CNE

Continuing Nursing Education Series

Comparing Three Methods of Assessing Peripheral Perfusion in Critically Ill Children

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Background: Evaluation of peripheral perfusion is a standard practice in pediatric intensive care units (PICUs), which includes the qualitative assessment of foot warmth. The perfusion indicator, derived from the pulse oximetry signal, is available, along with some bedside monitors.
Objectives: To describe the correlation between RN qualitative assessment of foot warmth, measured foot temperature, and perfusion indicator.
Methods: Simultaneous measurements of qualitative foot warmth, measured foot temperature, and perfusion indicator value were obtained on 39 critically ill children ages newborn to 18 years, at least every 2 hours for 48 hours, with 859 measurements completed.
Results: There was a positive correlation between all three parameters ($p = \leq 0.0001$); however, there was a large amount of variability within groups.
Conclusion: Qualitative assessment of foot warmth and peripheral perfusion indicator may be helpful in assessing the perfusion in critically ill pediatric patients, but neither is predictably specific as compared to measured foot temperature.

The assessment of perfusion in critically ill patients is a routine practice in most intensive care units (ICUs) and is described in the *American Association of Critical Care Nurses Core Curriculum of Pediatric Nursing* (Slota, 2006). Commonly, this assessment is done serially, such as every 2 to 4 hours throughout the patient's stay. Most pediatric intensive care units (PICUs) have policies or guidelines that specify the components of these assessments, which usually include the quality of peripheral pulses, capillary refill time, color, and extremity warmth. The evaluation of peripheral extremity warmth is an accepted practice in the assessment of peripheral perfusion. It is most commonly performed by caregiver tactile assessment of the warmth of the foot and/or toe. Peripheral warmth is an important aspect of care for critically ill children to assist in identifying alterations in perfusion, to monitor the effect of treatments, and to prevent decompensation through meticulous observations for early changes that allow timely interventions.

This qualitative method is widespread, although it is subjective and may lack inter-rater reliability. The nurse typically documents the degree of warmth based on descriptions that may or may not be standardized by individual units, such as warm, slightly warm, slightly cool, cool, and cold. It might be difficult to demonstrate a high level of inter-rater reliability within these categories. For example, what one provider might assess as slightly cool might be assessed as slightly warm by another. This provides for subjectivity in care across providers, shifts, and units. When available, objective and quantitative assessment parameters are preferred over those that are subjective or qualitative in nature. For this reason, a review of the literature was performed to determine the usefulness of a measured foot temperature as well as the derived perfusion indicator, which is available through the pulse oximeter signal on some monitors. A review of the literature demonstrated the validity of the measured peripheral skin temperature as an assessment of perfusion. Only one study was identified on the application of the perfusion indicator.

Review of the Literature

A classic study by Ibsen (1967) demonstrated that a decrease in effective circulating blood volume causes vasoconstriction, decreased peripheral perfusion, and a decrease in peripheral skin temperature. In this study, the skin temperature was measured on the thumb of adults as 500 mL of blood was removed. He recorded normal vital signs, with a drop in skin temperature. He postulated the blood pressure (BP) was maintained by vasoconstriction as measured by cooling of the thumb temperature. As the blood was re-infused, an increase in skin temperature was observed with no change in BP.

Additional studies in adult patients have found measured foot or toe temperatures to be valid assessment techniques. In an evaluation of 50 critically ill adults, toe temperature and tissue perfusion were compared. Tissue perfusion was evaluated by serum lactate

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Objectives and the CNE posttest can be found on pages 25-26.

values and cardiac index. Findings demonstrated a predictable correlation between toe temperature with serum lactate and cardiac index (Puri & Groves, 1984). Toe temperature was also used as an indication of the severity of shock in 100 adult patients (Joly & Weil, 1969). They described a highly significant correlation between cardiac index and toe temperature, and found that a toe temperature of less than 27 degrees Celsius was correlated with a cardiac index of less than 2L/min/m^2 95% of the time. They were also able to predict mortality based on early measurement of toe temperature.

