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Optimal Body Temperature in Transitional ELBW Infants Using Heart Rate and Temperature as Indicators

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Abstract

Extremely low birth weight (ELBW) infants are vulnerable to cold stress after birth. Therefore, caregivers need to control body temperature optimally to minimize energy expenditure.

Objective—We explored body temperature in relationship to heart rate in ELBW infants during their first 12 hours to help identify the ideal set point for incubator control of body temperature.

Design—Within subject, multiple-case design.

Setting—A tertiary NICU in North Carolina.

Participants—10 infants, born less than 29 weeks gestation and weighing 400-1000 grams.

Methods—Heart rate and abdominal body temperature were measured at 1-minute intervals for 12 hours. Heart rates were considered normal if they were between the 25th and 75th percentile for each infant.

Results—Abdominal temperatures were low throughout the 12-hour study period (mean 35.17° C-36.68° C). Seven of ten infants had significant correlations between abdominal temperature and heart rate. Heart rates above the 75th percentile were associated with low and high abdominal temperatures; heart rates less than the 25th percentile were associated with very low abdominal temperatures. The extent to which abdominal temperature was abnormally low was related the extent to which the heart rate trended away from normal in six of the ten infants. Optimal temperature control point that maximized normal heart rate observations for each infant was between 36.8° C and 37° C.

Conclusions—Hypothermia was associated with abnormal heart rates in transitional ELBW infants. We suggest nurses set incubator servo between 36.8° C and 36.9° C to optimally control body temperature for ELBW infants.

Keywords

neonatal; thermoregulation; body temperature; heart rate; hypothermia; ELBW infants; preterm infants

Extremely low birth weight (ELBW) infants (less than 1000 grams at birth and usually with a corresponding gestational age of 23-28 weeks) are exposed to many medical and nursing procedures from delivery, stabilization and admission procedures on their first day of life. These infants are likely to become hypothermic with central temperatures as low as 33° C (Bhatt et al., 2007; Horns, 2002; Kent & Williams, 2008; Knobel & Holditch-Davis, 2007; Knobel, Wimmer, & Holbert, 2005; Lee, Ho, & Rhine, 2008; Mathew, Lakshminrusimha, Cominsky, Schroder, & Carrion, 2007). Preterm ELBW infants have little to no ability to generate heat by non-shivering thermogenesis due to immature systems (Houstek et al., 1993). Because ELBW infants can not generate their own heat, their temperatures will continue to fall unless they are warmed. Hypothermia in premature infants continues to be associated with increased morbidity and mortality (Basu, Rathore, & Bhatia, 2008; Bauer, Hentschel, Zahradnik, Karck, & Linderkamp, 2003). Knowing the control point to set the incubator servo control for optimal skin temperature for this population will minimize stress to the other body systems related to hypothermia.

Hypothermia

Early research established that hypothermia is harmful to premature infants. (Day, Caliguiri, Kamenski, & Ehrlich, 1964; Silverman, Fertig, & Berger, 1958). Later studies have continued to link hypothermia with increased mortality and morbidity in premature infants (Basu et al., 2008; Bauer et al., 2003; Hazan, Maag, & Chessex, 1991; Vohra, Frent, Campbell, Abbott, & Whyte, 1999), as well as brain hemorrhage in ELBW infants (Dincsoy, Siddiq, & Kim, 1990; Gleisner, Jorch, & Avenarius, 2000; McLendon et al., 2003; Osborn, Evans, & Kluckow, 2003). Hypothermia has also been associated with a fall in systemic arterial pressure, a decrease in plasma volume, decreased cardiac output, increased peripheral resistance, and metabolic acidosis (Sinclair, 1992). As body temperatures decrease, heart rate may increase above mean initially, but eventually heart rate will decrease. Once the body temperature falls below 34° C, cardiac output reduces due to bradycardia (Deussen, 2007).

Historical and Current Thermal Recommendations for Neonates

Finding the optimal body temperature for premature infants has long been a subject of research with studies in the 1950's and 1960's determining that premature infants with a body temperature of 36°C or greater for the first 96 hours had a greater chance of surviving (Buetow & Klein, 1964). Early research determined infants heated to maintain an abdominal temperature of 36° C had lower mortality than infants given constant environmental heat at 31.8° C (Day et al., 1964). This early research was done with premature infants of 30-36 weeks gestational age, as ELBW infants rarely survived. Infants in these early studies were not treated with mechanical ventilation, which complicates comparing the mortality findings associated with hypothermia to physiological outcomes associated with thermoregulation in premature infants today.

