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## Extremely Low Birth Weight Preterm Infants Lack Vasomotor Response in Relationship to Cold Body Temperatures at Birth

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### Abstract

**Objective**—This study evaluated peripheral vasoconstriction in ELBW infants when body temperature decreased during the first 12-hours of life.

**Design**—An exploratory, within-subjects design with 10 ELBW infants. Abdominal and foot temperatures were measured every minute. Peripheral vasoconstriction (abdominal > peripheral temperature by 2° C) and abdominal-peripheral temperature difference were also evaluated.

**Results**—Abdominal and peripheral temperatures were significantly correlated within each infant. One 880 g infant exhibited isolated peripheral vasoconstriction; a 960 g infant had abdominal temperatures more than 1° C higher than peripheral temperatures. Eight smaller infants exhibited no peripheral vasoconstriction and spent most of their observations with peripheral greater than abdominal temperatures. In 8 infants, mean temperature difference was significantly higher when abdominal temperature was less than 36.5° C.

**Conclusion**—Most ELBW infants did not exhibit peripheral vasoconstriction during their first 12-hours of life, despite low temperatures. ELBW infants' vasomotor control may be immature during this period.

### Keywords

neonatal thermoregulation; hypothermia; vasoconstriction

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## Introduction

Extremely low birth weight (ELBW) infants are likely to become hypothermic with central temperatures as low as 33° C<sup>1,2</sup> necessitating constant nursing and medical attention to thermoregulation. ELBW infants (400–1000 grams at birth and usually with a corresponding gestational age of 23–28 weeks) are exposed to many stabilization procedures and cool room temperatures, cold infusions, and cold drapes from birth through the first 12 hours of life. Because ELBW infants are similar to poikilothermic (cold-blooded) animals; their temperatures will continue to fall unless caregivers intervene to warm them. Without the ability to generate heat, these infants can experience morbidity and mortality from such low body temperatures.<sup>3–6</sup>

Non-shivering thermogenesis (NST) is the primary method of heat production for the infant up to 1 year of age.<sup>7</sup> However, ELBW infants have little to no ability to generate heat by NST due to immature systems.<sup>8</sup> Peripheral vasoconstriction is one of the first steps in conserving heat to the body core along with heat production by NST. Researchers question whether ELBW infants have the ability to exhibit peripheral vasoconstriction during the first few days of life. One study did not show any peripheral vasoconstriction during the first day of life in ELBW infants<sup>11</sup> but another<sup>12</sup> found ELBW infants spent about 20% of their observations with peripheral vasoconstriction, even though infants in both studies had body temperatures less than 36° C. Mok et al.<sup>13</sup> showed occasional peripheral vasoconstriction in response to caregiver handling of ELBW infants; however, 80% of their sample weighed more than 800 grams. Researchers have shown ELBW infants less than approximately 800–1000 grams are more likely to exhibit peripheral vasoconstriction with increasing chronological age.<sup>11, 13</sup>

This study explored relationships between body temperature and heart rate, oxygen saturations as well as peripheral vasoconstriction in preterm ELBW infants over their first 12 hours of life in the NICU, using a multiple case study, within subjects design. This report gives results concerning body temperature and peripheral vasoconstriction for this study. Specific research questions were: 1) During the transition period (first 12 hours of life), what are the relationships between temperature and peripheral vasoconstriction (defined as exhibiting a difference greater than 2° C between abdominal [central] and foot [peripheral] temperature) within individual infants born weighing 500–1000 grams? 2) Are the relationships between temperature and peripheral vasoconstriction similar among infants?

## Methods

### Sample

After approval by the Institutional Review Board, a multiple case, within-subject design was used to explore body temperature and peripheral vasoconstriction in 10 ELBW infants over their first 12 hours in the NICU in a North Carolina hospital. Sample size was set at 10 in order to have a sample large enough to have representation of various weights, genders, and races of ELBW infants while maintaining a sample size small enough to permit detailed within-subject analyses. Infants were included if they had a birth weight between 500–1000 grams and a gestational age between 23–28 6/7 weeks by obstetrical dates determined by

ultrasound or clinical dating. Consent was obtained from mothers admitted for preterm labor.

### Instruments

Skin surface thermistor probes were attached once the infant was on the Giraffe warmer (GE Healthcare) and weight was verified. Central (abdominal) and peripheral (foot) temperatures were measured with a Mini-Logger (Mini Mitter, Oregon) monitor using two thermistor probes (Steri-Probe, Skin surface probe #499B, Cincinnati Sub-Zero). Abdominal surface temperature was used as central body temperature because we were unable to use esophageal temperature due to the critical illness in this extremely preterm population and because rectal temperature measurement cannot be done continuously for 12 hours due to risk of rectal perforation.<sup>14</sup> Abdominal surface temperature provides the closest temperature to deep tissue core temperature in this population because the probe is covered which provides near zero heat flux and the skin is thin lacking much body fat.<sup>15</sup> The central temperature study probe was positioned adjacent to the standard care incubator temperature probe in the key-hole opening of the duoderm on the skin surface of the abdomen and covered with reflective temperature probe cover. The peripheral temperature probe was secured to the sole of each infant's foot underneath the tape which held the pulse oximeter probe. The sole of the foot was used secondary to the practical ease of probe attachment and because most ELBW preterm infants do not have the ability to sweat when born,<sup>16</sup> which makes the choice of sole of the foot versus other areas of the foot acceptable. Temperature readings were sampled at one-minute intervals and recorded using Mini-Logger software on a laptop computer. These infants were followed during their first 12 hours of life and infants showed very little motor activity due to their immaturity and illness severity; therefore, motion should not have impacted thermistor measurement.

