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► To cite this version:

E Thecua, L Ziane, G Baert, P. Deleporte, B. Leroux, et al.. Devices based on Light Emitting Fabrics dedicated to PDTpreclinical studies. "The Feminine" 51st IPA Congress, Jul 2019, Londres, United Kingdom. hal-02518762

HAL Id: hal-02518762

<https://hal.science/hal-02518762v1>

Submitted on 25 Mar 2020

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Devices based on Light Emitting Fabrics dedicated to PDTpreclinical studies

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ABSTRACT

Whether preclinical studies either involve a cell or animal model, the distribution of light plays a determinant role in the reproducibility of results of photodynamic therapy (PDT) studies. Unfortunately, only few illumination devices dedicated to preclinical studies are available and are for the most, very expensive. Most research teams use home-made solutions that may not always be reproducible because of undefined light distribution, additive thermal emission, or unsuitable for shapes and volumes to illuminate.

To address these issues, we developed illumination devices dedicated to our preclinical studies, which embed knitted light emitting fabrics (LEF) technology. LEF technology offers a homogeneous light distribution, without thermal emission and can be coupled with various light sources allowing investigation of several PDT modalities (irradiance, wavelength, illumination duration/mode).

For in-vitro studies, we designed light plates, each allowing illumination of up to four 96-cells plates. For in-vivo studies, we designed mice boxes allowing three animals placement in prone position, equally surrounded by LEF and ensuring homogeneous extracorporeal illumination.

Optical validation was performed and reproducibility of both preclinical systems were assessed.

Both systems can deliver homogeneous light with an irradiance that can reach several mW/cm², with varying durations and wavelengths. First results of preclinical studies demonstrate a high reproducibility, with an easy setup, and a great adaptability of illumination modalities with these devices based on light emitting fabrics.

Keywords: Light emitting fabrics, textile, optical, fibers, bending, PDT, preclinical studies, illumination, MDB TEXINOV

1. INTRODUCTION

Over the last decades, photodynamic therapy (PDT) has proven to be efficient for certain types of cancer [1, 2]. Widely used in dermatological practice, PDT is one of the first-line treatments for the management of actinic keratosis and superficial basal cell carcinomas [3]. Furthermore, several preclinical and clinical trials suggest that PDT in intraoperative conditions represents a promising complementary therapeutic modality for the management of invasive cancers in neurosurgery, pneumology, otolaryngology and gynecology [4-7]. Indeed, in spite of shallow light penetration into biological tissues, photodynamic therapy is particularly appropriate for the treatment of subclinical lesions scattered in the cavity after maximal surgical removal of the tumor [8].

Therapeutic effect of PDT depends on a combination of parameters that include photosensitizer (PS) concentration, drug-light interval, oxygen in cells, fractionation mode, wavelength and total dose of light distributed in biological tissues [9]. To date, PDT parameters are under many investigations, as many for increasing direct tumor cell death rates as for

understanding immune-modulation aspects [10]. Whatever the fields of research (Chemistry, Physics, Biology, etc.), investigation teams have to choose a light source suitable to preclinical studies they undergo. To our knowledge, only few illumination devices dedicated to in vitro or in vivo PDT studies are available and they are for the most, very expensive. As a result, most research teams use home-made solutions or adapt optical fiber devices primarily dedicated to the human clinic [11-13].

In vivo preclinical studies laser sources are widely used as they provide high intensity with narrow spectral distribution. LASER sources can easily be associated to frontal end optical fibers or cylindrical diffuser end optical fibers previously introduced into tumor sites to perform intralesional illumination [13-15]. As visible light depth penetration within biological tissues is limited to few millimeters [16], external illumination are mostly dedicated to superficial lesions or in vitro studies. External illuminations can be performed in intracavitary locations with optical fiber devices (panels, balloons or cylindrical diffuser) [12, 17-21] and in topical locations with frontal end optical fibers, LASER beams or LED panels [22-26].