More recent researchers found that abdominal temperatures of at least 36.5° C, rather than lower temperatures, kept oxygen consumption to a minimum for preterm infants (Malin & Baumgart, 1987). Meyer et al. (2001) also found maintaining abdominal temperatures at a target of at least 36.8° C was easier under a radiant warmer than in an incubator during the first 24 hours of life.

Transeipermal water loss in infants is known to be inversely correlated with gestational age (Hammarlund & Sedin, 1979) and is a major route for heat loss in premature infants. Studies have led to interventions to decrease evaporative water loss. Prior to NICU admission, ELBW infants are routinely placed in plastic wrap or bags, after birth and while still wet with amniotic fluid to prevent heat loss from evaporation (Knobel et al., 2005; McCall,

Alderdice, Halliday, Jenkins, & Vohra, 2008). Additionally, studies have shown that heat loss in premature infants is decreased when relative humidity inside the incubator is greater than 50% (Bell, 1983; Lyon & Oxley, 2001).

These studies led to valuable changes to the thermal care of preterm infants. ELBW infants are placed in plastic wrap or bags in the delivery room to prevent heat loss prior to NICU admission. Once in the NICU, incubators are routinely used to keep ELBW infants surrounded in a warm, humid environment to maintain a warm body temperature and decrease evaporative heat loss. Incubators can control an infant's temperature by body temperature feedback from a thermistor which is attached to the infant's skin. The incubator has a computerized servo control that allows the care provider to set the control point for the infant's skin temperature; the heat flow in the incubator will increase or decrease in order to achieve the skin temperature set point. Although most NICU's have guidelines specifying the temperature to set the servo control, there is no empirical evidence on which to base these guidelines because little to no research has examined optimal set points for infants less than 29 weeks gestation.

Thermoneutrality is the state where an infant is at normal body temperature and oxygen consumption related to heat production is minimal (Sauer, Dane, & Visser, 1984). A neutral thermal environment is the environment that keeps an infant in a state of thermoneutrality. A nursing text book recommends an environmental temperature range between 34°-35°C for preterm infants at 30 weeks gestation and temperatures higher for more immature infants but no specific one given (Blackburn, 2007). Specific servo control points for skin temperature may vary with gestation since the ability to generate heat through non-shivering thermogenesis is dependent on gestational age (Houstek et al., 1993). Research is needed to determine skin temperature control points and environmental temperature needed for ELBW infants less than 29 weeks gestation.

Body Temperature and Heart Rate

Examining heart rate in relation to body temperature may help develop thermal guidelines for ELBW infants. From about 32-34 weeks gestational age to 1 year after birth, non-shivering thermogenesis (NST) is the primary method of heat production for infants (Hull & Smales, 1978). When an infant becomes cold, signals from the brain trigger sympathetic release of norepinephrine in the brown fat resulting in NST or metabolic heat production. NST is accomplished through oxidation of fatty acids in the brown fat through conversion of thyroxine (T4) to triiodothyronine (T3) by type II iodothyronine 5'-deiodinase, enabling thermogenin to enhance heat production (Nedergaard et al., 2001). Although the structure of brown fat is well developed in ELBW infants, the content of thermogenin and 5'-deiodinase is low until 32 weeks gestation, causing inefficient heat production (Houstek et al., 1993; Sauer, 1995). Additionally, ELBW infants are unable to conserve heat centrally due to inefficient peripheral vasoconstriction, which may prevent warm body temperature (Knobel, Holditch-Davis, Schwartz, & Wimmer, 2009; Lyon, Pikaar, Badger, & McIntosh, 1997).

Although the relationship of decreases in body temperature to heart rate has not been well studied, decreases in infant body temperature should lead, at least initially, to increased heart rate from the release of norepinephrine (Anderson, Kleinman, Lister, & Talner, 1998). Cooling of the sheep fetus in utero and outside the uterus has been shown to increase heart rate, blood pressure and norepinephrine concentration, consistent with sympathoexcitation (Van Bel, Roman, Iwamoto, & Rudolph, 1993). Therefore, cold body temperature or hypothermia should lead to increased heart rate initially as infants attempt to generate heat by NST.