### Procedures

Preterm infants at this hospital were placed in polyurethane occlusive wrapping upon delivery, resuscitated according to NRP 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 that was set on manual at maximum heat output prior to admission, then the infant was controlled at a body temperature of 36.5° C. The warmer converted to an incubator after placement of umbilical lines and humidity was then added and maintained between 60–80%. A data collector sat at each bedside and recorded procedures, manipulation to the infant and incubator environmental temperature at five minute intervals.

### Analyses

Temperature data were exported into Mini-Logger software (Mini-Mitter), converted into Excel files, then exported into SAS<sup>®</sup>, Version 8 (Cary, NC) for analyses. Analyses were conducted within each infant, using approximately 720 measurements (one each minute for 12 hours) for each variable, although these data were not consistently analyzable for all minutes due to instances when both temperature probes were not properly secured. Temperature measurements were plotted to display any trend over time by visual inspection. Peripheral vasoconstriction was assessed by taking the difference between the abdominal

and peripheral temperatures.<sup>15</sup> A decrease in peripheral temperature that occurs before an alteration in the abdominal temperature is an early sign of thermal cold stress due to peripheral constriction.<sup>15</sup> Larger differences ( $> 2^{\circ}\text{C}$ ) have been used to indicate vasoconstriction.<sup>11</sup> Temperature data were analyzed through descriptive statistics, two sample *t*-tests; and Pearson correlation coefficients within subjects. Alpha level was set at 0.05 level of significance, since we treated the within-infant observations as conditionally independent.

## Results

Infants in this study averaged very low abdominal temperatures throughout the 12-hour study period ( $35.17^{\circ}\text{--}36.68^{\circ}\text{C}$ ). Table 1 shows the infant demographics and their mean abdominal ( $T_c$ ) and foot ( $T_p$ ) temperatures. Gestational age was recorded from the obstetrical record, which was obtained from the last fetal ultrasound or by dates estimate. 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  $\pm 2$  weeks of gestational age in infants less than 1500 grams.<sup>17</sup> Therefore, in this study, weights were used as an approximate estimate of maturity and it was difficult to determine if they were appropriate for gestational age without accurate dating. There were no remarkable maternal histories recorded in this small sample. No infants received epinephrine in the delivery room and only one infant (B) received chest compressions briefly.

Axillary temperatures recorded on the bedside charts were as low as  $33^{\circ}\text{C}$ , and some axillary temperatures were recorded as too low to register. Axillary temperatures were taken infrequently by the nurses due to the minimal stimulation protocol; however, when axillary temperatures were recorded they were closely associated with the abdominal thermistor temperatures. Temperatures through initial parts of stabilization in the NICU were very low for most infants and 7 of 10 infants averaged hypothermic ( $< 36.4^{\circ}\text{C}$ ) temperatures across the entire 12-hour study period (Table 1). Abdominal temperature was closely and generally positively related to peripheral temperature in all 10 infants. Five infants had a moderate ( $.6 < r < .8$ ) and three infants had strong ( $r > .8$ ) positive correlations between abdominal and peripheral temperatures across all available measurements (see Table 2) which means that abdominal and peripheral temperatures were generally moving in the same direction instead of diverging as would be the case with peripheral vasoconstriction.

### Peripheral vasoconstriction

Only one infant exhibited peripheral vasoconstriction (abdominal temperature minus peripheral temperature [ $T_c - T_p$ ] by at least  $2^{\circ}\text{C}$ ) with 9% of his measurements exhibiting peripheral vasoconstriction (see Figure 1). This infant was an 880 gram, 26-week male. The largest infant in the study (960 gram, 26-week GA female) showed an attempt at peripheral vasoconstriction; 63% of her observations had a  $T_c - T_p$  of  $+ 1^{\circ}\text{C}$ . These two infants were the only subjects that had at least 8% their abdominal temperatures greater than their peripheral

temperatures by at least 1° C; the remaining eight infants exhibited generally higher peripheral temperatures rather than higher abdominal temperatures ( $-T$ ) (see Table 2).

