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Body Temperature in Premature Infants During the First Week of Life: Exploration Using Infrared Thermal Imaging

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Abstract

Background—Hypothermia is a problem for very premature infants after birth and leads to increased morbidity and mortality. Previously we found very premature infants exhibit abnormal thermal patterns, keeping foot temperatures warmer than abdominal temperatures for their first 12 hours of life.

Purpose—We explored the utility of infrared thermography as a non-invasive method for measuring body temperature in premature infants in an attempt to regionally examine differential temperatures.

Results—Our use of infrared imaging to measure abdominal and foot temperature for extremely premature infants in heated, humid incubators was successful and in close agreement using Bland and Altman technique with temperatures measured by skin thermistors.

Conclusions—Our study methods demonstrated that it was feasible to capture full body temperatures of extremely premature infants while they were resting in a heated, humid incubator using a Flir SC640 infrared camera. This technology offers researchers and clinicians a method to examine acute changes in perfusion differentials in premature infants which may lead to morbidity.

Keywords

thermoregulation; body temperature; infrared imaging; thermography

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Conflict of Interest:

None of the authors report any actual or potential conflict of interest.

1.1 Introduction

Hypothermia is a problem for very premature infants after birth and leads to increased morbidity and mortality (Lyu et al., 2015). Thermoregulation is compromised in premature infants because of an ineffective heat production mechanism and a limited capacity for heat preservation via rapid peripheral vasoconstriction (Knobel, 2014; Knobel et al., 2009). In our prior study, very low birth weight (VLBW) infants were unable to exhibit peripheral constriction in response to hypothermia and eight of ten infants had over 50% of their foot temperatures greater than their abdominal temperatures during their first 12 hours after birth (Knobel et al., 2009). As a result of these observations, we wanted to determine whether this same thermal pattern persisted into the first 2 weeks of life. If the abnormal thermal pattern persists, monitoring continuous skin temperature may provide an innovative, non-invasive method for early detection of perfusion injury, such as necrotizing enterocolitis.

Between 2010–2013, we conducted a study of 30 VLBW infants using a case study design to examine central and peripheral temperature over their first two weeks of life in relationship to their clinical outcomes. Our main study results analyzing the relationships of temperatures to morbid outcomes is reported in a separate paper that is under review (Knobel-Dail, Sloane, Holditch-Davis, & Tanaka, 2017). A separate aim was to analyze peripheral temperature in relationship to perfusion by measuring perfusion index with Masimo Radical 7 Pulse Oximeters. This methodology demonstrated that temperature correlated with infant foot perfusion (Knobel-Dail et al., 2016).

We explored the utility of infrared thermography (Knobel et al., 2011) as a non-invasive method for measuring body temperature in premature infants in an attempt to examine regional differences in temperatures. This exploratory methodology was employed to visually and quantitatively inspect differential temperatures seen between central and peripheral skin temperatures in our previous studies. Infrared thermal imaging offers a non-contact way of measuring temperature and may offer potential for use to detect alterations in temperature in hospitalized premature infants (Knobel, Guenther & Rice, 2011). There are limited reports of utilizing infrared thermal imaging with extremely premature infants in heated incubators (Abbas, Heimann, Jergus, Orlikowsky, & Leonhardt, 2011; Abbas & Leonhardt, 2014; Heinmann et al, 2013) and this manuscript reports our experience with this methodology.

1.2 Materials and Methods

Institutional Review Board approval was obtained at our university medical center in North Carolina. We evaluated study methods in a pilot study (Knobel et al., 2013), then enrolled infants between August 2010 and December 2013. Parents were approached for consent for their infant to participate if the infant was less than 29 weeks gestational age. Infants were eligible if their birthweight was between 500 and 1200 grams and if there were no visible anomalies or medical complications initially after birth. Permission from the infant's attending physician was also obtained prior to enrolling participants.

Abdominal (central) and foot (peripheral) temperatures were measured continuously and recorded every minute using Y series Steri-Probe® skin temperature probes (Model 499B, Cincinnati Sub-Zero, Cincinnati, OH) on each infant's skin surface attached to a 4 channel data logger, model SP-1400-44Y (Veriteq Instruments; Vaisala; Richmond, British Columbia, CA). The abdominal probe was secured near the flank/liver area with a fabric tape (Mepitac, Molnycke Health Care, Gothenburg, Sweden); foot probe was secured on the sole of a foot with the same tape. Temperature probes sites were checked every 6–8 hours as needed to ensure skin integrity. Temperature data were downloaded at the end of the first two weeks of life to an Excel file on a laptop computer and stored on a secure server. Data were exported into a SAS (SAS, Cary, NC) data set for each infant. There were 20,000 measurement points for each physiological variable for each infant.