Normal heart rate in premature infants can range anywhere from 100-200 beats per minute (Walsh, 1964). Heart rate averages vary depending on weight (Williams, Sanderson, Lai, Selwyn, & Lasky, 2009) and with gestation (Gagnon, Campbell, Hunse, & Patrick, 1987). Because heart rate may increase in relationship to body temperature, it is important to examine heart rate within the individual infant and look at changes from infant baseline.

The purpose of this study, therefore, was to examine the relationship between body temperature and heart rate in preterm ELBW infants over their first 12 hours of life in the NICU as a first step in determining the optimal body temperature for ELBW infants. Duration for data collection was set at 12 hours to encompass infant transition time from birth through NICU stabilization, which can range from 1 to several hours while the infant has umbilical lines inserted, placed on the ventilator, given surfactant, and follow-up radiographs are taken. Twelve hours were studied so that we would have several hours of stability after all procedures to allow for physiologic systems and temperature to normalize. Ten infants were examined first as case studies, within infants and then all infants were compared between subjects descriptively to provide evidence for future research. Specifically we addressed: 1) the relationship between central (abdominal) temperature and heart rate during the transition period (first 12 hours of life) within individual infants born weighing 400-1000 grams, 2) whether the relationships between temperature and heart rate were similar over infants, and 3) what the optimal abdominal temperature range was for each individual infant in which heart rate was most stable.

To explore the relationship between heart rate and body temperature for each infant, we correlated heart rate and body temperature and analyzed whether there were more normal heart rate observations above or below the hypothermic level of 36.4° C (American Academy of Pediatrics & College of Obstetrics and Gynecologists, 1988). We used 36.4° C for hypothermia because the American Academy of Pediatrics specified this temperature as the cut off point for hypothermia in infants in their 1988 guidelines. To help determine optimal body temperature, we examined heart rate in relationship to body temperature. Because normal heart rate specified in textbooks for neonates is quoted with a wide range, 100-200 beats per minute, (Walsh, 1964) and because each infant is so different, we defined normal heart rate for each infant as the 25th to 75th percentile for that infant from all the heart rate observations over the 12-hours of the study period. We defined abnormal heart rate as those observations below the 25th percentile or above the 75th percentile.

Methods

Sample and Setting

After approval by the Institutional Review Board, a multiple case, within-subject design was used to explore the relationships between body temperature and heart rate in 10 ELBW infants over their first 12 hours in the NICU in a hospital in North Carolina. This study was part of a larger study of thermoregulation in ELBW infants (Knobel & Holditch-Davis, 2007; Knobel et al., 2009). Sample size was set at 10 in order to have a sample large enough to include various weights, genders, and races of ELBW infants while maintaining a small enough sample to permit detailed within-subject analyses. Infants were included if they had a birth weight between 400-1000 grams and a gestational age between 23-28 6/7 weeks by obstetrical service dates recorded in the chart. These dates were routinely determined by ultrasound when available or prenatal obstetrical dating when no ultrasound was available.

Procedures

Consent was obtained from mothers admitted for preterm labor. Study enrollment began once infants were admitted to the NICU. Premature infants at this hospital were placed in

polyurethane bags (Knobel et al., 2005) upon delivery, resuscitated according to Neonatal Resuscitation Program standards, and then transported to the NICU under warm blankets. Each infant was placed on a Giraffe radiant warmer (GE Healthcare) equipped with a computerized heat control system set on manual at maximum heat output prior to admission. Once the infant was placed on the warmer, the infant was then servo controlled at a body temperature of 36.5° C, which was this NICU's standard. The warmer converted to an incubator after placement of umbilical lines, and humidity was added and maintained between 60-80% (this NICU's standard). Gestational age was obtained from the last fetal ultrasound or by dates estimate from the obstetrical record. Most of the time, Ballard estimates were not done on these infants at this hospital because every effort was made to give these fragile infants as little stimulation as possible during their first 12-hours of life. Dubowitz and Ballard examinations have been found to only be accurate within ± 2 weeks of gestational age in infants less than 1500 grams (Sanders et al., 1991). Therefore, in this study, weights were used as an approximate estimate of maturity and it was difficult to determine if the infants were appropriate for gestational age without accurate dating. Infants were weighed on a scale on the bed and enrolled if less than 1000 grams and less than 29 weeks gestation. Data collection began after weight was confirmed, and temperature probes and cardiopulmonary leads were attached, typically by 1 hour of age. A data collector sat at each bedside and observed the temperature probes to make sure they were securely attached throughout the study.

