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Seasonal Mapping of NICU Temperature Study conducted at the University of Washington Medical Center

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Abstract

Purpose—To create a thermal map of ambient air, radiant, and evaporative temperatures and humidity throughout the NICU nursery by season across a calendar year.

Subjects—Each of the 32 bed cubicles distributed in five rooms in a Level III nursery was measured.

Methods—Temperatures were recorded at a consistent time on one day during January, April, July, and October.

Main outcome measures—An electronic monitor (QUESTemp° 34, Quest Technologies, Oconomowoc, WI) was used to measure dry bulb, wet bulb, and globe thermometer temperatures.

Results—ANOVA revealed statistically significant ($p < .000$) differences in season, room, and season by room interaction. Room ambient air temperatures differed $< 2^{\circ}\text{F}$ across season. Radiant temperature paralleled air temperature. Humidity, the predominant difference across season, produced evaporative temperatures considerably lower than room air temperature, and the gradient between mean nursery dry bulb and wet bulb temperature was 9.3°F in summer and 16.8°F in winter.

Conclusions—The thermal map revealed seasonal thermal differences, particularly in humidity level and evaporative temperature. Room temperature alone does not reflect the total thermal environment. Recommendations include periodic assessment of nurseries including air, evaporative, and radiant temperatures as well as humidity to more fully appreciate the impact of the thermal environment on infants.

Keywords

nursery; thermal environment; humidity; evaporation

Introduction

The thermal needs of preterm and high risk infants are well documented^{1–4}. The neonatal intensive care unit (NICU) thermal environment must support two diverse populations, thermally fragile infants and mature adults including caregivers, parents, and other support personnel. To accommodate the thermal capabilities of these two groups specialized equipment, such as incubators and radiant warmers, are used to create a micro-environment suited to the thermoregulatory capacity of preterm infants while maintaining room temperatures supporting adult thermal comfort. A substantial amount of information informs thermal care of preterm and high risk infants, however there is limited attention paid to the thermal characteristics of the NICU itself. Nurses in our NICU raised concerns about variability of room temperature, particularly in relation to seasonal outdoor temperature and weather conditions. The purpose of this clinical research was to examine the NICU thermal environment throughout a calendar year. Specific aims of the project included: (1) Thermal mapping of the NICU, conducted in each of four seasons (winter, spring, summer, and autumn) that involved measurement of evaporative and radiation effects in addition to ambient air temperature, (2) Description of thermal characteristics of the NICU, and (3) Comparison of NICU temperatures by season.

Thermal care is central to reducing morbidity and mortality among preterm and high risk infants. Management of the thermal environment is a primary nursing activity. In addition to the use of incubators and radiant warmers, a number of thermal aids, such as plastic wrap, insulated hats, and heated gel pads, represent an array of interventions to maintain infants within a thermal neutral zone^{1, 3, 5}. Although incubators and radiant warmers are powerful tools, infants remain susceptible to influences of the NICU room environment⁵. Radiant warmers apply radiant energy and typically are the only devices that directly warm the infant. Although radiant warmers increase heat gain by radiation, the infant under a radiant warmer experiences heat loss from conduction, convection and evaporation. Incubators act to decrease heat loss by convection rather than directly heating the infant (unless incubator air temperature is higher than body temperature). Infants in incubators lose heat via conduction, convection, evaporation, and radiation. Whether a radiant warmer or incubator is used, the room thermal environment directly influences these forms of infant heat loss.

Standards for NICU thermal environment specify $72\text{--}76^{\circ}\text{F}$ ($22\text{--}26^{\circ}\text{C}$) as acceptable range for air temperature and relative humidity at $30\text{--}60\%$ ⁶. Typically monitoring of NICU thermal environment involves only these two factors. Although both temperature and

humidity are important the two measures do not provide a complete picture of the thermal environment particularly as it relates to thermally challenged preterm and high risk infants.

While the four channels of heat flux - convection, radiation, evaporation, and conduction - are highly interrelated, particular thermal measures are reflective of particular forms of heat flux. Convection, the transfer of heat between a solid surface and the air, is directly related to room temperature. Ambient air temperature is measured using a dry bulb thermometer and is synonymous with what is typically thought of as room temperature. Cool nursery air temperature promotes infant convective heat loss.

The effect of evaporation can be assessed using a wet bulb thermometer which is basically a thermometer covered by a wet fabric sleeve. Evaporation from the wet surface causes heat loss, reducing the temperature reading. The amount of evaporation and hence the difference between dry bulb and web bulb temperature is directly related to room humidity. Relative humidity is expressed as a percentage and is the ratio of water vapor in the air compared to the highest amount of vapor that could be obtained at a particular temperature. Given the nature of preterm infant immature skin, evaporation is a critical concern as fluid loss and heat loss are accentuated by limited keratinization of the epithelial surface ^{7, 8}.

A globe thermometer measures radiant temperature. The globe thermometer involves a black copper (or other highly conductive metal) ball surrounding a thermometer or thermal sensing device. Radiation is the exchange of electromagnetic energy or heat between two solid surfaces not in direct contact. The black copper ball is heated or cooled by this exchange of radiant energy with surrounding solid surfaces in the room. In direct sunshine, the globe thermometer temperature will be warmer than that of surrounding air due to radiant heat gain. Similarly when surrounded by cool solid surfaces the globe thermometer temperature will be lower than air temperature due to radiant heat loss. Radiation is a particular concern for preterm infants in incubators as the infant's body radiates heat to the incubator walls and the incubator walls in turn radiate heat to surrounding solid surfaces and heat is also exchanged between incubator exterior wall and surrounding air by convection.