A SC640, uncooled microbolometer (FLIR corp, Billerica, MA), was used to take daily images of each infant for the first 5 days of life (see Figure 1). The images were downloaded to a computer for analysis with Flir Examir software (Flir® Nashua, NH). Each pixel of the image displays a temperature in degrees Celsius and regions of interest can (ROI) be outlined using the software in order to calculate maximum, minimum and average temperatures (see Figure 1). Images can be visualized in gray scale with darker images being cooler than lighter images. A pseudo color scale can also be available to represent cooler (blue) or warmer (red) temperatures (see Figure 2). Temperature gradients can be distinguished visually as demonstrated in Figure 2 where this infant has cool toes on his right foot, with the big toe displaying what we would refer to as a “cath toe” from umbilical venous occlusion. Temperature measurement of the skin surface using IR is possible due to the high emissivity of the skin surface to radiation, at 0.98.

Details on the use of infrared imaging (IR) for infants and adults in healthcare are reported elsewhere (Knobel et al., 2011). We are reporting an exploratory method, so our main purpose was to assess the ability of the infrared camera to measure body temperature in extremely premature infants who were in heated incubators. We also compared skin temperatures measured by thermistor with temperatures detected by infrared thermography in corresponding ROI. In addition, we wanted to explore the use of images to visualize temperature differentials in each infant. We performed our initial assessment of the camera with infants in a pilot study and changed methods to improve imaging and thermal stability of the infant (Knobel et al., 2013).

Infants were held in position through the portholes on one side of a Giraff incubator while the operator of the camera took 3–4 images of the infant through the portholes on the opposite side of the incubator. The plastic walls of the incubator are opaque to infrared radiation so we could only view the infrared image through a porthole. The camera weighs approximately 1.8 kg and is easily held in front of the porthole. The camera lens was held approximately 30–45 cm from the infant, and the camera was positioned outside the incubator porthole. We positioned the infant so the entire body could be captured in a single image. This was not always possible because of the presence of equipment, blankets, diapers and other obstructions. Imaging at different angles minimized obstructions, but infant care and comfort always took priority. IR measurement of the skin surface is possible due to the high emissivity of the skin surface to IR, at 0.98 (Steketee, 1973).

1.2.1 Analysis

The main aim of this paper was to evaluate the agreement between two methods of measuring temperature: a skin temperature probe with a thermistor compared to temperature measured by IR at both the abdomen and foot. Comparison of methods using a Pearson's correlation would usually be one of the first approaches to comparing two methods of measurement of the same variable; however, the correlation approach is not the most appropriate test because it does not take into account variation between infants and variation within infants, while the regression approach does. Therefore, we decided to use two methods to assess the agreement between these two methods.

First, Bland Altman analysis (Bland and Altman, 1986) compares the difference between the methods against their mean, which allows us to investigate any possible relationship between the measurement error and the true value (Phatak & Nimbalkar, 2017). According to Bland and Altman, since we do not know the true value of temperature, the mean of the measure by the two methods is the best estimate we have.

According to Bland and Altman, if the variation between infants is high in comparison to the measurement error, the correlation coefficient may be high and in contrast, if the variation between infants is low, the correlation coefficient might be low. Variability or error threats to our two measurement methods can also be introduced through measurement technique, software used to obtain imaging values, and infant environment in the incubator. Second, we used linear regression to evaluate the relative association between the abdomen and foot for each method, assessing the slope and error for each. All analyses were conducted using SAS v9.3. P-values were declared statistically significant at 0.05.

1.3 Results

We obtained study consent from 107 parents prior to their infant's birth to enroll their infant in this study. Of those, 73 were not eligible for data collection because they did not meet inclusion requirements once born. Data were collected on 31 infants; we were able to obtain infrared images on 22 infants. The first two infants in the study were used for training purposes and not included in data analysis because the research assistants had not mastered thermal imaging until the third infant was imaged. Twenty infants had valid images with temperatures measures to review. There were 6 males and 14 females with 70% African American and 30% white infants. Infants ranged in birth weight between 590 and 1090 grams with a mean of 881 grams (SD 139.6) and 23 to 28 weeks gestational age with a mean gestational age of 26.9 (SD 1.15).