Instruments

Central temperature was measured using the abdominal temperature by a thermistor (Steri Probe®, Cincinnati Sub-Zero Products, OH). When the thermistor or temperature probe is covered by reflective tape on the abdomen, the measurement provides a temperature close to deep tissue measurement and approaches core due to near zero heat flux (Simbrunner, 1995). The abdominal thermistor was positioned in the key-hole opening of DuoDerm® placed on the infants' skin in order to secure the research thermistor and the NICU's normal incubator temperature probe which controlled each infant's body temperature. Each infant's nurse placed the research thermistor on the infant's left or right abdomen when they were attaching their standard temperature probe. The abdominal thermistor was attached to a Mini-Logger (Mini Mitter, Oregon) data logger, which sampled temperature to the nearest 0.1°C every minute continuously for 12 hours.

Heart rate was measured using a routine cardiopulmonary monitor, Spacelabs 90385 Clinical Workstation, through the EKG leads attached to each infant. These leads were attached by the infant's nurse as standard of care, and site of placement was dependent on infant's skin integrity; however, placement was on each side of the chest and one on the abdomen. Heart rate was recorded continuously and sampled at a rate of 12 samples per minute. Data was downloaded directly from the Spacelabs Monitor to a laptop computer through the datalogger option and using a hyperterminal communications program. Temperature data loggers were connected to a laptop and data downloaded after completion of data collection.

Analyses

Temperature and heart rate data were exported into Excel files (Microsoft®), then exported into SAS®, version 8 (Cary, NC) for analyses. Analyses were conducted within each infant using 720 measurements (one each minute for 12 hours) for each variable. Temperature and heart rate measurements were printed as trends over time and plotted curves were visually inspected for trends. Temperature and heart rate data were analyzed using descriptive statistics, simple linear regression and Pearson correlations using an alpha level of 0.05.

Results

Study sample

Table 1 shows the infant demographics, their mean abdominal (Tc) temperatures, and their normal heart rate ranges as determined by their inner 2nd and 3rd quartile range. Infants in this study averaged low abdominal temperatures throughout the 12-hour study period. Over the 12-hour study period, minimum abdominal temperatures for the 10 infants ranged from 29.0° to 34.0° C and their maximums ranged from 36.9° C to 38.3° C. Mean abdominal temperatures for all infants ranged from 35.2° to 36.7° C. Seven of 10 infants had a mean abdominal temperature for the study period less than the 36.4° C cut point for hypothermia as defined by the American Academy of Pediatrics (American Academy of Pediatrics & College of Obstetrics and Gynecologists, 1988). Six infants had hypothermic temperatures in more than 50% of their observations. Axillary temperature readings taken by the bedside nurse were recorded from the medical chart and ranged from 33.0°C to 37.7°C. These measurements were sporadic, with one to six measures per infant for the 12-hour data collection period and were not analyzed statistically with temperatures measured by thermistor.

The heart rate range was individual to each infant (see Table 1). Minimum heart rate for the 10 study infants ranged from 76 to 133. Maximum heart rate ranged from 164 to 194. The mean heart rates ranged from 127 to 166. Thus, at least one infant had a mean heart rate greater than the maximum heart rate of another and at least one infant had a mean heart rate lower than the minimum of another, showing the wide variation in heart rates.

Seven infants had significant correlations between heart rate and abdominal temperature at the $p < .05$ level ($r = -0.32$ to 0.72). Six infants showed positive correlations, but Infant “G” alone had a significant negative correlation ($r = -0.32$; see Figure 1) because most of the very low abdominal temperatures for this infant were associated with high heart rates and the high temperatures were associated with normal to low heart rates.

Infant “B” had the strongest correlation between heart rate and abdominal temperature ($r = 0.72$). This infant was a 680-gram 24-week infant who was unstable most of the 12 hours of the study and needed inotropic drugs, dopamine, dobutamine, and then epinephrine. Figure 2 shows the relationship between this infant’s abdominal temperature and heart rate. Heart rate tended to decline as temperatures decreased and increased as the infant’s temperatures increased. This infant was very unstable and did not compensate metabolically by raising his heart rate in response to low abdominal temperatures. Because the infant was colder during the first few hours of stabilization and became hypotensive as the study period progressed, inotropic drugs were added to his care. As the infant warmed over the study period, more and more inotropic intravenous infusions were given, with a side effect of an increased heart rate. Therefore, warmer abdominal temperatures appeared to be associated with higher heart rates, but, the inotropic infusions may have contributed to that association.