Conduction is the transfer of heat between two solid objects in contact with one another. In the NICU cool surfaces, such as bedding or weight scale, increase infant heat loss. Solid surface temperatures, which could be directly monitored with temperature probes, are altered by the effects of convection and radiation within the nursery room.

Methods

Design

A repeated measure descriptive and exploratory design was used to map the thermal environment of the Level III NICU located in Seattle, WA. Thermal measurements were conducted in each patient care cubicle throughout a year period with measurements recorded on one day in each of four seasons (January, April, July, October).

Setting

The 32 bed NICU, constructed in 1980, is arranged into five rooms (5 to 7 beds per room). Floor space of the NICU is roughly 8,000 square feet, with 3,200 square feet designated for patients. This averages approximately 100 square feet per patient. Rooms 1, 2, and 3 are contiguous as are Rooms 4 and 5 with open doorways adjoining the rooms. A wall of windows is oriented to the east in Rooms 1, 2, and 3, and a wall of windows oriented to the west in Rooms 4 and 5. In each room the windows are approximately 32 inches from the floor and extend the entire length of the room. Windows are double pane glass with adjustable mini blinds inserted between the glass layers. The open room design includes

half-wall partitions, approximately 54 inches high and extending approximately 59 inches from the surrounding wall that divide the room into patient care cubicles. The unit is staffed by 90 nurses and median daily census is 29.

The heating and cooling system includes wall mounted forced air heating units and overhead forced air vents. Air flow in patient care areas is controlled by a dedicated fan system that utilizes 100% outside air with temperature regulated to specified setting. Air change occurs at a rate of 12 room exchanges per hour.

Instruments

The NICU was assessed using a thermal environment monitor (QUESTemp[®] 34, Quest Technologies, Oconomowoc, WI) which incorporates dry bulb, wet bulb, and black globe thermometers as well as measurement of relative humidity and calculation of heat index. The thermal monitor provided a calculation of wet bulb globe thermometer temperature (WBGT) index, a weighted combination of evaporation and radiation effects as well as heat index. Heat index incorporates humidity and ambient air temperature and provides a measure of how the thermal environment “feels” to a typical adult (e.g., high humidity increases discomfort at high air temperature). The thermal environment monitor has an operating range of −5 to 100 °C and provided temperature accuracy of + 0.5 °C and humidity accuracy of ± 5%. Resolution was 0.1 °C and 1% humidity.

Procedure

On the day of recording, thermal monitors were placed in predetermined (and replicated) locations within each cubicle and allowed to stabilize. Values for temperatures and humidity were visually read from the monitor display screen and hand entered into a data collection form. Readings were obtained twice within a minute period, and averaged if different, a condition that occurred rarely. Recordings were performed at a similar time of day across the four seasonal assessments.

Results

Daily outdoor high and low temperature (F), obtained from the National Weather Service for the Seattle area were as follows: Summer, 59°, 78°; Autumn, 45°, 54°; Winter, 24°, 42°; Spring, 35°, 49°. Mean values for dry bulb, wet bulb, and globe thermometers along with combined wet bulb globe temperature are illustrated in Figure 1. Dry bulb and globe temperatures were warmest in winter and lowest in spring and summer. Wet bulb temperature (and hence combined WBGT) was lowest in winter and highest in summer. Using multivariate repeated measure ANOVA there were statistically significant season, room, and season by room interaction effects (season $F = 2614.44$ (15,13) $p < .000$; room $F = 2.089$ (20,104) $p = 0.009$; room by season interaction $F = 3.914$ (60,64), $p < .000$). Differences in room temperatures were < 2 °F. Univariate tests showed significant differences by season ($p < .000$) in dry, wet, globe, and WBGT temperature as well as humidity. Figure 2 illustrates the pronounced effect of humidity by season as well as wide variability of air temperature in winter compared to low variability in summer. The gradient between mean nursery dry bulb and wet bulb temperature was 9.3 °F in summer and 16.8 °F in winter.

Discussion and Conclusion

Temperatures and humidity differed both by season and nursery room. Differences between rooms were likely due to effects of external windows, air flow, and variation in the heating and cooling system. Although room temperatures differed somewhat, all nursery rooms

exhibited the same general trends in seasonal effects. Previous research has illustrated daily and weekly rhythm in NICU temperature⁹. While room air temperatures themselves were generally within the recommended range of 72–76 °F, the wet bulb thermometer temperatures indicate substantial cooling due to evaporation. Limitations of the project include measurement restricted to four days throughout the year and standardized to a consistent time of day. However the failure to identify outlying values and similarity of measures within time of measure suggest that the measurement strategy provided a reasonable picture of the thermal environment.

In summary, multi-room NICU presents a complex thermal environment. Dry bulb or ambient room temperature alone does not depict overall effects of convection, conduction, radiation, and evaporation. Room temperature is not consistent throughout the NICU. Outdoor temperature and humidity are seasonally dependent and influence heating and cooling in the NICU producing variation throughout the year. The effect of humidity on potential for evaporative heat loss is clearly evident. The findings from this descriptive study of one NICU suggest the need for nurses to more closely monitor room thermal characteristics. Practice suggestions include routine use of a thermal monitor to expand ongoing measurement to include dry bulb, wet bulb, and globe radiant temperatures. Additionally the NICU thermal environment should be assessed periodically throughout the year. Findings from such assessment may suggest modification of ambient air temperature and/or changes in room humidification level. Further adjustments may include use of draperies over exterior windows, positioning of incubators in relation to air vents, and augmenting incubator humidity.

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Figure 1.
Mean nursery dry bulb, wet bulb, radiant, and wet-bulb-globe thermometer temperatures by season (95% CI).