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Neonatal intensive care unit lighting: update and recommendations

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ABSTRACT
Achieving adequate lighting in neonatal intensive care units is a major challenge: in addition to the usual considerations of visual performance, cost, energy and aesthetics, there appear different biological needs of patients, health care providers and family members.
Communicational aspects of light, its role as a facilitator of the visual function of doctors and nurses, and its effects on the newborn infant physiology and development were addressed in order to review the effects of light (natural and artificial) within neonatal care with a focus on development. The role of light in regulating the newborn infant circadian cycle in particular and the therapeutic use of light in general were also reviewed. For each aspect, practical recommendations were specified for a proper well-lit environment in neonatal intensive care units.
Key words: *review, intensive care, lighting, ergonomics*

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INTRODUCTION

Continuous advances in neonatology have increased the chances of survival of preterm and critically ill newborn infants. Although neonatal intensive care units (NICU) provide highly specialized medical care, they do not necessarily offer an ideal environment for the development of newborn infants. There is a huge difference between intrauterine environment and the NICU environment.[1] The former is an econiche that offers maternal protection, continuous nutrient supply, stable temperature and chronobiological cycles, while the latter is characterized by an inappropriate, non-contingent, non-reciprocal and painful stimulation pattern in a moment of major structural and functional brain development. This transition to extrauterine life imposes even greater demands, due to the physiological limitations of inpatients and their restricted ability to adapt to the environment and reject unwanted stimuli. The physical environment (light, temperature, sound, radiations) in the NICU is a critical issue, which can affect the normal development of a newborn infant.[2] The interactive development theory indicates that the newborn baby actively responds to the environment looking for balance. These dynamics offer beneficial opportunities for preventive and therapeutic interventions.[3,4]

Once the newborn infant's individuality is recognized, Sparshott[5] categorizes many features of the neonatal unit environment: safety, comfort, right posture, proper development, communication, rest and sleep, dignified death. These principles correspond to an approach to medical care, which combine technological and human features: development-centered care to meet the newborns and their family's needs.

Argentina has initiatives, handbooks and guidelines for the implementation of this paradigm of care.[6] It also has a law regulating parents´ and children´s right during the process of birth (Law 25929) and a Regulation on the Organization and Operation of Neonatology Services and Neonatal Intensive Care (Res. 306/2002), which includes physical environment and its lighting. However, there is no legal and regulatory framework specifying the proper lighting parameters in a NICU.

The aim of this article is to review the effects of lighting in newborn infants and provide recommendations for proper lighting within the development-centered care. Methodological aspects of this review may be referred to in the *Annex* attached to this publication.

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LIGHT ENVIRONMENT IN A NEONATAL INTENSIVE CARE UNIT

Both artificial and natural lighting play several roles in the NICU environment: it communicates and conveys sensations, supports the visual function of doctors and nurses, affects the newborn infant's physiology and development, and regulates the circadian function, in addition to its therapeutic use.[7-10]

Communicational aspects of lighting

A safe and family-centered NICU must be considered the newborn infant's "first home". It should have a cozy atmosphere, caring for patients and family members' comfort.[11,12] The interior decoration and the careful environment design may turn a high technology clinical area in a more enjoyable place for newborn infants and family members.[9,13,14]

Evidence suggests that natural light (NL) and contact with nature deeply influence human health and welfare.[15] In the clinical field, more studies dealing with the possible positive effects of lighting on health have been conducted compared to the positive effects of natural landscapes seen from inside.[15] In addition, the use of NL systems and strategies helps reduce power consumption and improves interior space quality of use.[16-20]

To maximize these benefits, NL contribution should be carefully planned, as there are problems associated with uncontrolled sunlight´s entrance: it interferes visual performance (glaring, screen reflections, spots of light), it affects visual and thermal comfort, and has unwanted radiation (infrared, ultraviolet).

Recommendations:

- Generate points of interest, either by contrast or by color, emphasizing, through lighting, desirable stimuli such as photographs or artistic images.[20]
- Achieve a flexible lighting system, which is adjustable either individually or by areas within the Unit so as to meet the varied needs of newborn infants who share the NICU.
- Incorporate NL in the hospitalization area and locate cribs more than 60 cm away from windows. Sealed double glazed is preferable so as to minimize heat loss.
- Include external elements of solar control (sunshades, eaves, louvers) in windows, which are easy to maintain and clean, and which allow flexible use as needed. Use neutral colors to minimize color distortion.[21]
- Avoid direct sunlight radiation both on patients and on IV fluids and data display screens. Avoid glare on doctors´ and nurses´ eyes.[21]

Light as visual function support of doctors and nurses

Lighting level (measured in lux) in neonatal units has described a parabolic curve since the second half of the twentieth century.[22] NICUs from the 80s were bright and well-lit, matching technological burst and the highly sophisticated neonatal care.

