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The Improvement of the Irradiance Uniformity in LED Phototherapy to Match the Standard Requirements

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Authors' contributions

This work was carried out in collaboration between all authors. Author SMR designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Author KAM managed the engineering fabrication of the study and literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Light Emitting Diode (LED) phototherapy (SEDRA 811) luminaire from *Medical Engineering Group (*MEG) was improved after the collaboration between the R&D group of MEG and National Institute for Standards (NIS). The initial LED luminaire consists of 10 Blue super LEDs which provide irradiance levels of 332 to 5719 µW/cm^2±4.5% distributed over the effective surface area (treatment bed). The uniformity of these irradiance levels were 0.06 at the total effective area and 0.2 at central area. A new

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design of the LEDs position over the luminaire using elliptical lenses improves the irradiance uniformity to 3.7 times. At the new design the overall irradiance distribution was improved, the high irradiance levels areas shared their intensities with their neighbors of low irradiance levels. So while the high areas were reduced by 42%, the low ones were increased by 54%. As a result the new design provides more homogenous irradiance levels lying in the intensive levels. Also it provides the uniformity to reach 0.4 (the accepted border) at the central area (20 X 40 cm).

Keywords: Phototherapy; Irradiance; LED application; neonatal jaundice.

1. INTRODUCTION

The past 30 years has seen an increase of publications concerning photobiological research and photomedicine; this reflects the advantage of optical radiation for preventive action plus therapy. Of course, adequate knowledge and experience with handling optical radiation are essential when all uses (of optical radiation) are concerned. The aim is always to maximize the benefit whilst minimizing the risk. Accurate dosage is a target for correct treatment. In 1958, Cremer, Perryman, and Richards were able to demonstrate the *vivo* effect of blue light on the reduction of serum bilirubin levels [1].

Smith (2012) defined Photobiology broadly to include all biological phenomena involving non-ionizing radiation. It is recognized that photobiological responses are the result of chemical and/or physical changes induced in biological systems by non-ionizing radiation [2]. The unique advantage of phototherapy is that light can be used as a powerful and a safe treatment at the same time. All interactions of light with biological systems utilize specific light-absorbing molecular units (Chromophors) located within the illuminated tissues [3]. The most common phototherapy source is Fluorescent lamps which is a low-pressure mercury lamp with a fluorescent layer on the inside of the glass envelope to transform the short-wave ultraviolet energy of mercury into useful radiation depending on the type of phosphorus. So its spectrum is the combination of both light directly emitted by the mercury vapor, and light emitted by the phosphorescent coating [4]. Recent trends in lighting depends on widening the use of LED in lighting, especially in the interior lighting. This is in addition to the expansion of using LED in many devices and various applications. LEDs are becoming much more widely used in medical applications LEDs have several differences from lasers however. The output spectrum is less monochromatic than lasers, with a typical LED having a Full-Width Half-Maximum of 30 nm compared to 2 nm for a laser. Also LEDs are non-coherent sources and hence it is not used in applications where coherence is considered important. Finally, the emitted light is non-collimated, and this makes it very difficult to focus it into a fiber optic cable for endoscopic and internal applications. On the other hand, it is much easier to illuminate large areas of the body with LED arrays than it is with lasers. Now LEDs are made from different materials and emit wide range of spectra extended from infrared to ultraviolet [4].

Neonatal jaundice is treated by Phototherapy (PT) which is known to be a safe and noninvasive type of therapy. It has been shown that PT is a photodynamic stress and can induce lipid peroxidation [5]. Icterus (*Jaundice*) is the most common medical problem in neonates. Around 50–70% of term and 80% of preterm neonates suffer from icterus. Severe hyperbilirubinemia is considered as a medical emergency since bilirubin is a neurotoxic material. It leads to neurologic defects even in healthy term neonates. Therefore, management of hyperbilirubinemia in newborns should be a critical issue. For the past four decades, PT has remained a standard treatment for neonatal hyperbilirubinemia. The effect of PT depends on the intensity of radiation (which in turn depends on the characteristics of radiation, number of radiation sources, and the exposed body area), the distance between the body and the source of radiation. Because of this, several studies have compared the efficacy of single and double PT [6]. The bilirubin molecule absorbs visible light ranging from 400 and 500nm, with peaks around 460 nm, In devices with blue bulbs, the wave length of each achieves from 425 to 475 nm, with irradiance equal to 22 μw/cm^2/nm, the minimum irradiance is 4μw/cm^2/nm [7] Two types of PT devices are currently available: the conventional PT light which has been used for over 40 years and the fibreoptic PT device which has been available for nearly 15 years. These devices typically use one or more tungsten halogen bulb, a metal halide gas discharge tube, long or compact (or folded) fluorescent lamps, or most recently, LEDs. Intensive PT implies irradiance in the blue-green spectrum (wavelengths of approximately 430–490 nm) of at least 30 μW/cm^2/nm (measured at the infant's skin directly below the center of the PT unit) and delivered to as much of the infant's surface area as possible [8].

