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Abnormal Environmental Light Exposure in the Intensive Care Environment

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Abstract

Purpose—We sought to characterize ambient light exposure in the intensive care unit (ICU) environment to identify patterns of light exposure relevant to circadian regulation.

Methods—A light monitor was affixed to subjects' bed at eye level in a modern intensive care unit and continuously recorded illuminance for at least 24 hours per subject. Blood was sampled hourly and measured for plasma melatonin. Subjects underwent hourly vital sign and bedside neurologic assessments. Care protocols and the ICU environment were not modified for the study.

Results—A total of 67,324 30-second epochs of light data were collected from 17 subjects. Light intensity peaked in the late morning, median 64.1 (interquartile range 19.7–138.7) lux. The 75th percentile of light intensity exceeded 100 lux only between 9 AM and noon, and never exceeded 150 lux. There was no correlation between melatonin amplitude and daytime, nighttime or total light exposure (Spearman's correlation coefficients all <0.2 and p>0.5).

Conclusions—Patients' environmental light exposure in the intensive care unit is consistently low and follows a diurnal pattern. No effect of nighttime light exposure was observed on melatonin secretion. Inadequate daytime light exposure in the ICU may contribute to abnormal circadian rhythms.

Introduction

The circadian system modulates many important physiologic functions throughout the body, including brain arousal, sympathetic tone, cardiovascular function, coagulation, immune system activity, glycemic control and metabolism.[1] An emerging literature suggests that the circadian system is severely disturbed in critically ill patients, and circadian disruption may exacerbate their multiorgan dysfunction.[1] A subset of retinal ganglion cells serve as

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photoreceptors for circadian responses, projecting directly to the central circadian pacemaker in the suprachiasmatic nucleus.[2] Melatonin secretion, a crucial signaling link between the central and peripheral oscillators of the circadian system and the most commonly used and robust marker of circadian phase in humans, is strongly affected by light, and abnormal patterns of light exposure derange the central circadian rhythm.[2,3] The goal of this study was to characterize light exposure to patients in a typical intensive care unit environment and identify adverse light effects on melatonin secretion.

Methods

Patients presenting to the neurosciences intensive care unit at Northwestern Memorial Hospital with a diagnosis of spontaneous intracranial hemorrhage between April 2014 and April 2015 were prospectively enrolled in an observational cohort study within the first two days of admission. A light monitor (Actiwatch-L; Philips/Respironics, Bend, OR, USA) was affixed to the hospital bed at the patients' eye level and continuously recorded illuminance for approximately 24 or 48 hours per subject. Subjects underwent a highly standardized care protocol, as we have previously detailed, that included hourly vital signs and hourly neurochecks that included a complete Glasgow Coma Scale (GCS), Richmond Agitation Sedation Scale assessments every other hour, and Confusion Assessment Method for the ICU (CAM-ICU) at least twice daily, with sedatives held if applicable, performed by a trained neuroscience nurse.[4,5] Care protocols and the ICU environment were not modified for this study. The ICU rooms face east with obstructed sun exposure, and a window occupies 42% of the external wall area. Artificial lighting consists of overhead panels containing tubular bright white fluorescent light bulbs. Patients' faces are oriented to the side walls. Blood was sampled hourly from an indwelling arterial catheter, and plasma melatonin levels were determined by radioimmunoassay (IBL International GmbH, Hamburg, Germany).

We determined the median and interquartile range of illuminance measurements for every half hour interval of the day. We compared illuminance during daytime (7 AM to 6:59 PM) and nighttime, and between summertime and wintertime. In order to characterize a high nurse-patient interaction environment with substantial continuous care activities, we only selected patients who were undergoing hourly vital sign measurements and hourly bedside neurologic examinations. We have described the nursing care protocol, including the hourly serial neurologic examinations, elsewhere.[4]

The plasma melatonin amplitudes were calculated as the difference between the peak and minimum levels during the study period. Illuminance measurements were compared between summer and winter groups using the Wilcoxon rank sum test. We evaluated whether the distribution of daytime illumination measurements was different than nighttime measurements in individual subjects using the Mann-Whitney U test. We tested for a correlation between melatonin amplitude and measures of light exposure using Spearman's correlation. The study was approved by the Institutional Review Board (IRB) at Northwestern University. Written informed consent was obtained from the patient or their legally authorized representative.

Results

We obtained 67,324 illuminance measurements in 17 subjects, with 39,882 (59%) of measurements occurring during summertime and 32,401 (48%) during daytime. Most patients had mild to no impairment in consciousness (median GCS 15 [interquartile range 14–15]), and only 2 (12%) received any sedatives or sedating analgesics during the study, and delirium was rare (6% of patient ever delirious during the study period by CAM-ICU). The characteristics of the cohort are summarized in the Table.