The mean abdominal temperature by thermistor was 36.44°C, (SD 0.81°, min 33.21°C, max 38.12°C) compared to the mean abdominal temperature by IR of 36.57°C, (SD 0.75°, min 35.20°C, max 38.90°C). The mean foot temperature by thermistor was 35.76°C, (SD 0.94°, min 33.79°C, max 38.31°C). Mean daily incubator temperature was 34.65°C, ranging from 34.18°C to 35.33°C over the 5 days. Skin temperature measured by a skin thermistor probe was compared with IR values in the same region by plotting the data and creating a regression line (Altman and Bland, 1983), see Figures 3 and 4. The regression plot for the abdomen has a tighter "cloud" of agreement between about 35.5°C and 38°C for each

measure (IR and Skin) compared to the plot of heel temperature. However, the two points at the low end of Skin thermistor temperatures (at about 33°C) are influential data points and their effect renders the p-value for the abdomen slope based on the regression analysis to a non-significant level of 0.15. The standard error for the slope of the abdomen is 0.12 and the standard error for the slope of the foot was much larger at 0.175, suggesting that there was less overall agreement (ie. more noise) than for the abdomen. However, while the nature of the relationship for the foot is more diffuse in general it is more consistent overall; therefore, regression analysis results in a significant positive slope at $p=.0071$.

Our plots of the abdominal temperature by thermistor and infrared methods (Figure 5) and foot skin temperature by thermistor and infrared methods (Figure 6) reveal a better agreement in abdominal temperature measures. Each mark represents the difference between the infrared and skin temperature and on the abdominal temperature plot, the marks are tightly aligned around 0 over the range of temperature means (X axis) for each infrared-skin difference (Y axis). The temperatures measured by IR and thermistor for the abdomen (Figure 5) are largely in agreement. There is more a difference at the low end of the mean abdominal temperature (approximately 34.5°C) with two pairs of readings in which the disagreement is high and at the higher end of means (37.5°C and approximately 37.8°C). For the foot temperature comparison, the agreement is not as good, although, the mean difference is still centered around 0. The standard deviation is higher, resulting in wider 95% confidence interval lines.

1.4 Discussion

Our use of IR to measure abdominal and foot temperature for extremely premature infants in heated, humid incubators was successful and in close agreement with temperatures measured by skin thermistors. We compared abdominal temperatures by IR in the same ROI as the skin thermistor which was visible on IR images. Comparing thermistor and IR foot temperatures was more difficult since the region of interest was not visible on the image; one explanation would be that foot temperature was measured on the sole of the foot which was not always visible to the examiner of the IR image.

Very few researchers have conducted IR with infants housed in incubators (Abbas et al., 2011; Abbas & Leonhardt, 2014; Heinmann et al, 2013) and this research has not occurred with extremely premature infants in the early neonatal period. In contrast, we measured temperature over the first few days of life of very preterm infants, which is a clinically important period during which infants are in very warm, humid incubators. Heinmann et al. examined 10 extremely premature infants ranging from 740 grams –1450 grams at birth in Germany in an incubator and during skin to skin care with a long wave IR-FPA bolometric detector. Infants in their study were covered with a polyethylene sheet while being imaged through an incubator opening. Incubator temperature averaged 32.8°C and infants averaged 36 days of age. These researchers found that optimal infrared imaging occurred in and out of incubators, in multiple positions while infants received skin to skin care with a parent. Our team conducted infrared imaging of infants once a day over their first 5 days of life in incubators with a mean environmental temperature of 34.66°C, and humidity levels between 80–60%.

Abbas and Leonhardt (2014) have conducted studies using a thermography tracking system for virtual temperature sensing of infants being cared for under warmers and in incubators. They have had success using infrared video to track geometric profiles and shapes over infants' bodies with temperature profiles. The researchers suggested that their continued studies in this area may reduce the need for skin thermistors for infant temperature monitoring. Our study used infrared thermal imaging once on each infant daily. Our Flir SC640 infrared camera has video capabilities; however, the data requirements are very large and impractical for this exploratory study. Abbas and Leonhardt's (2014) virtual thermal sensing of temperature offered an option of thermal measurement in extremely preterm infants with fragile skin if the technology can be developed into a fiscally practical monitoring technique. Because abnormal temperature patterns are prevalent in extremely premature infants (Knobel et al., 2009; Lyon and Pikaar, 1995; Mok et al., 1991), perhaps virtual temperature sensing could help to guide clinicians to care for this vulnerable population in the future.