Similar findings were noted in work comparing measured toe temperature to ambient room temperature. Henning, Wiener, Valdes, and Weil (1979) found the temperature gradient served as a more predictable indicator of survival than either invasive arterial BP or cardiac index. A similar study also evaluated measured toe temperature as compared to ambient room temperature in adults with septic shock. Vincent, Moraine, and van der Linden (1988) observed a lower toe temperature correlated with a low cardiac index, stroke index, and oxygen transport. Kholoussy, Sufian, Pavlides, and Matsumoto (1980) measured core rectal temperature and toe temperature in 65 critically ill adults admitted to a trauma shock unit. They found that an abnormal core-to-toe temperature gradient defined as greater then 4 degrees Celsius either coincided or preceded other alternations in clinical status, such as unstable vital signs.

The pediatric literature is somewhat limited, but two articles that found similar results to the adult studies were identified. Aynsley-Green and Pickering (1974) described a number of cases where core versus peripheral temperatures were used to monitor critically ill children. When a gradient developed, the children were treated with IV fluid with an observed normalization of vital signs and increase in peripheral temperature. In the second study, 70 infants and children were evaluated after congenital heart surgery, and a correlation was found between toe temperature warm-up time and other parameters, including cardiac index and blood pH (Knight & Opie, 1981).

In a study that compared three toe temperature assessment techniques (measured toe temperature, bedside registered nurse [RN] subjective assessment, and expert RN with advanced, focused training subjective assessment),17 children were studied after open heart surgery with 119 assessments completed (Fagan, 1988). Researchers observed good correlation between the three measurement techniques.

A novel but unproven approach for assessing peripheral perfusion is available as standard equipment. Phillips Medical Systems pulse oximetry probe can derive a "perfusion indicator" from the pulse oximetry signal. This perfusion indicator is derived from the ratio of the pulsatile component of the light reaching the light-sensitive cells to that of the non-pulsatile component. The signal's intent is to provide information about the quality of the pulse oximeter signal. While the authors were designing their study, one adult study that evaluated this technology for this purpose was identified. The peripheral perfusion index derived from the pulse oximetry signal as a non-invasive indicator of perfusion was considered. Lima, Beelen, and Bakker (2002) evaluated 108 healthy adults and 37 critically ill adult patients. In the critically ill group, 74 measurements were performed, including capillary refill time, arterial oxygen saturation, central-to-toe temperature gradient, and other hemodynamic variables. Lima et al. (2002) reported a significant correlation between changes in peripheral perfusion indicator and changes in core-to-toe temperature difference, and proposed the use of the peripheral perfusion indicator as a measurement of perfusion.

Although a moderate amount of literature exists to support measured toe or foot temperature as an indicator of perfusion in critically ill patients, it has not become standard of care across all PICUs. In most PICUs, qualitative evaluation of warmth continues to be the standard of care as a parameter of assessing perfusion in critically ill children. Due to the subjective nature of qualitative assessments, it may not accurately reflect the actual temperature, and therefore, may not be the best method for assessing changes in perfusion. Additionally, the perfusion indicator derived from the pulse oximetry signal may have value in assessing perfusion, but it has not been studied in children.

Purpose

The purpose of this study was to compare and correlate three methods of assessing peripheral perfusion in critically ill children. Methods included measured foot temperature, bedside RN qualitative assessment of foot warmth, and perfusion indicator value derived from the pulse oximetry signal.

Methods

Setting and sample. This study was conducted in a 26-bed multispecialty PICU at Children's Hospital and Regional Medical Center in Seattle, WA. The PICU is a quaternary referral center caring for critically ill medical and surgical patients from newborn to 21 years of age. Eligible participants included children in the PICU who were critically ill, intubated, and expected to remain so for at least 48 hours. A convenience sample of 39 critically ill children were enrolled. Exclusionary criteria included children undergoing extracorporeal membrane oxygenation (ECMO) or children with skin breakdown, tissue grafts, or necrosis of a lower extremity.