The median and interquartile range of light exposure at the patients' face level was 9.3 [0.9–48] lux, shown by half-hour intervals across the 24 hour day in Figure 1. Daytime light intensity was greater for each individual subject compared to nighttime measurements ($p < 0.01$ for every subject), and likewise across all measurements in the study (median 24.3 vs 3.7 lux, $p < 0.01$). Light intensity peaked at 11:00 AM at a median 64.1 [19.7–138.7] lux. The 75th percentile of light exposure measurements exceeded 100 lux only between 9:30 AM and noon, peaked at 142 lux and never exceeded 200 lux. Light conditions were uniformly dim in the nighttime (75th percentile all < 100 lux). Daytime light exposure was higher during summer days versus winter days (median 32.1 vs 19.8 lux, $p < 0.01$). There was only one instance in which a subject was exposed to sustained, light of > 200 lux for > 10 minutes between 10 PM and 6 AM, the hours during which melatonin acrophase normally occurs. The profile of melatonin measurements across the 24 hour time period is shown in Figure 2. Average values show a typical circadian pattern with acrophase at 4:00 AM, although a wide variability of amplitudes were observed with many patients showing no clear nocturnal rise. There was no correlation between melatonin amplitude and average daytime light exposure ($\rho = 0.17$, $p = 0.52$), nighttime light exposure ($\rho = 0.07$, $p = 0.80$) or total light exposure ($\rho = 0.09$, $p = 0.74$).

Discussion

Our data demonstrate that a high care contact ICU setting exposes critically ill patients to light intensities that rarely exceed 150 lux during the brightest portions of the day, and are uniformly < 100 lux during the night. There was a diurnal variation in illumination, but with rare and brief exceptions, patients were in a continuously dim light environment. Melatonin secretion was abnormal in many patients, but we observed no relationship between plasma melatonin amplitude and light exposure.

For perspective, ambient lighting outside during an overcast day is approximately 10,000 lux, and up to 100,000 lux midday on a sunny day. Numerous experts have hypothesized that ICU light exposure is *excessive*, and interventions have been piloted to reduce lighting intensity in the ICU environment to address the concept of nocturnal light pollution.[6,7] This dedicated study of ICU illumination found that patients receive minimal nighttime light exposure with no discernible relationship between light exposure and nocturnal melatonin amplitudes, and that the major light-related environmental abnormality is very low daytime lighting. No prior comprehensive study of light in the ICU has been published. A few case series of sleep or circadian rhythms in the ICU have reported average data consistent with our findings, with median daytime light in the range of 70–200 lux and sleep/nighttime light

in the range of 1.7–20 lux, although no study has evaluated for an effect of light exposure on melatonin or looked at lighting rhythms or individual variability.[8–10]

Prospective studies have intriguingly shown an association between visible daylight and favorable outcomes in critically ill patients, like lower delirium incidence and greater survival after myocardial infarction. Based on our findings of dim daytime light exposure, a potential role for daytime light supplementation is suggested. Bright light is a well-known Zeitgeber (an environmental stimulus that entrains the circadian rhythm). Inadequate daytime light may fail to entrain melatonin rhythms. Coupled with the loss of other Zeitgebers like feeding times and the disruption of sleep, it may contribute to the dysregulation of biological rhythms throughout the body. Increasing daytime light can normalize circadian rhythm timing and has been shown to increase normal nocturnal melatonin secretion with resulting improvements in circadian modulated physiologic parameters in both translational and human studies.[11–13]

Architectural characteristics and care patterns vary between institutions, including the frequency of bedside care activities and institutional approaches to nighttime lighting. Several characteristics of our study mitigate these limitations. We likely obtained a high estimate of light exposure because our ICU has large, unobstructed windows in every room and a high frequency of patient-provider bedside interactions. Moreover, many critically ill patients will have their eyes closed such that ambient light does not reach their retinas, so the effective “light dose” is lower than the sensor detected. Finally, a variety of other factors can influence melatonin secretion including medications and feeding. We sought to minimize confounding by other factors by enrolling a cohort of patients with a single diagnosis for whom the management is performed by an institutional protocol that does not utilize medications like beta blockers, stimulants or corticosteroids, and in which the nursing care protocol is very uniform.

Conclusions

Several conclusions are reached. First, light exposure in an unmodified ICU environment with a high frequency and intensity of patient care interventions follows a diurnal pattern. Second, impaired nocturnal secretion of melatonin was observed in many of these critically ill subjects, but nocturnal light pollution was minimal and unlikely to be a major culprit. However, we also found that daytime light intensity rarely reaches levels known to effectively entrain the central circadian rhythm. In the context of prior research, these data suggest that supplementing daytime light is more promising than efforts to further reduce nighttime light as a therapeutic intervention to reestablishing or regulating circadian rhythms in the ICU environment.