### Peripheral temperatures greater than abdominal temperature

Seven infants (500–710 grams, 24–25 weeks GA) showed a pattern in which at least 50% of their peripheral temperature measurements were higher (by any amount) than their matched central temperature observations (see Table 2). This pattern can be seen in Figure 2 for a 590 gram, 24 week gestational aged male infant (I). This infant had an abdominal temperature range of 31.24° C to 36.91° C. Study monitors were attached and began recording at 1 hour of age for this infant. Stabilization of the infant (attachment of the ventilator, monitors and umbilical line placement) in the NICU took place for approximately 1 hour prior to beginning data collection. Even though admission temperature was 35.4° C, rectal temperature at 1 hour of age and post stabilization was recorded as too low to register. In contrast, the larger infant that exhibited peripheral vasoconstriction kept his abdominal temperature higher than his peripheral temperature. This infant was an 880-gram African American male (D) delivered by vaginal delivery at 26-weeks gestation. The temperature monitors were attached at 1 hour of age and the infant was cold upon admission (34.8° C axillary); however, his temperature increased fairly quickly. Umbilical line placement took place over the first 3 hours of age. It is interesting to note that when the infant became cold around 6 hours of study time, his peripheral temperature dropped representing peripheral vasoconstriction for approximately 1 ½ hours, then both temperatures increased together to a warmer temperature level.

### Hypothermia

Using 36.4° C as the cut-point for hypothermia, we originally wanted to examine whether there was increased observations with peripheral vasoconstriction below that limit. Because only one infant displayed peripheral vasoconstriction for minimal observations, we looked at whether the temperature difference between abdominal and foot temperatures ( $T$ ) increased when abdominal temperatures were lower than or equal to 36.4° C compared to when abdominal temperatures were greater than 36.4° C (see Table 3). Nine of the ten infants had significantly increased mean  $T$  values between abdominal and peripheral temperatures, when their abdominal temperatures were less than or equal to 36.4° C compared to when their temperatures were greater than 36.4° C. Seven of these nine infants had negative mean  $T$  values, meaning most of their peripheral temperatures were greater than their abdominal temperatures and one infant had a  $T$  value that was very close to 0, meaning the abdominal and peripheral temperature were almost the same during most of the study (see  $t$  tests in Table 3). The remaining infant (D) had a significant increase in mean  $T$  when abdominal temperature was less than or equal to 36.4° C, however, most of the abdominal temperatures were higher than the peripheral temperatures ( $+T$ ). Infant D (880 grams) had more observations that appeared to be towards peripheral vasoconstriction (abdominal > peripheral temperature by 2° C) when his abdominal temperatures were less than or equal to 36.4° C (out of 422 observations).

In addition, the correlation between extent to which  $T$  increased or decreased and the number of degrees the abdominal temperature fell below 36.4° C was significant in 7 of 10

infants (see Table 3). Two of the significant correlations (infants “C” and “I”) were negative, meaning  $T$  increased as abdominal temperature decreased. Both of these infants weighed between 500–600 grams. The five remaining infants had a significant positive correlation between  $T$  and the decrease in abdominal temperature, meaning  $T$  decreased as abdominal temperature fell. This would make theoretical sense as one would expect peripheral vasoconstriction (decrease in foot temperature) when abdominal temperature is decreased.

Looking at the graphic trends (see Figure 1) from the infant that exhibited peripheral vasoconstriction, it is evident that once the infant exhibited peripheral vasoconstriction, the abdominal temperature climbed higher than 36.4° C as the peripheral temperature decreased (symbolizing vasoconstriction). These data would not have been in the analysis of temperatures less than 36.4° C.

Study data collection took place for each infant’s first 12-hours of life; therefore, concomitant infant conditions were largely unknown. It can be assumed that each infant’s ductus arteriosus was either open or closing; however, it was impossible to know patency status during the study period. Additionally, blood culture results were not available until at least 48–72 hours after birth and were not collected as part of this study. Maternal antibiotics were administered prior to delivery in eight of the ten infants (Table 1). Two infants manifested hypotension requiring inotropic drugs. Infant B received a Dopamine infusion at one and a half hours of age, progressing to a Dobutamine infusion at seven hours of age, and then required an Epinephrine infusion at ten hours of age. The only other infant (E) in this sample with persistent hypotension during the first 12-hours of life received a Dopamine infusion at two hours of age. Mortality and morbidity data were not collected past the 12 hours of data collection.

## Discussion

Most ELBW infants in this study appeared to be unable to exhibit peripheral vasoconstriction. Only one infant (880 grams) exhibited peripheral vasoconstriction as measured by the traditional definition of an abdominal-peripheral temperature difference of more than 2° C.<sup>11,15</sup> Smaller infants (500–710 grams) and the most premature (24–25 weeks gestation) infants were most likely to have peripheral temperatures 1–2° C higher than their abdominal temperature. We speculate that the weight at which ELBW infants can exhibit peripheral vasoconstriction is greater than 800 grams, which represents no greater than about 26-weeks gestation, because we did not see peripheral vasoconstriction in infants weighing less than 800 grams.