Hypothermia and Heart Rate

Analyses were conducted to determine at which temperature range ($>36.4^{\circ}$ C or 36.4° C) the heart rate for each infant was most stable, that is in the normal range. Chi square analyses were used to compare the proportions of observations in the normal (25th to 75th percentile) and abnormal heart rate range ($< 25^{\text{th}}$ or $> 75^{\text{th}}$ percentile) for each infant when their abdominal temperature was greater than 36.4° C and less than or equal to 36.4° C. Table 2 shows the results of these analyses. Six of the 10 study infants had a statistically significant larger percentage of observations in the normal heart rate range when

temperatures were above 36.4° C. Therefore, having a normothermic temperature was associated with normal heart rate in this sample.

Body Temperature and Abnormal Heart Rate

To examine the relationship between the extent to which the heart rate was above or below the normal range and that the abdominal temperatures were below the hypothermic level of 36.4°C, a Pearson correlation was calculated between the amount the abdominal temperature was below 36.4°C and the corresponding extent of abnormality (either above or below normal) in heart rate for each infant. For all abdominal temperature observations 36.4°C, extent of abnormality was defined as the difference of the observed temperature from 36.4°C. Extent of abnormality for heart rate was determined as the difference between the observed heart rate and the normal heart rate limits, determined by the corresponding 25th and 75th heart rate percentiles. Only observations in which both the temperatures and heart rate met the abnormal criteria were included in this analysis.

The number of 1-minute observations included in the Pearson correlation is indicated on Table 3, which also presents the results of the analyses. Six of 10 infants had significant positive correlations between the extent of abnormality in the abdominal temperatures and the extent of abnormality in the heart rate. One additional infant had a negative correlation ($r = -0.45$). Figure 3 shows the scatterplot of the infant, Infant B, with the strongest positive correlation ($r = .85$). As shown in Figure 3, as this infant's abdominal temperature decreased below the cut point of 36.4° C (0 point on the x-axis) until approximately 34.4°C, the infant's heart rate increased above the upper normal limit. Once the temperature decreased low enough (< 34.4°C), the heart rate decreased below the lower normal limit, most likely because the infant was unable to compensate for such a low temperature.

Four other infants (E, F, H, I) exhibited a pattern of heart rates below the normal limit being associated with temperatures decreased below approximately 34.5°C. Infant "A" had heart rates lower than the low normal limit for most temperatures less than 36.4°C. This infant was not able to increase her heart rate in association with hypothermia.

One infant, "G", had a significant negative correlation, $r = -0.45$. As this infant's abdominal temperature decreased further below 36.4°C, the heart rate increased above the upper limit of 147 for that infant. This infant appeared to be able to compensate well for low temperatures by increasing heart rate. The three remaining infants, (C, D, J), did not show a clear relationship between the heart rate data and abdominal temperatures 36.4°C.

Optimal Cut-point in Abdominal Temperature as Indicated By Heart Rate

Heart rate data were also used to determine whether there was an optimal cut-point in body temperature at which the number of abnormal heart rate observations was minimized and amount of normal heart rate observations was maximized. The percentage of heart rate observations at the below normal, normal, and above normal ranges was determined for each infant at different body temperatures. Then, percentage of heart rate observations within each heart rate level was plotted on the y-axis, and abdominal temperature observations were rounded to the nearest 10th degree and plotted on the x-axis for each infant. Percentages (see Table 4) and graphs (not shown) were examined. The optimal abdominal temperature range for infants in this study appears to be between 36.8°C and 36.9°C (see Table 4). In this range, observations for most infants were in the normal range (> 50% of observations for 8 of 10 infants) while minimizing heart rate observations in the below normal range and above normal range (< 25% of observations in 8 of 10 infants).

Discussion

ELBW infants were found to have high rates of hypothermia (body temperature < 36.4°C). Heart rate seemed to be a good indicator of cold stress. Abdominal temperature was significantly correlated with heart rate in 7 of 10 infants and the two infants who were most unstable had the strongest correlation between abdominal temperature and heart rate. Both of these infants received dopamine infusions and one also received dobutamine and epinephrine infusions. These inotropic medications increase blood pressure, improve cardiac stability, and improve cerebral perfusion (Pellicer et al., 2005). Dopamine has also been shown to release energy from brown fat in rats, which may increase heat production (Maxwell, Crompton, Smyth, & Harvey, 1985). Therefore, the two most unstable infants showed improvement in their abdominal temperature as they became more stable, corresponding with the passing of time in the study period and beginning inotropic infusions.