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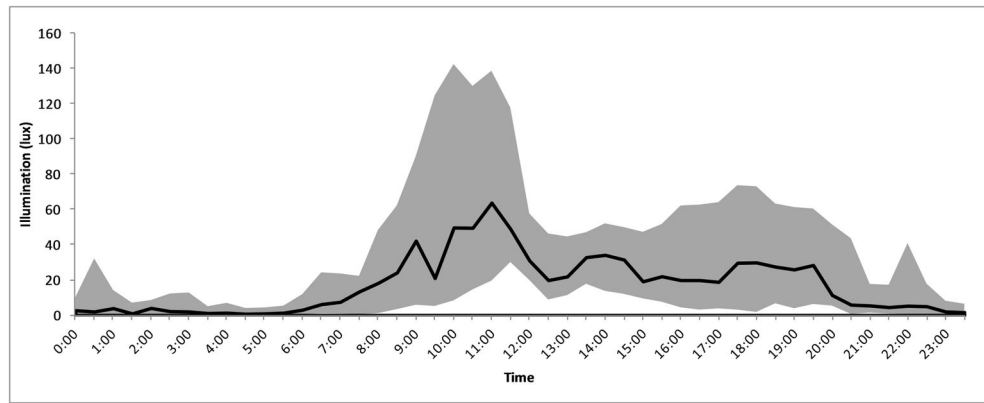


Figure 1.
Light Exposure in the ICU
The median (solid black line) and interquartile range (shaded) of face level illuminance of ICU subjects is shown for every half hour interval through the day.

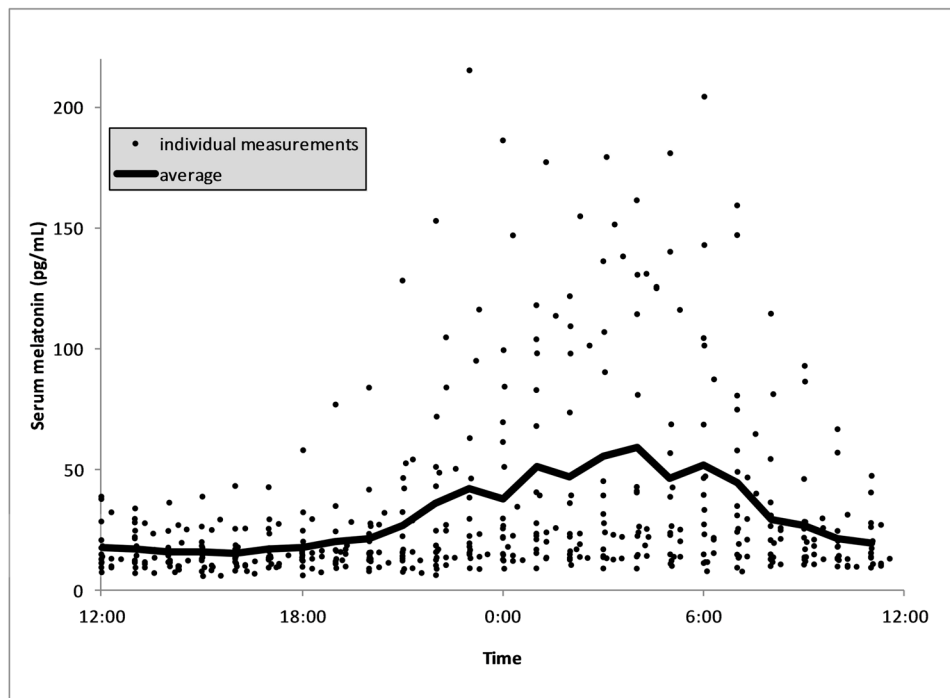


Figure 2.
Serum Melatonin Profiles
The average (solid black line) and individual serum melatonin measurements for ICU subjects through the day is shown.

Table

Patient Characteristics

Subjects	17
Age	62 [57–69] years
Sex (female)	11 (65%)
Glasgow Coma Scale score	15 [14–15]
CAM-ICU positive during study period	1 (6%)
Mechanically ventilated	4 (24%)
Any sedatives or sedating analgesics at any time during the study	2 (12%), 1 propofol, 1 propofol + fentanyl
Intercurrent infection during study period	0 (0%)
Interval between illness onset and study initiation	33 [16–50] hours
Daytime hours monitored	16 ± 5 hours
Nighttime hour monitored	17 ± 5 hours
Average daytime light exposure (07:00:00 to 18:59:30)	42 [22–70] lux
Average nighttime light exposure (19:00:00 to 06:59:30)	25 [9–42] lux
Melatonin amplitude	21.6 [10–59.9] pg/mL

Data shown are median [interquartile range]. CAM-ICU: Confusion Assessment Method for the ICU.