Procedure. The study was approved by the Institutional Review Board (IRB) at Children's Hospital and Regional Medical Center in Seattle and carried out with the ethical standards set forth in the Helsinki declaration of 1975. Informed consent and Healthcare Information and Portability Accountability Act (HIPAA) consent were obtained from the parents prior to enrollment.

Once consent was obtained, the pulse oximetry probe was applied to the great toe. All patients received pulse oximetry monitoring as standard of care, but in the study, the probe was standardized to placement on the great toe. The skin temperature probe was applied to the skin below the same great toe on the medial plantar surface. The temperature probe was insulated with the provided foam adhesive to prevent interference from ambient temperature. The bedside nurse caring for the patient was instructed to rotate the pulse oximetry probe according to unit standard of care every 8 hours. At the same interval as pulse oximetry probe rotation, the bedside RN was instructed to rotate the skin temperature probe to ensure it remained on the same foot as the pulse oximetry probe. The bedside RN documented qualitative assessment of foot warmth every 2 hours on the nursing flow sheet according to unit standard of care. Qualitative measurements were described as one of the following: warm, slightly warm, slightly cool, cool, or cold. Simultaneous measured foot temperatures were recorded every 2 hours by the bedside monitor in degrees Celsius.

The perfusion indicator was derived from the pulse oximeter probe and recorded every 2 hours by the bedside monitor. Measurements were recorded for 48 hours, with a goal to obtain 24 samples per patient. Each sample set was to include the RN qualitative assessment, measured foot temperature, and derived perfusion indicator. The bedside RN was blinded to the

Table 1.
Demographics

Age	Number	Average PRISM III (Range)	Open-Heart Surgery	Respiratory Failure	Sepsis	Oncological Diagnosis	Post-Op Liver Transplant
0 to 1 year	14	6 (0 to 15)	12	1	0	0	1
1 to 8 years	13	8 (0 to 26)	3	4	4	2	0
8 to 18 years	12	9 (3 to 14)	4	2	5	1	0

Table 2.
Correlation Between Measured Foot Temperature and RN Qualitative Assessment of Foot Warmth

Statistic Type	Statistic Value	*p* Value
Spearman rank correlation (*p*) (all ages)	**0.64**	**< 0.0001**
Age 0 to 1 years	0.63	< 0.0001
Age 1 to 8 years	0.69	< 0.0001
Age 8 to 18 years	0.53	< 0.0001
Pearson linear correlation, *r*, and proportion of total variation explained (*r*2) (all ages)	**0.70 (0.49)**	**< 0.0001**
Age 0 to 1 years	0.67 (0.45)	< 0.0001
Age 1 to 8 years	0.71 (0.50)	< 0.0001
Age 8 to 18 years	0.71 (0.50)	< 0.0001

Table 3.
Correlation Between Measured Foot Temperature and Perfusion Indicator

Statistic Type	Statistic Value	*p* Value
Spearman rank correlation (*p*) (all ages)	**0.57**	**< 0.0001**
Age 0 to 1 years	0.54	< 0.0001
Age 1 to 8 years	0.66	< 0.0001
Age 8 to 18 years	0.36	< 0.0001
Pearson linear correlation, *r*, and proportion of total variation explained (*r*2) (all ages)	**0.46 (0.21)**	**< 0.0001**
Age 0 to 1 years	0.36 (0.13)	<0.0001
Age 1 to 8 years	0.55 (0.30)	< 0.0001
Age 8 to 18 years	0.38 (0.15)	< 0.0001

measured foot temperature (parameter was stored in monitor, but not displayed on bedside monitor), and unaware of collection of the perfusion indicator as part of the study. The perfusion indicator was not used as standard of care in the PICU prior to or during this study.

The measured foot temperature and derived perfusion indicator were retrieved from bedside physiological monitors retrospectively and matched to the times of the RN qualitative assessment of warmth. Only simultaneous assessments were included in the data set.

