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The effects of ultraviolet supplementation to the artificial lighting on rats' bone metabolism, bone mineral density, and skin

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ABSTRACT

Working and living under artificial lighting environment for a long duration do not allow sufficient sunlight exposure, resulting in an adverse effect on bone. Common artificial light source, white LED light, does not include ultraviolet irradiation that plays an important role in bone metabolism. Ultraviolet supplementation in artificial lighting environment can be used to simulate the effect of sunlight irradiation on bone metabolism. In this paper, we report the effects of long-term exposure of low-dose ultraviolet irradiation on the rats' bones and skin. We studied the changes in body weight, bone metabolism markers, bone mass content, bone mineral density, and skin of rats, under long-term exposure of low-dose ultraviolet irradiation. We found that the rats exposed to ultraviolet irradiation showed an increase in bone formation rate, decrease in bone resorption rate, and improvement in bone mass content and bone mineral density without adverse effects on skins. This paper provides an effective basis for future application of LED light to create a healthier, safer, and more comfortable indoor lighting environment.

1. Introduction

The general public in modern society carries out living activities indoor under the artificial lighting environments for 90% of the time. White LED lamps have become the main indoor lighting source and gradually replacing traditional light sources such as incandescent lamps due to their advantages in energy saving, environmental protection, and longevity. Working and living in an artificial lighting environment for a long duration do not allow exposure to sufficient sunlight may result in adverse impact on people's physical and mental health. Studies have shown that lack of exposure to sunlight increases the risk of diabetes [1,2]. In addition, a large number of studies have reported that lack of sufficient sunlight will lead to the insufficient synthesis of vitamin D and thus affecting bone metabolism [3]. Lack of sunlight exposure for long duration can lead to bone loss [4] and damage to the bone system. It is also evident that submarine crews involved in long-haul missions has had adverse health effect owing to lack of sunlight exposure for bone health [5].

These issues attributed to the fact that the typical white LED spectrum does not include the ultraviolet band compared to the sunlight spectrum. However, ultraviolet (UV) irradiation is one of the critical conditions for maintaining bone health. > 80% of vitamin D is synthesized through ultraviolet irradiation in the sun [6]. Ultraviolet light is mainly used to promote the synthesis of vitamin D in human skin, thereby promoting the absorption of intestinal calcium to maintain bone mass content, reduce bone loss, prevent osteoporosis and reduce the incidence of fractures [7]. Therefore, white LED lamps cannot achieve the same purpose of maintaining human health as the sun.

It is essential to develop healthier, safer and more comfortable indoor lighting source for the health of the general public as well as special occupational groups such as submarines, underground military personnel and astronauts who required to work and live in a closed, isolated and artificial lighting environment for long-term. The proper amount of supplemental ultraviolet irradiation is beneficial to the synthesis of vitamin D and prevents osteoporosis. Although extensive studies have reported that ultraviolet irradiation has improvement on bone metabolism [8–10], there is no information available in the

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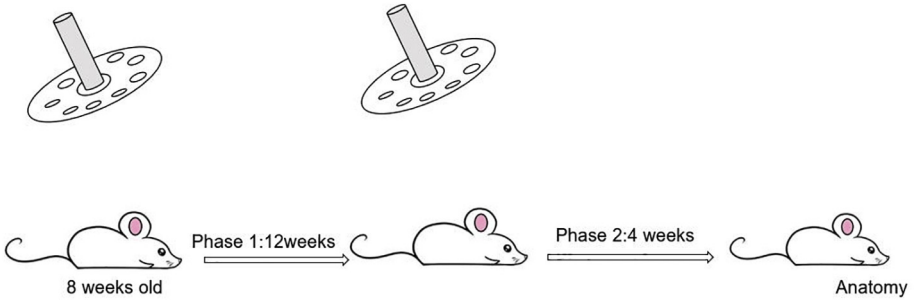

Fig. 1. Two-phase experimental schedule. The first phase lasts for 12 weeks and the second phase lasts 4 weeks.

literature on low-dose ultraviolet supplementation to the white light LED to simulate the effect of sunlight irradiation on bone and skin.

Here, we report a comprehensive study on the effects of long-term low-dose ultraviolet supplementation to the white light LED on the bones and skin of normal rats. The findings of this study provides a deep understanding of creating strategies and developing artificial lighting for the healthy artificial light environment.