Inotropic infusions also cause heart rate to increase; however, dopamine does not cause as much of an increase as epinephrine (Heckmann, Trotter, Pohlandt, & Lindner, 2002; Pellicer et al., 2005). The infant who had the strongest correlation between abdominal temperature and heart rate received dopamine first, then dobutamine, and finally epinephrine. The exact relationship between abdominal temperature and heart rate is not known; however, we speculate the inotropic infusions improved blood pressure and cardiac stability in these two infants resulting in warmer abdominal temperature over the study period. Since an increase in heart rate is often seen with provider care and as a side effect of inotropic infusions, and lower abdominal temperatures were seen with provider care, (Mok, Bass, Ducker, & McIntosh, 1991) it would seem appropriate that heart rate and abdominal temperature would be strongly correlated. Future studies need to examine aspects of stability in ELBW infants while correlating abdominal temperature and heart rate. In this study, stability was not defined *a priori* and dividing the infants based on stability was not possible due to the small sample size.

In this study, 6 of 10 ELBW infants maintained their heart rate in their own normal range more often when their abdominal temperature was higher than 36.4°C, the American Academy of Pediatrics (1988) definition of hypothermia. Therefore, the abdominal temperature for ELBW infants should be at least 36.4°C. Not only did maintaining temperature above the hypothermic cut point help keep heart rate in the normal range for these infants, but decreasing the abdominal temperature further below the hypothermic cut point was associated with moving the heart rate further above or below the normal range. In seven infants, the extent of heart rate abnormality was significantly correlated with the extent to which the abdominal temperature decreased below the hypothermic point.

In this study five infants had higher heart rates in association with temperatures between 34.4°C and 36.4°C. Once abdominal temperature decreased below approximately 34.4°C, these five infants were unable to increase their heart rates further. Thus, there is a point at which ELBW infants are unable to compensate metabolically for extremely low temperatures and they start to deteriorate. Hypothermia has been associated with a fall in systemic arterial pressure, a decrease in plasma volume, decreased cardiac output, increased peripheral resistance, and metabolic acidosis (Sinclair, 1992). If this condition is left uncorrected, most likely death would ensue. No previous research has examined heart rate, hypothermia and mortality in ELBW infants, so further research on this topic is needed.

Study results also indicated that ELBW infants' abdominal temperatures should be kept higher than 36.4°C. Previous research was not specific as to the point at which normal temperature ends and hypothermia begins in the neonates. The American Academy of

Pediatrics specified hypothermia for neonates as 36.4°C in the 1988 guidelines but did not specify a hypothermic designation in subsequent guidelines (American Academy of Pediatrics & College of Obstetrics and Gynecologists, 1988). Researchers have defined hypothermic cut points as 35.0°C (Costeloe, Hennessy, Gibson, Marlow, & Wilkinson, 2000), 35.5°C (Thomas, 2003), 35.6°C (Bredemeyer, Reid, & Wallace, 2005) and 36.4°C (Knobel et al., 2005). Thus, there is no clear definition of hypothermia in ELBW infants.

We used the Academy of Pediatrics traditional hypothermia cut point of 36.4° C and found that 6 of 10 infants had normal heart rate observations when abdominal temperature was greater than 36.4°C. Six of ten infants had a significant correlation between the extent the abdominal temperature was below 36.4°C and the extent the heart rate was above or below the normal range. Therefore, a cut point of at least 36.4°C should define hypothermia for the ELBW infant. However, the cut point may need to be even higher.

Limitations

Because this study had an exploratory design and only 10 ELBW infants, it had several limitations. The results of this study should be generalized with caution beyond this sample because the study took place in one particular NICU with the care for each ELBW infant under this NICU's standard management protocols. Additionally, this small sample did not include a large number of gender, weight, gestation and ethnic combinations. Thus we were not able to determine the effects of demographic variations in birth weight and gestation for the ELBW infant population. The methods of this study were exploratory and therefore the study needs to be replicated with a larger population of ELBW infants.