With only one infant exhibiting peripheral vasoconstriction by traditional definition, our findings confirmed those of Lyon et al.<sup>11</sup> Infants weighing less than 1,000 grams at birth exhibit poor vasomotor control during the first day of life. Horns<sup>12</sup> found that ELBW infants exhibited peripheral vasoconstriction about 20% of the time when enrolled from 12–24 hours of age and then studied longer than 24 hours. She examined infants weighing 570–880 grams at birth but did not specify which infants in her sample exhibited peripheral vasoconstriction. Previously, Lyon et al.<sup>11</sup> found increasing occurrence of peripheral

vasoconstriction in ELBW infants as they aged over 5 days. Infants weighing less than 800 grams in our study did not exhibit peripheral vasoconstriction in their first 12-hours in the NICU presumably due to immature vasomotor tone.

Ability to constrict vessels peripherally may be related to the postnatal chronological ages of the ELBW infants as well as their birth weights and gestational age. Lyon et al.<sup>11</sup> found that ELBW infants studied on the first day of life showed higher peripheral than abdominal temperatures 18.3% of the time, but this decreased to 4.9% of the time by 5 days of age. Vasomotor control is mediated through the autonomic nervous system by sympathetic control. There is very little research examining maturation of the sympathetic nervous system, however, researchers have shown that the parasympathetic system is correlated with gestational age as well as matures postnatally over time.<sup>18</sup> Sympathetic development is much slower than parasympathetic development and has been shown to increase with gestational age as well as postnatal age.<sup>19</sup> Neuromaturation occurs in an orderly fashion with respect to tone and reflexes, being related to postmenstrual age (chronological age plus gestational age), genetics and the environment.<sup>20</sup> We speculate that as the neurologic system develops over postnatal age, so does the ability for peripheral vasoconstriction.

Altogether, 7 of 10 infants exhibited higher peripheral than abdominal temperatures for most of the 12-hour transition periods. Nine of ten infants had a significant increase in the differences between abdominal and peripheral temperatures when abdominal temperatures were less than or equal to 36.4° C. Therefore, colder body temperatures resulted in increased difference between the peripheral and abdominal temperatures. The three smallest (birth weights 510–590 grams) and most preterm infants in the study increased the difference between their peripheral and abdominal temperatures as their central temperature fell. As body temperature fell below 36.4° C, the smaller more premature infants probably were unable to increase metabolism to generate heat and apparently had very little vasomotor control. Abdominal temperatures decreased in relationship to the inability to generate heat; however, the peripheral temperature did not fall, thus increasing the difference between the peripheral and abdominal temperatures.

Peripheral temperatures may have been higher than abdominal temperatures because these extremely premature infants lacked vasomotor control, and the feet had less heat flux and radiant heat loss as feet temperatures approached the ambient temperature in the incubator. Abdominal temperature, used as a proxy for an infant's central body temperature or core temperature,<sup>15</sup> most likely decreases in association with caregiver handling, nursing, and medical procedures. Because ELBW infants lack the ability to generate heat adequately, their trunks will stay colder longer than their feet and the vasodilated foot would warm faster than the abdomen as the incubator ambient temperature is increased. These infants are controlled by abdominal skin temperature and the environmental air temperature will increase as warm air is blown into the incubator when the infant's body temperature falls below the set point. Future research should include environmental temperature as a variable and this reading should be tested in relationship to abdominal and peripheral temperatures.

Lyon et al.<sup>11</sup> noted an association between death and the proportion of time that the peripheral temperature was greater than the abdominal temperature, however; this was not

significant once birth weight was taken into consideration. This association may occur because the time the peripheral temperature is higher than the abdominal temperature is time when the infant is cold centrally and because a higher peripheral temperature indicates poor, if any, vasomotor control. Mortality was not recorded in the current study since subjects were only studied for the first 12 hours of life.

Future research needs to be directed towards exploring chronological development of vasomotor tone in preterm infants less than 800 grams. Vasomotor tone may mature postnatally over time and knowing this maturation point will give healthcare providers information as to when preterm infants can begin to actively conserve heat. Until that time, it is imperative that healthcare providers take the utmost care in providing adequate heat and preventing hypothermia through initial transition and into the first few days of life. Poor vasomotor tone in the first few days of life may be linked with mortality and morbidity outcomes for these infants.

Poor or inadequate vasomotor tone during the first few days of life in preterm infants may be associated with susceptibility to intraventricular hemorrhage during the first week of life which has been associated with low superior vena cava flow and possible hypoperfusion-reperfusion cycles.<sup>21</sup> Arteriolar vasoconstriction and vasodilation are responsible for regulation of cerebral blood flow with varying perfusion pressures<sup>22</sup> and may mature postnatally as well. Cerebral blood flow has been found to increase with chronological age over the first two weeks of life postnatally.<sup>23,24</sup> We believe that immature vasomotor tone, reflected by the inability of the preterm infant less than 800 grams to initiate peripheral vasoconstriction when hypothermic, is associated with a time during which the infant has immature autoregulation and is subject to brain injury. This may explain why hypothermia is associated with increased brain injury or intraventricular hemorrhage<sup>21</sup> and requires further study.