Nowadays, there is a trend to use lower lighting levels. With the use of current monitoring systems, the need for direct observation has decreased, so it is not necessary to use intense light to monitor newborn infants.[23] It is generally agreed that newborn infants are more stable and consume less energy in low light conditions, which are also necessary for procedures such as echocardiograms or transillumination.[24]

Moreover, in a NICU, speed and mainly accuracy are essential for tasks performance. Higher levels of lighting allow greater visual acuity, and improve signal-noise ratio for visual tasks and visual functions speed.[7] A good perception of color is crucial for the clinical examination of patients.[25] The color rendering index (CRI) allows to determine color rendering properties of a light source. Taking as a standard the NL (CRI = 100), this index measures how "natural" colors are perceived when illuminated by an artificial light source.

Recommendations:

- Examine the infant, the color of their skin and mucous membranes, and their perfusion anywhere in the room, with a range of general illumination of 10-600 lux.[26]
- Use individualized light sources of, at least, 2000 lux to examine the newborn infant or to perform specific procedures in short periods avoiding the exposure of nearby patients.[24]
- Avoid reflections on screens by diffuse general lighting so as not to hinder the reading of important visual information, either on monitoring screen or during diagnostic procedures.
- Interior surfaces (walls, floor, ceiling) should be clear with a matt finish so that the interior light is distributed diffusely to avoid glare.[9,13]
- Sources of artificial lighting must have a CRI

greater than 80.[21] Their optical reflectors must have a natural finish to maintain the properties of color rendering.

Effects of light on the newborn infant physiology and development

The newborn infant visual system is not fully developed at birth, and over the last trimester of pregnancy, major developments of the nervous and visual systems occur, continuing their structural and functional maturation during childhood.[27] Lighting influences postnatal development of vision and visual processes and the maturation of the visual cortex, which is affected by premature visual experiences.[8,24,28,29] Factors that regulate the amount of light reaching infants´ eyes are biological: eyelid opening, transmission through them, pupil diameter (starting at 30-34 weeks old after birth) and transmission features of the ocular media.[30] Until full-term gestational age, light is not necessary for visual development, and it does not seem appropriate to subject the preterm infant to intense light when this does not occur *in utero*.[31]

Evidence indicates that exposure to very bright light can harm the immature eye.[32] High lighting levels have been associated with adverse clinical outcomes: less weight gain, behavioral and sleep disturbances, in addition to stress in very preterm or seriously ill patients.[7,24,33-35] A sudden change in the amount of light also affects the newborn infant: Shogan and Schumann[36] reported rapid saturation declines in preterm infants after a sudden increase in lighting. Preterm newborn infants are visually more vulnerable: they get tired easily, have very thin eyelids and their immaturity prevents them from closing their eyes consistently, so they have limited resources for protection from light.[37,38] Changes in ambient lighting include temporary effects: a reduced level of lighting produces an immediate and transient opening of the eyelids, followed by a significantly longer period when this dimmer illumination is kept. It has been published that effects of light reduction in the NICU include a better stability of the newborn infant, respiratory stability, decreased heart rate and respiratory rate, blood pressure and motor activity, shorter time in ventilation and oxygen support.[30]

Recommendations:

- Limit visual stimulation that competes with auditory and tactile information prevailing in a NICU to avoid sensory interference during this stage of development.
- Avoid direct light to the newborn infant's eyes at all times.
- Use progressive lighting to enable a gradual dark-light shift to reduce the stress produced in the newborn infant by a sudden change in ambient lighting.

Light as a regulator of the circadian cycle of the newborn infant

Rivkees[39] notes that, although fetus development takes place in the dark, this environment is rich in auditory, tactile and kinesthetic sensory stimulation. Keeping preterm patients in a continuously dark environment while in the NICU, deprives them of the circadian stimuli they would have received during gestation.[40]

The fetal biological clock is an endogenous system that generates circadian rhythms in response to maternal signals (activity, heart rate, cortisol, melatonin, body temperature), at least from the third quarter of gestation.

As the light entering the retina is the main external regulator of the human circadian system, in 1997, the American Academy of Pediatrics suggested introducing regular cycles of day-night lighting in the NICU.[41,42] This is to preserve life and provide proper medical care in a uterus-like environment, thus continuing as much as possible, the experience that has been interrupted at an early stage.

Research supports the importance of circadian rhythms for the fetus and the relative lack of them in preterm infants.[39,40,42-44] Evidence indicates that, between weeks 28 and 32 of gestation, cyclical lighting has positive clinical effects on the newborn infant, but there is little information on the effect of circadian rhythm on physiological functions, growth and development of the central nervous system.[40,42,45-50] There is still no consensus on how to introduce circadian cycles with artificial lighting in practice neither is there an implementation protocol regarding cycle length and maximum/minimum lighting levels.[50]

Recommendations:

- Implement a cyclic lighting schedule. During the day, between 100 and 200 lux, with some natural light. At night, artificial light lower than 50 lux, with a NL-like spectral distribution.
- Day/night lighting should be capable of increases up to 600 lux with independent control for separate lights.[51]