Using temperature probes on the skin of ELBW infants also led to limitations. Because the data collector was unable to touch the infant periodically, ascertaining if the temperature probe was adhering closely to the skin was difficult. The skin of the newly born ELBW infants is usually gelatinous and thin. Additionally, humidity was added to the incubators. The skin probe was covered by a reflective cover. Because the skin was wet from the humidity and was immature, adhesive did not adhere well. Occasionally, skin probes lifted off the skin and may have registered air temperature instead of skin temperature. Air temperature was usually at maximum output capability of the incubator and as high as 39.5°C. Using a thermistor to measure temperature only allows precise measurement of that one particular area of the skin, which is not necessarily equal to the surrounding areas of the skin. In our future studies, we will employ thermal imaging with infrared to measure large areas of skin surface simultaneously.

Implications for Nursing Practice

The traditional cut point of hypothermia (36.4°C) may not be enough to minimize abnormalities in heart rate. This study found the optimal abdominal temperature to minimize abnormal heart rates and maximize normal heart rates in ELBW infants was between 36.8°C and 36.9°C. Based on early research with infants approximately 29 weeks gestation, current standard of care is that servo control for abdominal temperature in ELBW infants be set at 36.5° C (Sauer et al., 1984). However, our findings indicate that the range should be higher. In the current study, heart rate increased above each infant's 75th percentile when abdominal temperature decreased to between 34.4°-36.4°C range and heart rate decreased below the 25th percentile when abdominal temperature decreased lower than approximately 34.4°C. Therefore, nurses need to set the servo control between 36.8°-36.9° C for ELBW infants during their first few days of life. Because hypothermia is prevalent during the first 12-hours of life when stabilization procedures take place for ELBW infants, nurses should take care to monitor body temperature and heart rate closely, to prevent decreases in body temperature and abnormally high or low heart rates.

Keeping the heart rate of an ELBW infant in a normal range is important to maintain cardiac output and minimize increased or low cardiac output (Guyton, 1968). Many infants did not reach the normal heart rate range until the end of the study period. The first several hours were associated with low abdominal temperatures, and many heart rate fluctuations from normal. Nurses need to be aware that low and high heart rates may be a sign of cold stress during the initial stabilization hours. Temperature is usually not monitored continuously during procedures, but cardiopulmonary monitors can display continuous heart rate, allowing nurses to monitor heart rate. Abnormal heart rate trends are a good indicator of cold stress, allowing the nurse to know when to check the infant's temperature and intervene.

Previous researchers have found that ELBW infants exhibited extremely low temperatures during the first few hours of life, and this current study confirms that this problem still exists (Bhatt et al., 2007; Costeloe et al., 2000; Horns, 2002; Kent & Williams, 2008; Lyon et al., 1997; Mathew et al., 2007). Thus all nursing and medical care providers need to be cognizant of the ELBW infants' inability to generate heat when exposed to cold temperatures and the propensity of these infants to develop extremely low temperatures during stabilization procedures. Abdominal temperature should be controlled minimally at 36.5°C and results of the current study suggest the control point should be between 36.8° and 39.9°C.

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Callouts

1. Premature infants can become hypothermic during stabilization procedures.
2. Examining heart rate in relation to body temperature may help develop thermal guidelines for ELBW infants.
3. Nurses should set incubator servo temperature to control abdominal temperature between 36.8° C and 36.9° C to minimize energy expenditure and optimally control body temperature for ELBW infants.

Figure 1. Scatterplot with Regression Line of Heart Rate and Abdominal Temperature for Infant G

Note: 25th percentile < 134; Normal = 135-146; 75th percentile > 147

Figure 2. Scatterplot with Regression Line of Heart Rate and Abdominal Temperature for Infant B

Figure 3. Scatterplot with Regression Line of Observations of Abdominal Temperature 36.4° C with Corresponding Abdominal Heart Rate Observations for Infant B

Table 1
Infant Demographic Characteristics and the 25th and 75th Percentile for Heart Rate for Each Infant

Infant	Gen	Race	GA	Weight in grams	PNC	Del Mode	Apgar Scores	Tc mean	Tc SD	25 th percentile HR	75 th percentile HR
A	F	AA	25	630	Y	CS	1,5,7	36,68	0,71	135	142
B	M	AA	24	680	N	Vag	1,7	36,05	1,25	162	173
C	F	C	25	550	Y	CS	1,2,6	35,51	2,03	121	132
D	M	AA	26	880	N	Vag	8,8	36,23	0,94	156	166
E	F	C	25	720	Y	CS	4,7	35,28	0,99	160	173
F	F	AA	25	670	Y	Vag	2,4,6	35,17	1,33	134	143
G	F	C	26	510	Y	CS	4,8	35,79	0,88	134	147
H	M	AA	25	710	N	Vag	1,5,7	36,44	1,17	139	147
I	M	C	24	590	?	CS	2,6	35,61	1,3	122	135
J	F	AA	26	960	Y	Vag	4,5	36,6	0,34	134	145