### Limitations

Limitations in examining peripheral vasoconstriction in this study included that peripheral vasoconstriction is altered not only by thermoregulation but also by other factors stimulating the autonomic nervous system including responses to stressful stabilization procedures, the dynamic nature of transitional circulatory changes, and fluid and medication administration. This was a small pilot study, limited to 12-hours of data collection. Our subsequent study will examine status of ductus arteriosus when peripheral temperatures are greater than abdominal temperatures, ongoing disease status, morbidity, and mortality information to give a more complete clinical case presentation in which to analyze each subject.

Because this was a small study, results cannot be generalized to the larger population of preterm ELBW infants. Future studies need to include a larger sample of infants with analyses within subjects as well as between subjects, perhaps using stratification of gestational age and weight classes. Another limitation is the use of thermistors for temperature measurement. A temperature measured on the skin under a reflective tape is not necessarily equal to an adjacent skin surface site that is not covered, due to local vasodilatation caused by the insulated covering. Skin surface temperature can also be measured by thermal imaging with infrared technology, which allows measurement of



multiple skin surface sites simultaneously. Our future studies will employ this technique to better examine skin surface temperature for central and peripheral measurements. This study was also limited in that environmental temperatures were documented by an observer, and not recorded using research data loggers continuously. Our future study will measure temperature inside the incubator continuously to use in analyses with body temperature.

Lastly, this study and future studies are limited by the obstetrical prenatal assessment of gestational age. Gestational age was recorded by obstetrical dates or fetal ultrasound when available; both estimates have large variation in exact gestational age assessment. For this reason, we use birth weights as an approximate measure of maturity when the preterm infant is less than 1000 grams at birth.

We did not track brain hemorrhage outcomes in this small sample; however, future research should examine brain injury in association with body temperature and vasomotor tone during the first week of life. Because it is essential to understand physiological responses to hypothermia in ELBW infants which may lead to increased morbidity and mortality in this vulnerable population, we will continue to study peripheral vasoconstriction as a mechanism to conserve heat. Studying this concept in extremely preterm infants may lead to new information about maturation of vasomotor tone and add evidence to factors which may affect risk for intraventricular hemorrhage during the first week of life.