2. MATERIALS AND METHODS

A PT initial luminaire was designed by *Medical Engineering Group (*MEG) [9] based on 10 super LEDs with circular lenses. They were distributed over the LEDs metal core Printed Current Board (PCB) as shown in the schematic diagram Fig. 1.

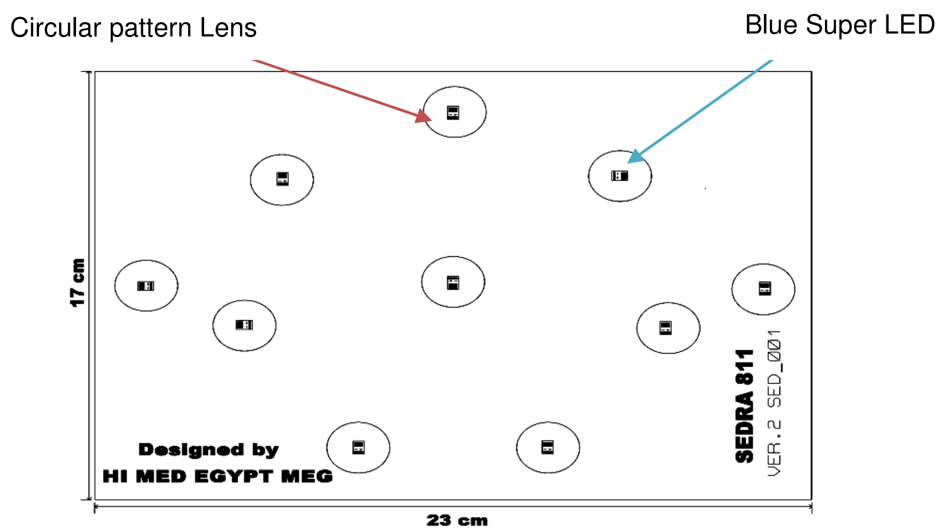

Fig. 1. Schematic diagram of LEDs distribution of the initial PT design

Improved luminaire based on 10 super LEDs with elliptical lenses illustrated at Fig. 2.

The irradiance levels of the initial and improved LED PT luminaire have been measured using a calibrated reference PT radiometer from international light- USA, model "ILT74 Hyperbilirubinemia" whose maximum response is found at 450 nm. The reference radiometer traceable with unbroken chain to National Institute of Standard and Technology (NIST, USA).

The effective surface area at the baby bed (irradiated area 30 X 60cm) at 50 cm from the luminaire was divided during the testing process into 3 rows and 7 columns resulting in 21 points. The LED source was given enough time to warm up prior to recording the readings, then the irradiance levels have been measured at each of the above mentioned points.

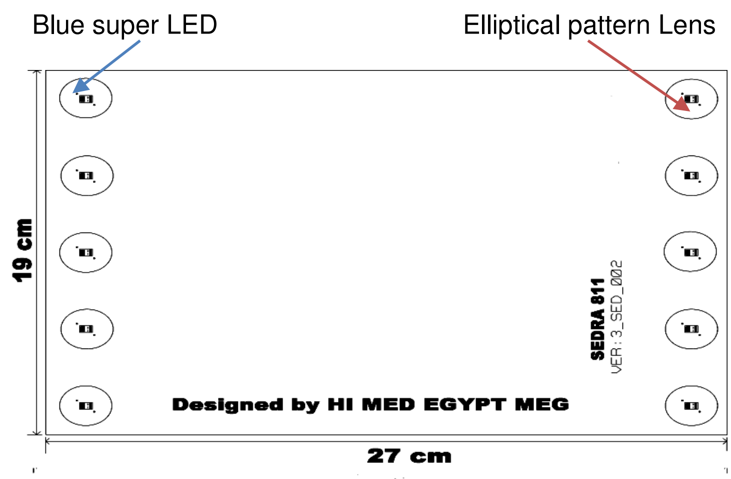

Fig. 2. Schematic diagram of LEDs distribution of the modified PT design

The uniformity of the irradiance level over irradiated area calculated using equation 1