2. Materials and Methods

2.1. Animals

Female rats are more sensitive to UV irradiation producing vitamin D. Therefore twenty 200 ± 20 g 8-week-old female Sprague-Dawley (SD) rats (provided by Beijing WeitongLihua Animal Experiment Technology Co., Ltd.) were used in this study. During the experiment, rats were housed in plastic squirrel cages according to groups (n = 10 per group). The cage cover is a light-permeable, breathable iron mesh. Ordinary feed and drinking water were available ad libitum. The animals were maintained in controlled conditions (12-h light-dark cycle, temperature 24 ± 2 °C, air humidity 30–55%). The weights of rats were monitored once a week.

2.2. Experiment Design

The experiment was conducted for four months in two-phase, with the first 12 weeks as phase 1 and the following four weeks as phase 2 (Fig. 1). Twenty 8-week-old female SD rats of 200 ± 20 g weight were randomly divided into control and UV groups. The control group was reared in a white LED lighting environment while the UV group was reared in UV supplemented under a white light LED. Fig. 2 shows the spectrum of the white light LED lamp and UV lamp (purchased from Guangzhou Ramp Optoelectronics Technology Co., Ltd.). The white light LED spectrum does not contain the UV band. The LED white light illumination of the terrarium activity area is 1000 lx, approximately equaling to 255 μW/cm^2. The wavelength of the UV LED lamp is 280–340 nm with wave peak at 315 nm (Fig. 2). The UV lamp irradiation intensity is adjustable in two stages. The UV irradiation intensity was 13–16 μW/cm^2 in phase 1. The UV intensity was set 25–30 μW/cm^2 in phase 2. Both phases of irradiation time are 30 min per day. There are two reasons for the changing the UV intensities. Firstly, we want to understand how a sudden increase of UV radiation for a period influences bone metabolism and bone parameters in rats. Secondly, we want to explore the relationships between bone changes and radiation intensity of UV. It is hoped to provide a reference for the future selection of UV light intensity for bone improvement or prevention of bone loss. Rats were measured weekly for food intake and body weight. As previously described, the backs of rats were shaved regularly using electric scissors as an area of irradiation [11].

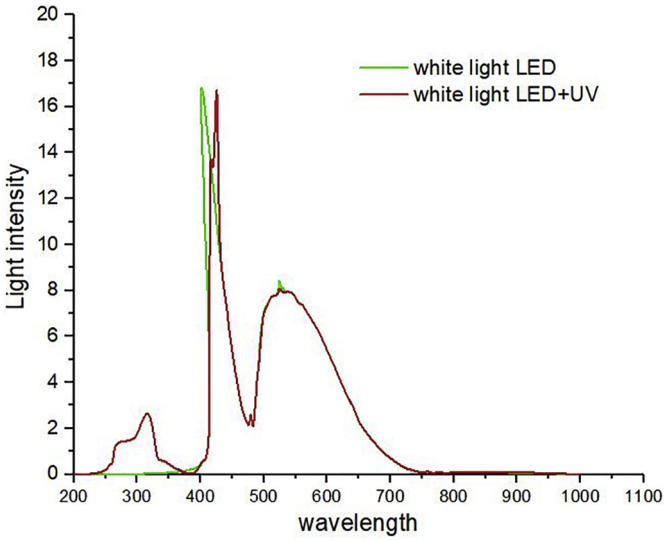

Fig. 2. Spectrum of the white light LED lamp and UV lamp used in the experiment.

2.3. Blood Samples Analysis

Before the UV irradiation and at the end of each phase, rats were fasted 12 h. Blood collection began at 8:00 am the next morning for two hours. Then blood specimen was drawn from each rat's tail veins. Each collected blood sample was dispensed using a centrifuge tube and centrifuged at 3000 rpm/s for 20 min using a cryogenic centrifuge. After standing, the separated plasma supernatant was collected and stored at −20 °C until the time of measurement. Repeated freezing and thawing were avoided. This method was based on a previous study [12].

ELISA kits (provided by Beijing Ruigebo Technology Development Co., Ltd.) for serum 25-hydroxy vitamin D (25(OH)D), parathyroid hormone (PTH), procollagen Type I carboxy N-terminal propeptide (P1NP) and bone alkaline phosphatase (BALP) assays were used according to the manufacturer's protocols.

2.4. Dual Energy X-Ray (DXA) Analysis

The rats were deeply anesthetized with pentobarbital sodium solution with mass fraction of 1% by intraperitoneal injection. The rats were scanned with a bone densitometer (provided by the School of Biology and Medical Engineering, Beihang University). Each rat was measured for bone mass content (BMC) and bone mineral density (BMD) of the whole body, femur and tibia were designed according to the report by Zhuang H et al. [13]. Before measurements, a tissue calibration scan was performed with the Hologic phantom for the small animal. All measurements were performed by the same operator,