Instrumentation. The measured foot temperature was obtained using the Philips® Viridia monitor (Philips Medical Systems) and a disposable Mon-a-therm® skin temperature probe (Mallinckrodt Medical). The measurement range available was 0.1 to 45 degrees Celsius, with a sensitivity of 0.1 degrees.

The peripheral perfusion indicator was obtained using the Philips Viridia monitor (Philips Medical Systems) and disposable Nellcor® pulse oximetry probes (Mallinckrodt Medical). The measurement range available was 0.1 to 15. The sensitivity was not defined by Philips Medical Systems, although the company states a signal quality of 0.3 to 1 was considered acceptable to measure arterial pulses for pulse oximetry. A measurement of greater than 1 was considered optimal.

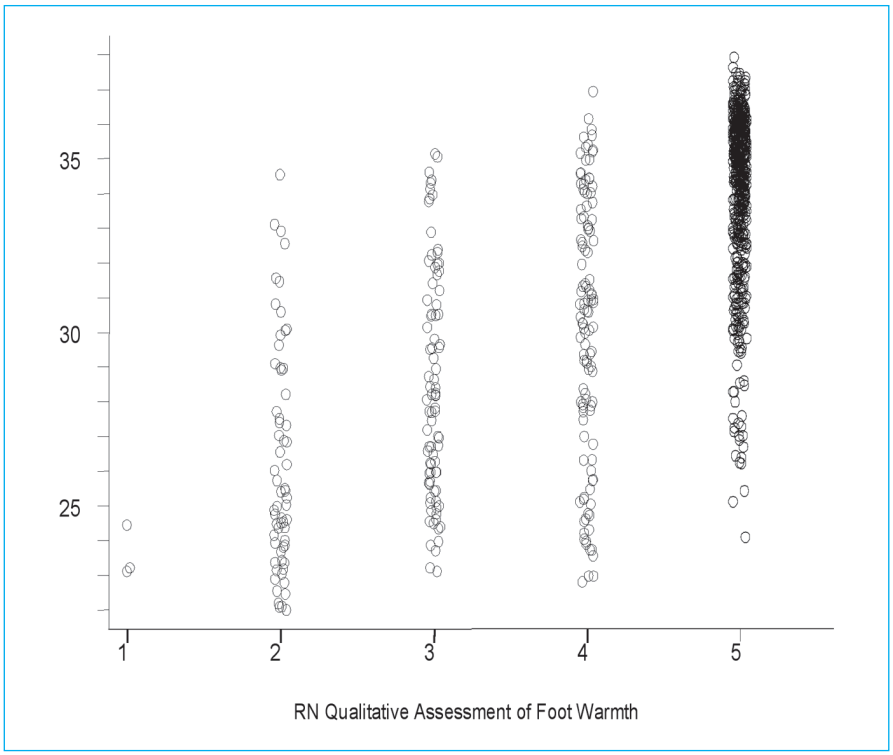
Data Analysis and Findings

Thirty-nine critically ill patients were enrolled (see Table 1). Ages ranged from 0.1 to 18 years, with an average of 4.8 years. An attempt was made to enroll patients in three general age ranges: less than 1 year old (14), 1 to 8 years old (13), and 8 to 18 years old (12). Diagnoses were generalized and divided into four categories: status post open heart surgery (n = 19), respiratory failure (n = 7), septic shock (n = 9), and primary oncological diagnosis (n = 3). There was also one patient recovering from a liver transplant.

PRISM III – Pediatric Risk of Mortality scores were collected at 12 hours after admission to the PICU. This score is based on 17 physiological parameters subdivided into 26 groups (Pollack, Patel, & Ruttimann, 1996). Factors, such as metabolic status, condition on admission to the ICU, and worse vital signs, were included. The score has no absolute upper limit, but in general, a higher score is associated with a higher risk of mortality. Many PICUs use this scoring system as an indication of the patient acuity. The range of the authors' PRISM III scores was 0 to 26, with an average of 7.8.