- The use of individual blankets is an alternative, and a higher mean duration of non-REM (rapid eye movement) periods has been reported in stable preterm infants protected by blankets.[52]

Therapeutic use of light

Neonatal jaundice is the most common disorder among newborn infants. It is estimated that 60%-70% of newborn infants have jaundice.[53] It is a benign and self-limited condition that normally goes away before the age of one month.[54] However, the serum unconjugated bilirubin level should be monitored to avoid toxic levels to the central nervous system. Phototherapy maintains or lowers blood bilirubin levels through photolysis. The newborn infant's skin is exposed to light and their eyes are usually protected. However, newborn infants in neighboring cribs do not always have their eyes covered, and even infants under treatment sometimes remove their eye protection.[7] To counteract this, the optical fiber blankets wrapping newborn infants are an already published alternative.[55]

With a less dense macular pigment and ocular media that transmits more short wavelength (blue) and ultraviolet energy, the newborn infant has a higher risk of eye damage by short-wave light, among many other susceptibilities associated with the developing visual system.[56] With a peak sensitivity of 440 nm, exposure to this area of electromagnetic spectrum could cause oxidative damage to photoreceptors and prevent normal regeneration process. This process was described on *in vitro* studies and animal models.[57-59] Both the human circadian system and bilirubin photolysis require shortwave light. These processes have their greatest spectral sensitivity at 450 nm, area adjacent to peak of 440 nm of blue light damage function.[8,60]

Retinopathy of prematurity (ROP) is a major cause of blindness. Babies born with less than 1500 g and/or less than 32 weeks of gestational age are at an increased risk. This group should be monitored through serial ophthalmologic exams until complete retinal maturation is accomplished. When the disease was first described, it was suggested that early exposure of the retina to light could increase the number of free radicals, which contributes to ROP development.[61] Since the fifties of the twentieth century, excessive use of oxygen has been known to increase the risk of ROP.[62] Animal studies showed injury to the retina after exposure to extremely bright lights for long periods, something that is not usually practiced in a NICU.[10,33,63,64]

Interest in lighting was revived after the work by Glass and his colleagues,[65] who reported a ROP incidence reduction by lowering lighting in the NICU. Searching for a definitive answer about the effect of light on ROP, a multicenter randomized study called LIGHT-ROP was conducted. In this study, no significant differences were found in the severity of ROP among newborn infants exposed and unexposed to light.[66] While it is generally accepted that light is not a risk factor for ROP development, it is still a controversial issue.[67-69]

According to Fielder and Moseley,[30] light does not affect ROP development, but its role in the pathogenesis of other ophthalmologic sequelae of preterm birth is unknown.

Recommendations:

- Lamps in the blue region of the spectrum (460-490 nm) are the most effective ones in treating hyperbilirubinemia.
- When using lamps for therapeutic purposes, limit the intensity of light source to the minimum required by the task and minimize exposure time.
- Avoid exposing the newborn infant's eyes to ultraviolet and infrared radiation through the use of appropriate lamps, lenses or filters.

CONCLUSIONS

Getting proper lighting in a NICU is a huge challenge. Apart from issues related to visual performance, cost, energy and aesthetics, the wide variety of biological needs of patients, health care providers and family members must be addressed.

A growing body of knowledge has been developed around the positive and/or negative effects of environmental factors on newborn infants, grouped in a relatively recent disciplinary field: environmental neonatology. However, there is less availability of guidelines and recommendations for the practical implementation of such scientific knowledge.

This update was based on several sources (legal, empirical, technical, scientific) to describe the current status of the visual environment in a NICU. Far from being comprehensive, this update is intended as a guide to rationally define lighting in hospital admission area without neglecting the patients, family members and providers' complex needs.

Lastly, this paper is thought of as a trigger to formulate, through discussion and consensus,

a framework of legal and regulatory reference in our own country, according to development-centered neonatal care principles. A safe and bright environment that fosters the newborn infant's development requires low-tech and little economic investment (compared to the NICU equipment) but high performance interventions when considering the benefits to newborn infants described herein. n

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ANNEX

Methodology

A background search was conducted, comprising applicable Argentine laws (mandatory) and regulations (optional), international acts and standards, professional association guidelines, postgraduate theses, technical and academic reports, and peer-reviewed scientific articles. The search engine was Google Scholar, and the following key words and their combinations (in English) were used: NICU, hospital, healthcare, lighting, natural light, developmental care, environmental factors, human factors, environmental neonatology, standards, guidelines, checklist, design, preterm, jaundice, blue light hazard. And, in Spanish: UCIN, hospital, iluminación, luz natural, cuidado centrado en el desarrollo, maternidad centrada en la familia, neonatología ambiental, estándares, guías, lista de chequeo, diseño, prematuros, ictericia neonatal. A time filter was applied for the search of bibliography published between 1990 and 2015. An initial search and the critical review of documents resulted in the identification of key authors and publications; papers prior to the selected period were included in the reference material based on their relevance in terms of originality and impact. As a result, 70 technical and scientific documents were added to the corpus, serving as the basis of this update.