with a fullerene filter. According to this aim, pain reactions in all experimental groups were expressed as % of the corresponding control group (Fig. 4).

Statistical analysis showed that the effects of the interference filter do not differ significantly from the standard filter of the corresponding color. If we compare the analgesic effects of the interference and absorption filters application, in the case of red, analgesia is 40% and 46%, respectively. In case with light-blue filters, the interference reduced pain by 23%, and absorption—by 31%. The interference green filter provided an analgesic effect for 39%, and the absorption—36%. Thus, the red filter turned out to be the most effective, and the light-blue one the least. No significant differences between the effects of interference and standard filters of the corresponding color were found. Analgesia from light passing through the fullerene filter was 43.5%. Our experimental data allow us to conclude that interference filters in terms of biological efficiency are comparable with absorption and fullerene filters.

4. Discussion

We consider the results of studies devoted to a comparative assessment of the effect of light after modification with interference, absorption, and fullerene filters. The main result is the proof of two facts: (1) Polychromatic polarized light, modified by the interference red, light-blue or green filter, statistically reliably relieves pain; (2) There are no significant differences between the analgesic effects of interference and absorption filters of the corresponding color, as well as the fullerene filter.

It was theoretically possible that an interference filter, due to more efficient transmission of light and lower power losses, should have provided a better biological effect. However, our experimental studies have not confirmed this assumption.

Comparative analysis of the biological effectiveness of the interference and absorption filters has not been conducted previously. In the present work, for the first time, under equal experimental conditions, it was
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studied the effect on the formalin-induced pain response in animals to the light of BIOPTRON-compact device PL equipped with an interference filter in comparison with light modified with absorption or fullerene filters. The effects of three interference filters are evaluated: red, light-blue, and green. The light transmitted through each of these filters statistically significantly reduced the pain response to formalin. In the groups where the animals immediately after creating the pain locus received a PL session passed through interference filters, the duration of the pain response for 60 minutes of observation was 60% (red light), 77% (light-blue light) and 61% (green light) of the control group (without light application). Based on these data, the red and green filters turned out to be the most effective, and light-blue—the least. Duration of the pain response in the group that received a 10-minute exposure to the locus of pain of light passing through the fullerene filter was 56.5% of the magnitude of the similar reaction in the control (without light application).

Our previous studies with application on the locus of pain or on the acupuncture point of the BIOPTRON device light equipped with absorption light filters showed that such light also has an analgesic effect. Red light also proved to be the most effective among all colors [10, 13].

The efficiency of the filters is probably associated not only with the wavelength, but also with the power of the light flux. Measurements made by the OPHIR NOVA II instrument (Table 1) showed that the power density of the light flux with the red interference filter was 46.0 mW/cm², and with the light-blue interference filter it was 32.7 mW/cm². In the case of using absorption filters, the power density of the light flux at the output of the opaque nozzle was 49.3 mW/cm² (red filter) and 17.3 mW/cm² (light-blue filter). Prevalence of the wave range in development of the biological effect is indirectly confirmed by differences in the illuminance of the filters under consideration. Probably the multicomponent composition of each of the filters, which provides its wave range (color), simultaneously affects the quality of illuminance, which has a noticeable dissimilarity. A fullerene filter having only one component (carbon) in a relatively low concentration (0.3‰) provides a light flux density of 40.3 mW/cm² and an illuminance of 4,240 lux. Nevertheless, the final answer to the question of what is the leading biotropic factor (wave range, light power density or illuminance of the application surface) has not yet been obtained. The fact of the presence of the effect is not in doubt, however, a similar effect arises under the action as by light of different origins the same by light with different technical characteristics.

No significant differences between the analgesic effects of interference and absorption filters of the corresponding color were found. When using red filters, analgesia was 40% (interference) and 46% (absorption). When using light-blue filters, interference weakened pain by 23%, and absorption—by 31%. The green interference filter provided an analgesic effect of 39%, and the absorption—36%.

Despite similarity of the analgesic efficacy of the studied light variants, each of the filters, in addition to the leading wavelength range, creates an original additional spectrum. For example, polarized red interference has an extended range, i.e. wider than laser or LED. The polarized light after the red absorption filter is complemented by an infrared component. The polarized light after the fullerene filter becomes toroidally polarized with a spectrum in the green-infrared range. Similar features are characteristic for other filter options (green, light-blue). In addition, we should note the various absorbing properties of the chemical compounds involved in creating a specific color of the absorption filters, the heterogeneity of the composition of reflective films in interference filters, as well as the difference in the properties of basic materials (glass, plastic). All this affects the power density of the light
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flux and the amount of illumination of the application zone. Accordingly, the number of biological structures that respond to a certain type of the light (absorbing quanta, having different frequencies and power) may be different for light obtained by different methods. We cannot argue that the methodology for determining a biological reaction (formalin test) is exhaustive and excludes the possibility of unaccounted biological responses. Other methods may provide additional data. Therefore, when using different light options for clinical purposes, it is advisable to take into account the above circumstances, the knowledge of which will allow more reasonably to create therapeutic techniques.

5. Conclusions

This study proved that the Bioptron polarized light, which passed through an interference filter, statistically reliably attenuates the painful behavioral response (formalin test) in laboratory animals. After 10 minutes of exposure to the pain locus by red, light-blue or green interference light, the pain was 60%, 77% and 61% of the control value (without light application), respectively. The polarized light of the Bioptron device, converted by a red, blue, or green absorption filter, reduced pain down to 54%, 69%, and 64% of the control. After applying light transmitted through a fullerene filter, the pain response was 56.5% of the control. It was concluded that there were no significant differences between the effects of interference and absorption filters of the same color, as well as a polychromatic fullerene filter.

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