$$G = \text{min. reading/ max. reading [10,11]} \qquad (1)$$

3. RESULTS AND DISCUSSION

The average readings, in µW/cm^2 for both luminaries initial and modified are shown in Figs. 3 and 4 respectively.

It is found that the irradiance levels of the irradiated effective area which were separated 50 cm from the laminar varied between 200 at the borders to 6000 at the center. These irradiance levels are at highest level in the center and decrease dramatically towards the borders. Calculations of uniformity carried out at the total effective surface area and central area 20 X 40 cm. The results for the initial luminaire were found to be 0.06 at total effective area and 0.2 at central area.

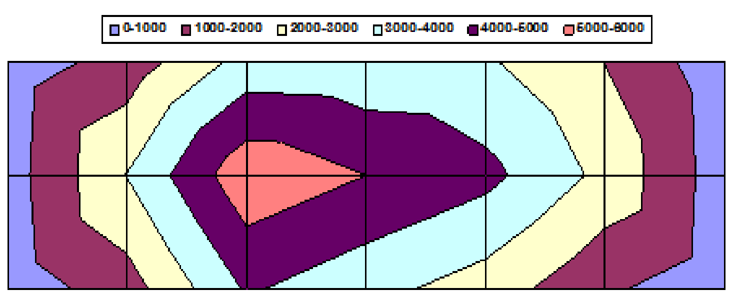

Fig. 3. Irradiance levels of the luminaire located 50 cm away from the effective surface area for the initial luminaire design

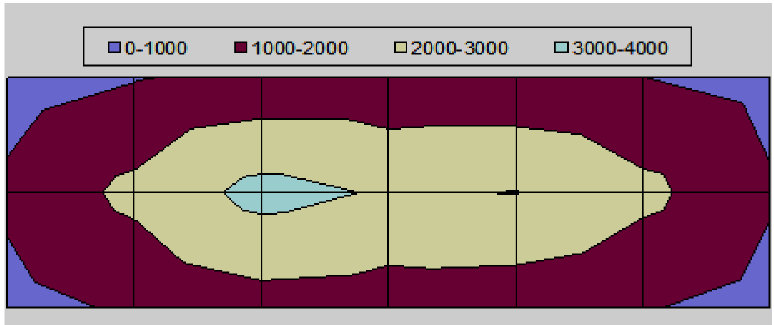

Fig. 4. Irradiance levels at distance of 50 cm of the luminaire and the effective surface area for the modified luminaire

The new design improve the overall irradiance distribution, the irradiance levels areas shared their intensities with their neighbors. So it is noticed that while high areas were reduced by 42%, the low irradiance areas were increased by 54%. The end benefit gained from the new design is that it provides more homogenous irradiance levels lying in the intensive levels, and the uniformity calculated using equation (1) comes very close to 0.4 at the central area (20 x 40 cm) which reaches the accepted border as required by the standards [10,11]. In other words the uniformity increased 3.7 times at the total effective area and two times at the central area. So the irradiance level 0.4 at the central area reaches the accepted border of uniformity.

4. CONCLUSION

The progress in using the LEDs irradiation sources is rapidly increasing therefore; MEG designed a PT luminaire based on 10 super LEDs. By measuring the irradiance level using calibrated PT radiometer (Traceable to NIST – USA), it was found that it produced irradiance which varies from three hundreds to more than five thousands but with very low uniformity 0.06. R & D department (of MEG Company) with NIS (Egypt) improved the performance of the luminaire by new arrangement of 10 super LEDs and by using other lenses. The new design improves the irradiance uniformity to match the requirements of the standards IEC 60601-2-50-2000. It rises to nearly 0.4 at the central effective area 20 x 40 cm. While the high irradiance levels were reduced by 42%, the low irradiance areas were increased by 54%. However; the whole irradiance levels produce sufficient level for intensive PT (more than 30 µW/cm^2/nm).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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