Only complete data sets with all three components of perfusion assessment were used in the analysis, and 859 data sets met this requirement. Each assessment set was considered an independent event. There was an average of 22 measurements completed per patient with a range of 9 to 31. For most patients, all 24 measurements repre-

Figure 1.
Correlation of Measured Foot Temperature and RN Qualitative Assessment of Foot Warmth (All Ages)



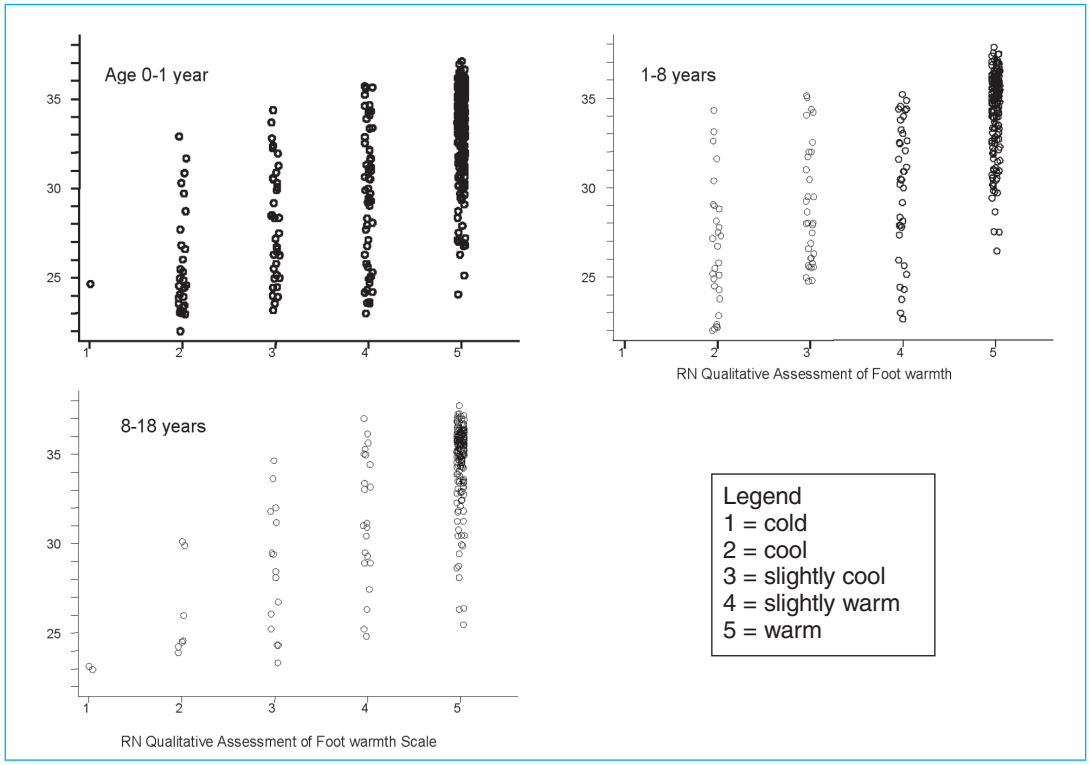
Legend
1 = cold; 2 = cool; 3 = slightly cool; 4 = slightly warm; 5 = warm.

sented complete data. Some patients had missing data points related to lack of documentation or poor performance of the pulse oximetry probe with loss of signal. For 7 very ill patients, additional sets of data were included because the data set was completed for those patients, representing more frequent assessment of perfusion than every 2 hours. Analysis was initially completed with all ages, then by age groups 0 to 1, 1 to 8, and 8 to 18 years old.