Whether preclinical studies either involve a cell or animal model, light plays a determinant role in the reproducibility of results. An undefined spatial and/or spectral light distribution or unsuitable for shapes and volumes to illuminate, and additive thermal emissions during illumination, could result in inconsistent dosing [26] and slow down preclinical studies and thus the development of a modality that can be clinically useful and benefit patients. To address these issues, we developed illumination devices dedicated to our preclinical studies, which embed knitted light emitting fabrics (LEF) technology.

2. MATERIALS AND METHODS

2.1 Light emitting fabrics with knitting warp technology

Developed in the framework of CIP PHOS-ISTOS European project, light emitting fabrics (LEF) technology consists in the integration of step index optical fibers (TORAY, Tokyo, JAPAN) with a polymethyl methacrylate (PMMA) core and a fluorinated cladding within a fabric structure during the knitting process. Controlling macrobendings and yarn tension during the knitting process, homogeneous light emission over the entire surface of the sample can be obtained. Produced in one step by warp knitting technology, LEF are made of polyester yarn and embed 37 POF/cm² and can have an effective area over 500 cm² while keeping flexible and conformable properties. [27, 28]



Figure 1. Light emitting fabric sample coupled to 635 nm LASER source (left) and FLUXMEDICARE® device (right)

Several clinical studies using LEF for PDT of actinic keratosis have been published [29, 30] and launched industrialization of FLUXMEDICARE device (MDB TEXINOV, Saint Didier de La Tour, FRANCE). LEF technology appeared also as a relevant and reliable lighting solution for PDT preclinical studies as no additive thermal emission have been described [27, 31].

Gathering free plastic optical fibers within a metallic bundle allow LEF to be coupled to any LASER source by the mean of 2 beam expanders. Thereby, LEF results on a passive light emitting surface, such as frontal or cylindrical diffuser end optical fibers.

2.2 In vitro preclinical devices based on light emitting fabrics

In-vitro PDT preclinical studies often mobilize several operating conditions that should be conducted simultaneously or within a short period of time.

To our in-vitro PDT preclinical studies, two light plates have been designed. Each light plate embeds 600 cm² of LEF allowing the simultaneous illumination of up to four 96-cells plates. Transparent plastic sheets provide hygienic barrier and water protection to light emitting fabrics, and can be cleaned and disinfected before/after each use. Lightproof black covers allow the operator to stay in the room by preventing additional activation of the PS with stray light and prevent internal light reflection that can lead to inconsistent dosing.



Figure 2. Light plates connected to 670 nm LASER source without black covers

2.3 In vivo preclinical devices based on light emitting fabrics

In the framework of the development of an original humanized SCID mouse model of ovarian peritoneal carcinomatosis, a specific device dedicated to mice illumination has been designed. Inspired from results published on mice extracorporeal PDT [11, 32] we designed a mice box allowing three animals placement in prone position, equally distributed on 250 cm² of LEF. Equally surrounded by LEF, full body illumination is provided, with the exception of the head to allow continuous gas anesthesia. Disposable plastic protections provide a hygienic barrier and isolate animals from the LEF.

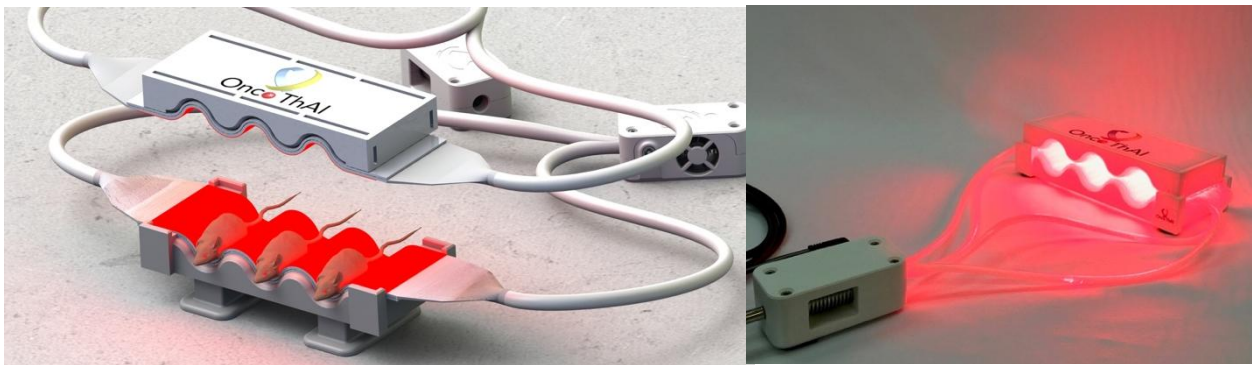


Figure 3. Mice box connected to 670 nm LASER source – picture with mice (Left), photo without mice (Right)