Because of the difficulty we encountered in imaging the infants' entire body from outside the incubator, through a porthole, this technology does not appear to be clinically useful for continuous monitoring of body temperature profiles. It appears to be a useful technology for a snapshot of body temperature when pathology is expected; however, imaging can be much better achieved if the infant is cared for on a radiant warmer and unencumbered by wrap for developmental care.

Continued research is needed to examine ongoing differences in temperature between the central body (abdominal/flank areas) and the periphery (feet and hands). Compiling results from all methods of data acquisition in our study confirmed temperature differentials exist between the central and peripheral body over the entire first two weeks of life (Knobel-Dail et al., 2017). Monitoring central and peripheral temperature continuously in extremely premature infants is essential (Lyon and Freer, 2011) and may prevent morbid outcomes due to early detection of ischemia and possibly sepsis (Leante-Castellanos et al., 2012; Messaritakis, Anagnostakis, Laskari, & Katerelos, 1990). Researchers need to focus on optimized ways to monitor continuous body temperature in premature infants.

There are many ways infrared thermography can be used clinically and these uses may be adopted in the NICU for premature infants. Chiang et al (2008) used infrared imaging to detect fever in crowds for surveillance of SARS. Surveillance for hypothermia or hyperthermia of all infants from a distance using infrared temperature measurement of their forehead is possible, especially in a delivery room situation. Thermography has been used to assess shunt patency which could be employed in the NICU (Goetz, Foertsch, Schoenberger & Uhl, 2005). Researchers have shown that infrared thermography can be used to study temperature profiles of infants on warming tables, especially for a global picture of body temperature in the delivery room (Christidis et al., 2003). Many other opportunities exist where infrared thermography can be used in the diagnosis and ongoing treatment of skin lesions involving perfusion or lack of blood flow (Saxena & Willital, 2008).

1.5 Conclusions

Our study methods demonstrated that it was feasible to capture full body temperatures of extremely premature infants while they were resting in a heated, humid incubator using a Flir SC640 infrared camera. Although very few researchers have used this technology with extremely premature infants, infrared imaging offers a way to capture temperature differentials over the entire body surface. This technology offers researchers and clinicians many uses when differential perfusion is in question such as with skin ulcers, skin cancer, and compartment syndrome (Katz et al., 2008; Knobel et al., 2011) and has future potential in guiding clinicians caring for infants with intestinal perfusion problems such as with necrotizing enterocolitis (Rice et al., 2010). More research studies are needed with infrared imaging and clinical conditions.

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Abbreviations

IR	infrared red
ROI	Region of interest
VLBW	Very low birth weigh

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A.1.1 Figure 1.

Infrared image as seen in the FLIR Examinir software on the computer. This image was used to compare foot temperature (red box 1) with abdominal temperature (green box 2).

A.1.2. Figure 2.

Thermal image using “Ironbow” display feature. This image was shot through a porthole of an incubator and only captures the infant’s body from neck to feet. An infrared camera can use the internal software to display the recorded image in colors to represent heat variations versus a black and white display. The grades of color against elevations in temperature are seen in the image in the temperature legend.

A.1.3 Figure 3.

Regression of temperature measurements using abdominal Infrared (IR) and skin thermistors (Skin) temperature. Displayed temperatures represent pairs of IR and Skin measures obtained from sample (20 infants with 1–3 measures each).

A.1.4 Figure 4.

Regression of temperature measurements using foot Infrared (IR) and skin thermistors (Skin) temperature. Displayed temperatures represent pairs of IR and Skin measures obtained from sample (20 infants with 1–3 measures each).

A.1.5. Figure 5.

Bland-Altman plot for Abdominal IR-Skin temperature measurement. Y Axis represents difference between pairs of temperatures for each of 20 infants, all measures included (1–3) with Abdominal IR minus Abdominal Skin temperature. X Axis represents the mean temperature between each abdominal IR and Skin temperature for all measures. Upper and lower lines indicate 95% Confidence Interval of the difference.

A.1.6. Figure 6.

Bland-Altman plot for Foot IR-Skin temperature measurement. Y Axis represents difference between pairs of temperatures for each of 20 infants, all measures included (1–3) with Foot IR minus Foot Skin temperature. X Axis represents the mean temperature between each foot IR and Skin temperature for all measures. Upper and lower lines indicate 95% Confidence Interval of the difference.