The authors found that measured foot temperate and RN qualitative assessment of foot warmth were positively correlated and statistically significant in all groups ($p \leq 0.0001$) (see Table 2). However, the degree of overlap between the ranges of measured foot temperatures for adjacent categories on the qualitative RN assessment was very high. It is impossible to map distinct temperature bands to the qualitative assessments (see Figure 1). On analysis by age (0 to 1 year, 1 to 8 years, 8 to 18 years), there were similar results, although a trend was recognized that those greater than 8 years old had less overlap than in younger children (see Figure 2).

Measured foot temperature and the perfusion indicator were also positively correlated and statistically signifi-

Figure 2.
Correlation of Measured Foot Temperature and RN Qualitative Assessment of Foot Warmth (by Age)



cant in all groups ($p = < 0.0001$) (see Table 3). However, a preponderance of perfusion indicator measurements at zero remains with all foot temperatures (see Figure 3). An age relationship to the correlation may exist because perfusion indicators were noted greater than 8 in the two older groups, but none were noted in the youngest group (see Figure 4).

Discussion

Although there was a statistically significant correlation between all three parameters, the correlation was not distinct or predictable when looking at individual patients. When reviewing individual patients and data points, there was significant overlap in many parameters. For example, for any given measured foot temperature, a significant range of RN assessments was recorded to be warm, slightly warm, slightly cool, and cool, with only three recordings of cold. Specifically, at measured foot temperatures in the ranges of 28 to 32, there were numerous RN assessments recorded to be warm, slightly warm, slightly cool, and cool. Additionally, similar results were noted when comparing the measured foot temperature with the perfusion indicator. A perfusion indicator of zero was noted at every measured foot temperature.

Limitations

A variety of ages and conditions was studied. As noted, the PRISM III scores varied from 0 to 26, indicating a wide range of acuities. The authors did not control the bedside RNs that performed the assessments. The RN who was assigned to the patient was used, believing that this more accurately reflected the ICU environment. The authors did not attempt to control the environmental temperature and did not note if patients were cared for under any extraneous warming device, such as warming tables or warming blankets.

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Figure 3.
Correlation of Measured Foot Temperature and Perfusion Indicator (All Ages)

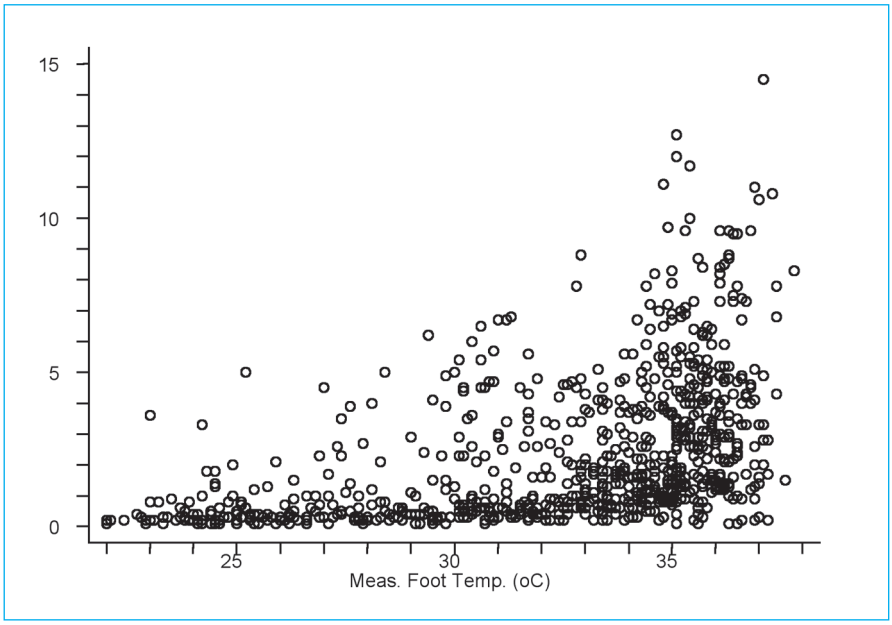

Figure 4.
Correlation of Measured Foot Temperature and Perfusion Indicator (by Age)