2.4 Measurements methodology

Positioning templates were used to hold an opto-electronic sensor (PD300, OPHIR, Israel) and a power meter (Laserstar, OPHIR, Israel) in 12 holes regularly placed over all effective areas. The measurement process required maintaining each device in a blind room, while connected to a 670 nm LASER source (OncoThAI, Lille, FRANCE) of a total output power settled on 8.5W for the mice box, and 7.1 W for light plates. Mean irradiance is calculated for each target area: Three cavities for the mice box, and four cells plates areas of each light plate.

International standard IEC 60601-2-57 defines safety and performances of devices designed to create photobiological effects on humans or animals, for therapeutic, diagnostic applications in the wavelength range of 200 nm to 3 000 nm. International standard IEC 62471, specifies corresponding exposure limits to evaluate the photobiological safety of light source for operators. According to both standards we conducted measurements of the accessible emission from light plates and mice boxes where connected to 635 nm or 670 nm LASER sources at a standardized distance of 10 cm with a photodiode sensor (PD300RM, OPHIR, Israel) and a power meter (Laserstar, OPHIR, Israel). The accessible emission informs us on the safety risk category according to which light sources must be classified and handled with personal protective equipment and special care.

3. RESULTS AND DISCUSSION

To date, preclinical devices have been used around eighty times for the light plates, and ten times for the mice box.[33]

First results of preclinical studies demonstrate a high reproducibility, with an easy setup, and a great adaptability of illumination modalities with these devices based on light emitting fabrics.

As the mice box and light plates can be light in by connecting an optical fiber patch to any LASER source of whatever wavelength, several PDT light modalities (irradiance, fractionation, light dose) have been undergone very easily.

3.1 Irradiance

Each target area of light plates and mice box delivered respectively $1.26 \pm 0.27 \text{ mW/cm}^2$ and $11.08 \pm 0.58 \text{ mW/cm}^2$, with a global effective optical yield of 22% resp. 33%.

Considering effective surface of all optical fibers, corresponding to optical fiber core only, theoretical yields of the bundle connectors are 70%. Relatively low yield of light plates can be easily explained by the delicate task that represents gathering and mixing several thousand plastic optical fibers within a metallic bundle. Laser gaussian beam distribution remains a critical point in LEF connection: by keeping only the central part of the laser beam reach the bundle full of fibres provides homogeneous light distribution but induces significant losses.

Fluence rate delivered within biological materials (cell lines, and peritoneal cavity of nude mice) are currently under investigation.

3.2 Photobiological Evaluation

According to both IEC 60601-2-57 and IEC 62471 standard methodologies, all PDT preclinical devices fulfill light exposure limits, and can be used safely without personal protective equipment. Retinal blue light hazard, retinal thermal hazard and thermal hazard exposure limits of "Risk Free Group" where above accessible emission of our devices.

4. CONCLUSION

To overcome the lack of affordable light sources suitable to PDT preclinical studies, we developed illumination our own devices dedicated to our in-vitro and in-vivo preclinical studies, which embed knitted light emitting fabrics (LEF) technology. For in-vitro studies, we designed light plates, each allowing illumination of up to four 96-cells plates. For in-vivo studies, we designed mice boxes allowing three animals placement in prone position, equally surrounded by LEF and ensuring homogeneous extracorporeal illumination. Optical validation was performed and both preclinical systems can deliver reasonably homogeneous light with an irradiance that can reach several mW/cm^2 with varying durations and wavelengths.

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