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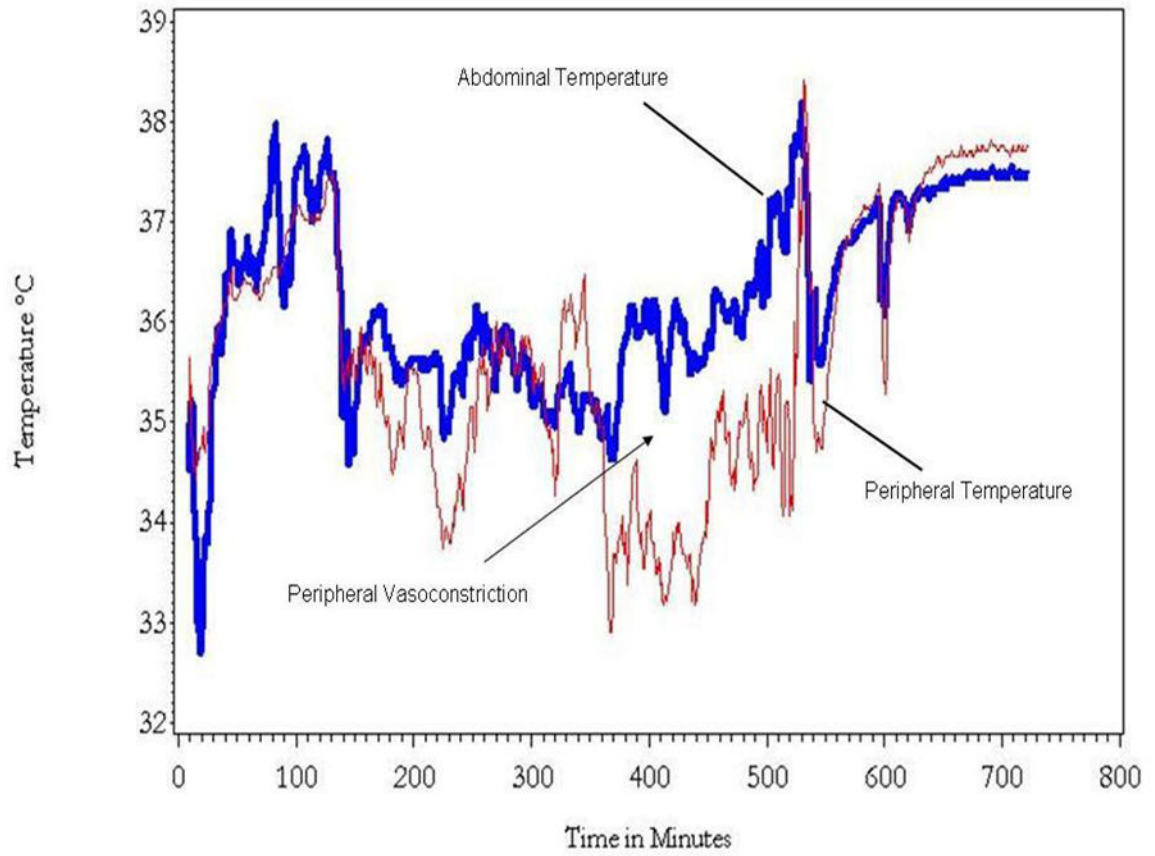
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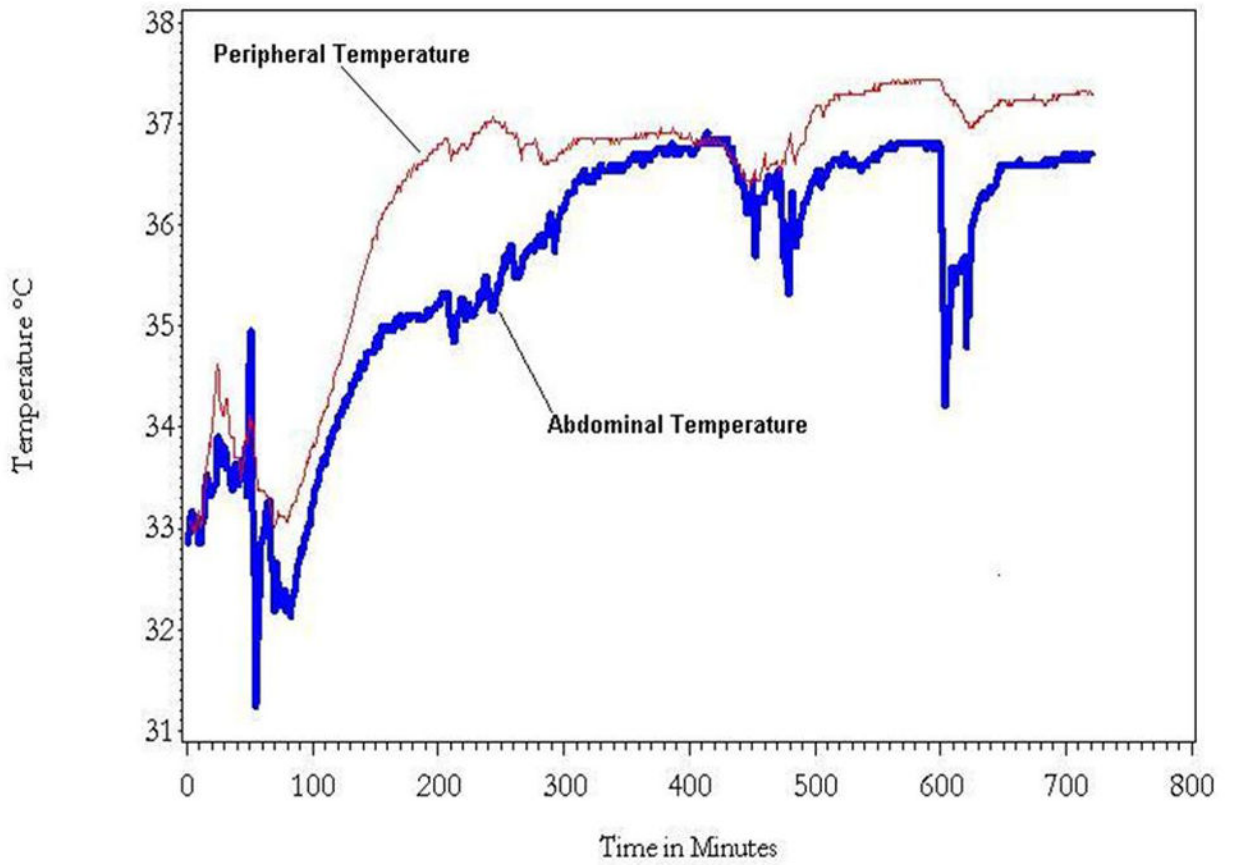
## References

1. Knobel R, Holditch-Davis D. Thermoregulation and heat loss prevention after birth and during neonatal intensive-care unit stabilization of extremely-low-birth weight infants. *J Obstet Gynecol Neonatal Nurs.* 2007; 36:280–7.
2. Thomas K. Preterm infant thermal responses to caregiver differ by incubator control mode. *J Perinatol.* 2003; 23:640–5. [PubMed: 14647160]
3. Buetow K, Klein S. Effect of maintenance of “normal” skin temperature on survival of infants of low birth weight. *Pediatrics.* 1964; 34:163–70. [PubMed: 14211076]
4. Day R, Caliguiri L, Kamenski C, Ehrlich F. Body temperature and survival of premature infants. *Pediatrics.* 1964; 34:171–81. [PubMed: 14211077]
5. Hazan J, Maag U, Chessex P. Association between hypothermia and mortality rate of premature infant--Revisited. *Am J Obstet Gynecol.* 1991; 164:111–2. [PubMed: 1986597]
6. Vohra S, Grent G, Campbell V, Abbott M, Whyte R. Effect of polyethylene occlusive skin wrapping on heat loss in very low birth weight infants at delivery: A randomized trial. *J Pediatr.* 1999; 134:547–51. [PubMed: 10228287]
7. Hull, D.; Smales, O. Heat production in the newborn. In: Sinclair, J., editor. *Temperature regulation and energy metabolism in the newborn.* Gurne & Stratton; New York: 1978. p. 129-56.