Note. Gen= Gender; GA= Gestational Age; PNC= Prenatal Care- Yes or No; Del Mode= Delivery Mode; Tc= Central (Abdominal) Temperature; HR= Heart Rate in beats per minute; ?= information not available.

Table 2
Percentage of Observations in the Normal Heart Rate Range for Hypothermic and Normothermic Temperatures for Study Infants

Subject	Percentage of Observations in Normal Heart Rate Range		Chi square
	> 36.4°C	36.4°C	df=1
A	69.9	41.5	40.78*
B	64.1	28.4	77.91*
C	59.9	55.7	1.23
D	52.9	54.5	0.16
E	44.7	50.8	0.65
F	68.8	48.8	20.90*
G	77.9	43.4	52.78*
H	66.6	30.9	73.10*
I	65.3	46	27.45*
J	51.3	56.4	1.19

* $p < .05$ for chi square of proportion of observations in the normal heart rate range comparing observations at abdominal temperature > 36.4° C and 36.4° C

Table 3
Pearson Correlations of the Extent of Abnormality of Abdominal Temperature¹ and the
Extent of Abnormality of Heart Rate²

Subject	n	r value
A	100	0.26*
B	156	0.85*
C	201	0.02
D	171	0.09
E	239	0.27*
F	260	0.35*
G	334	-0.45*
H	134	0.57*
I	215	0.33*
J	65	-0.01

Note: n = number of 1-minute periods with abnormal temperatures and abnormal heart rates.

*
p < .05

¹ Extent of abnormality in abdominal temperature equals how far the temperature fell below 36.4° C.

² Extent of abnormality in heart rate equals how far the heart rate was below the 25th and above the 75th percentile.

Table 4
Percentage of Observations in the Below Normal, Normal, and Above Normal Heart Rate Percentages of Heart Rate Observations at Different Abdominal Temperatures for each Infant

Infants												
Temperature Level	Heart Rate Level	A	B	C	D	E	F	G	H	I	J	Mean
36.5°	Below Normal	16.7	26.2	42.9	16.7	0	0	7.8	0	0	16	12.7
	Normal	66.7	57.1	57.1	66.7	50	53.3	72.6	73.7	76.1	62	63.6
	Above Normal	16.7	16.7	0	16.7	50	46.7	19.6	26.3	23.9	21	23.8
36.6°	Below Normal	20	22.7	33.3	0	0	0	0	16.7	1.7	27	12.1
	Normal	65	66.3	61.9	60	0	80	100	58.3	48.8	41	58.1
	Above Normal	15	11	4.8	40	100	20	0	25	49.6	33	29.8
36.7°	Below Normal	9.1	9.1	23.1	50	0	0	0	37.5	0	36	16.5
	Normal	72.7	87.9	69.2	0	46.7	0	100	50	75	54	55.5
	Above Normal	18.2	3	7.7	50	53.3	100	0	12.5	25	10	28
36.8°	Below Normal	16.7	3	32	0	0	0	0	22	2.4	31	10.8
	Normal	70	67.3	68	82.4	25	100	100	68.3	75	49	70.5
	Above Normal	13.3	29.7	0	17.7	75	0	0	9.8	22.6	20	18.8
36.9°	Below Normal	0	1.5	61.1	0	10	0	0	15.2	0	18	10.6
	Normal	82.8	40.6	33.3	80	90	83.3	100	68.2	80	55	71.3
	Above Normal	17.3	58	5.6	20	0	16.7	0	16.7	20	27	18.2
37.0°	Below Normal	2.4	0	34.8	13.3	0	12.8	0	9	0	16	8.8
	Normal	68.3	70.6	30.4	80	0	85.1	100	74.4	0	42	55.1
	Above Normal	29.3	29.4	34.8	6.7	0	2.1	0	16.7	0	42	16.1

Note: Heart rate levels: Below Normal= <25th Percentile; Normal = 25th Percentile; Above Normal = > 25th Percentile