8. Houstek J, Vizek K, Pavelka S, Kopecky J, Krejcova E, Hermanska J. Type II iodothyronine 5'-deiodinase and uncoupling protein in brown adipose tissue of human newborns. *J Clin Endocrinol Metab.* 1993; 77:382–7. [PubMed: 8393883]
9. Sauer, P. Metabolic background of neonatal heat production, energy balance, metabolic response to heat and cold. In: Okken, A.; Koch, J., editors. *Thermoregulation of sick and low birth weight neonates.* Germany: Springer-Verlag Berlin; 1995. p. 9-20.
10. Nechad, M. Structure and development of brown adipose tissue. In: Trayburn, P.; Nicholls, D., editors. *Brown adipose tissue.* Great Britain: Edward Arnold Publishers; 1986. p. 1-30.
11. Lyon A, Pikaar M, Badger P, McIntosh N. Temperature control in very low birthweight infants during first five days of life. *Arch Dis Child, Fetal Neonatal Ed.* 1997; 76:F47–F50. [PubMed: 9059187]
12. Horns K. Comparison of two microenvironments and nurse caregiving on thermal stability of ELBW infants. *Adv Neonatal Care.* 2002; 2(3):149–60. [PubMed: 12903226]
13. Mok Q, Bass C, Ducker D, McIntosh N. Temperature instability during nursing procedures in preterm neonates. *Arch Dis Child.* 1991; 66:783–6. [PubMed: 1863124]
14. Bailey J, Rose P. Temperature measurement in the preterm infant: A literature review. *Journal of Neonatal Nursing.* 2000; 6:28–32.
15. Sinbrunner, G. Temperature measurements and distribution of temperatures throughout the body in neonates. In: Okken, A.; Koch, J., editors. *Thermoregulation of sick and low birth weight neonates.* Germany: Springer-Verlag Berlin; 1995. p. 53-62.
16. Harpin VA, Rutter N. Development of emotional sweating in the newborn infant. *Arch Dis Child.* 1982; 57:691–5. [PubMed: 7125688]
17. Sanders M, Allen M, Alexander G, et al. Gestational age assessment in preterm neonates weighing less than 1500 grams. *Pediatrics.* 1991; 88:542–546. [PubMed: 1881734]
18. Longin E, Gerstner T, Schaible T, Lenz T, Konig S. Maturation of the autonomic nervous system: Differences in heart rate variability in premature vs term infants. *J Perinat Med.* 2006; 34(4):303–8. [PubMed: 16856820]
19. Gournay V, Drouin E, Roze JC. Development of baroflex control of heart rate in preterm and full term infants. *Arch Dis Child Fetal Neonatal Ed.* 2002 May; 86(3):F151–4. [PubMed: 11978743]
20. Allen MC. Assessment of gestational age and neuromaturation. *Mental Retardation and Developmental Disabilities Research Reviews.* 2005; 11:21–33. [PubMed: 15856445]
21. Osborn DA, Evans N, Kluckow M. Hemodynamic and antecedent risk factors of early and late periventricular/intraventricular hemorrhage in premature infants. *Pediatrics.* 2003; 112:33–9. [PubMed: 12837865]
22. Paulson O, Strandgaard S, Edvinsson L. Cerebral autoregulation. *Cerebrovascular Brain Metabolism Review.* 1990; 2:161–92.
23. Kehrer M, Blumenstock G, Ehehalt S, Goelz R, Poets C, Schoning M. Development of cerebral blood flow volume in preterm neonates during the first two weeks of life. *Pediatric Research.* 2005; 58:927–30. [PubMed: 16183816]
24. Meek J, Tyszczuk L, Elwell C, Wyatt J. Cerebral blood flow increases over the first three days of life in extremely preterm neonates. *Archives of Diseases in Childhood, Fetal/Neonatal Edition.* 1998; 78:F33–F37.



**Figure 1.** Abdominal and peripheral temperatures for 880-gram, 26 week GA male infant showing peripheral vasoconstriction during the 12-hour study period.



**Figure 2.** Abdominal and peripheral temperatures for 590-gram, 24 week GA male infant showing higher peripheral than abdominal temperatures during the 12-hour study period.

Demographic data for study infants and mean temperatures over 12-hour transitional period

**Table 1**

Infant	Gen	Race	GA	Wt in g	PNC	Del Mode	Mat Anbx	PN Ster	Apgar Scores	Tc mean	Tc SD	Tp mean	Tp SD
A	F	AA	25	630	Y	CS	Y	?	1,5,7	36.68	0.71	37.1	0.91
B	M	AA	24	680	N	Vag	N	N	1,7	36.05	1.25	36.49	0.69
C	F	C	25	550	Y	CS	Y	Y	1,2,6	35.51	2.03	37.06	1.00
D	M	AA	26	880	N	Vag	Y	Y	8,8	36.23	0.94	35.73	1.30
E	F	C	25	720	Y	CS	Y	Y	4,7	35.28	0.99	36.36	0.96
F	F	AA	25	670	Y	Vag	N	Y	2,4,6	35.17	1.33	35.1	0.99
G	F	C	26	510	Y	CS	Y	Y	4,8	35.79	0.88	36.71	0.91
H	M	AA	25	710	N	Vag	Y	Y	1,5,7	36.44	1.17	36.75	0.95
I	M	C	24	590	?	CS	Y	?	2,6	35.61	1.3	36.32	1.29
J	F	AA	26	960	Y	Vag	Y	Y	4,5	36.6	0.34	35.5	0.49

Gender (Gen), Gestational Age (GA), Mother received prenatal care: Yes/No (PNC), Maternal antibiotics prior to delivery: Yes/No (Mat Anbx), Prenatal Steroids: one or more doses prior to delivery: Yes/No (PN Ster), Abdominal skin temperature (Tc), Foot skin temperature (Tp), Standard deviation (SD)

**Table 2**  
 Pearson Correlations between Abdominal and Foot Temperature for Each Infant and Frequencies of Abdominal Temperature (Tc) vs. Foot Temperature (Tp) for Study Infants

Infant	Weight in grams	n	r	Tc>Tp Percent (N)	Tp>Tc Percent (N)	Total I-min observations
A	630	546	0.22*	43.9% (240)	56.0% (306)	546
B	680	693	0.87*	34.8% (241)	65.2% (452)	693
C	550	543	0.68*	11.1% (60)	87.1% (473)	543
D	880	713	0.71*	62.6% (446)	34.2% (244)	713
E	720	643	0.77*	4.8% (31)	94.9% (610)	643
F	670	723	0.75*	61.6% (445)	36.7% (265)	723
G	510	451	-0.28*	9.3% (42)	90.7% (409)	451
H	710	719	0.87*	20.5% (147)	75.8% (545)	719
I	590	721	0.92*	3.1% (22)	94.7% (683)	721
J	960	557	0.64*	99.5% (554)	0.5% (3)	557

\* p < .0001 r: Pearson Correlation Coefficient n: number of observations (Some infants have less than 720 temperature readings because observations needed to consist of a valid abdominal temperature matched with a valid foot temperature. In some instances, one or both of the temperature probes were not secured properly and did not yield valid readings.)

**Table 3** Means, Pearson Correlations<sup>1</sup> Coefficients, and t-Tests<sup>2</sup> of Observed Abdominal Temperatures 36.4° C and the Time Matched Abdominal- Peripheral Temperature Difference

Infant	BW in Gms	Mean abdominal temperature for all observations when AbT 36.4° C (SD) [N]	Mean abdominal temperature for all observations when AbT >36.4° C (SD) [N]	Mean T° C for observations when AbT 36.4° C (SD)	r	r <sup>2</sup>
A	630	35.77 (0.46) [142]	37.06 (0.37) [404]	-0.35 (0.99)	0.03	-8.80*
B	680	34.60 (1.47) [179]	36.67 (0.14) [514]	-0.29 (0.61)	0.82*	-11.12*
C	550	34.64 (2.10) [337]	37.00 (0.31) [273]	-1.00 (0.77)	-0.35*	-14.74*
D	880	35.58 (0.57) [422]	37.18 (0.38) [291]	0.50 (0.92)	0.53*	6.33*
E	720	35.06 (0.84) [565]	36.88 (0.37) [83]	-1.13 (0.69)	0.04	-19.02*
F	670	34.59 (0.99) [543]	36.93 (0.23) [180]	0.07 (0.89)	0.71*	-15.65*
G	510	35.58 (0.81) [327]	36.74 (0.43) [136]	-0.52 (1.12)	-0.10	-5.59*
H	710	34.84 (1.08) [200]	37.05 (0.28) [519]	-0.32 (0.57)	0.32*	-13.77*
I	590	34.77 (1.22) [398]	36.65 (0.11) [323]	-0.71 (0.52)	-0.23*	-16.29*
J	960	36.21 (0.31) [122]	36.71 (0.26) [528]	1.08 (0.35)	0.54*	0.10

\* p<.0001

<sup>1</sup> Pearson Correlation: The extent to which the T increased or decreased as the abdominal temperature fell below 36.4° C was significant in 7 of 10 infants.

<sup>2</sup> t-test: Mean T values (abdominal-foot temperature) were significantly greater when temperature values were less than or equal to 36.4° C in 9 of 10 infants.

<sup>3</sup> df for t-test varied from 129 for subject G to 705 for subject D

BW: Birth Weight

T: Abdominal-Peripheral Temperature Difference

Gms: Grams

SD: Standard deviation

AbT: Abdominal Temperature

N: number of measurements when AbT 36.4° C or >36.4° C

FT: Foot temperature