Thermographic Imaging: A Novel Method of Diagnostic Hemodynamic Monitoring

A. Project Aim:

I hypothesize that differences between core and peripheral body surface temperature, as detected by infrared thermal imaging, will correlate with established clinical indicators of cardiac output. A mathematical model reflecting these temperature gradients will effectively predict impending compromise of clinical cardiovascular status in Pediatric patients following congenital heart surgery.

Specific Aim1: Establish baseline thermographic data for healthy pediatric infants less than 6 months of age.

Specific Aim2: Test the hypothesis that thermographs obtained in the first 24 hours post operatively following surgery for congenital heart disease will correlate to currently accepted clinical indicators of cardiac output.

Specific Aim3: Test the hypothesis that thermal images can be converted into a numerical index that correlates with established, invasive measures of cardiac output.

B. Background:

Infants undergoing corrective or palliative surgery for congenital heart disease are at high risk for low cardiac output syndrome (LCOS) [1] following their operation. LCOS carries high risk for morbidity and mortality without prompt recognition and appropriate intervention [1, 2]. Currently accepted, objective measures of cardiac output include urinary output, heart rate, mixed venous oxygen saturation and lactate acid production. Variations in these indices create a clinical picture over a time scale of minutes to hours. While they represent the mainstays of monitoring, they do not provide effective moment-to-moment assessment that can drive early recognition of a problem and support rapid intervention. To that end, various measures of tissue perfusion such as near-infrared spectroscopy (NIRS) estimation of tissue oxygenation, clinical capillary refill testing and palpation of skin surface temperature of the extremities have been utilized to make moment-to-moment assessments. NIRS is expensive, subject to inconsistency and provides only highly localized assessment of perfusion. Capillary refill is subjective at best and fraught with inherent operator variability that makes reproducibility of results between individuals virtually impossible. Environmental conditions, systemic vascular resistance, and other hemodynamic conditions influence peripheral skin temperature. Despite these and other shortcomings, peripheral skin temperature remains the cornerstone of bedside assessment as well as basis for changes in treatment in spite of multiple studies that question its utility and accuracy [3-6].

After more than a decade of research documenting poor correlation between subjective peripheral skin temperature assessment and outcomes, a 2014 case report used thermographic imaging to detect early stages of shock in a pediatric patient [7]. Thermographic imaging (Fig. 1) is not new technology, but this is a novel application. It allows precise multi-point temperature discrimination that is accurate, affordable, portable, and reproducible. Thermography detects infrared radiation emitted from the surface of an object. The emitted infrared radiation is related to the object’s temperature thus allowing for accurate, reproducible measurement of surface temperature by way of cutaneous heat radiation. Every material has an associated emissivity value representing the material’s effectiveness in emitting thermal radiation with values ranging from 0 to 1. The closer to 1 an object’s emissivity value, the closer and more reliable the temperature measured will be to the actual surface temperature. The emissivity of skin is approximately 0.98 making human skin particularly suitable for temperature measurement using thermography [8]. Non-contact temperature...
measurement via thermography may actually be more accurate than contact-based methods[9]. These advantages address many of the current shortcomings of peripheral temperature measurement by touch or a local thermistor and make thermography a novel, non-invasive monitoring modality. However, there are currently extremely limited data available, particularly in the pediatric population.

C. Preliminary Data:

While thermography has a broad range of applications, reports of clinical utility have been limited. Rich, et al described the use of thermographic imaging to detect pneumothorax in experimental rat models [10]. In 2012, researchers used thermographic imaging to detect minute temperature changes consistent with deposits of brown adipose tissue in healthy children [11]. The documented ability of thermographic imaging to detect early shock in a pediatric patient [7] highlights the vast potential of this novel approach. Extensive work has been done describing baseline thermographic data in upper and lower limbs of healthy adults [8]. These data established several key principles regarding the nature of thermographic images in healthy adult subjects. The first principle is the general symmetry in terms of mean temperatures for both sides of the body as shown in Figure 1. Also observed, the mean temperatures of extremities such as fingers, toes, or dorsal surfaces of the feet are lower in relation to their “core” areas, namely, the volar and plantar surfaces. Finally, when considering the hands, there is a decrease in temperature from the thumb to the fifth digit. In the feet, the hallux and fifth digit have elevated temperatures in relation to the second, third, and fourth digits. Such baseline thermographic data has not yet been generated in the pediatric population. Previous novel successes with thermography in pediatric population, as well as the lack or normative data in children merit further evaluation of the utility of this technology in the pediatric setting. The pediatric cardiac intensive care unit serves as a unique “clinical laboratory” for thermography studies as in this setting extensive data regarding the perfusion and well being of the patients are being continuously captured. Thermography data may be indexed and/or compared to these standards.

D. Research Design and Methods:

Specific Aim1

Rationale: Normative thermographic data have not been established in healthy pediatric patients. Such data are essential and will serve as the foundation for comparison for future studies in patients who have undergone surgical correction of congenital cardiac abnormalities.  

Experimental Design: Healthy subjects will be recruited from the Vanderbilt Pediatric Resident Continuity Clinic at their 2-week, 1-month, 2-month, 4-month, and 6-month Well Child Check-ups. Thirty patients will be selected in each age group and baseline thermographic images obtained. Subjects will be left naked at room temperature for 2 min prior to initiation of imaging and data will be obtained once per minute for 5 min and used only if they are able to remain calm. Demographic data will be recorded for each subject including anthropometric measurements. Anatomic sites of interest will include the canthus or the eyes (closest approximation of core temp), ventral surface of the hands and feet, anterior aspects of the leg, forearm, chest, and abdomen. Each of these areas will be annotated using a standardized template and mean thermographic temperatures will be tabulated from each of the annotated areas of interest. The standard for establishment of “true” core temperature will be a rectal thermometer measurement. Patients with inter-current illness or complicating existing diagnosis will be excluded.

Fig. 2 (8)
**Expected Outcome:** Baseline thermographic maps will be created for healthy pediatric patients in each age group. An important aspect of this data set from healthy subjects will be determination of the range of variability in surface temp mapping.

**Statistical Consideration:** Descriptive statistical analysis will be utilized to the describe the data obtained.

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**Specific Aim 2**

**Rationale:** In infants with congenital heart defects undergoing corrective or palliative cardiac surgery, the early recognition of adverse alterations in tissue perfusion and cardiac output is key to decreasing postoperative mortality and morbidity. Thus, utilization of monitoring strategies, such as thermographic imaging, that yield real-time accurate and reproducible indices of changes in tissue perfusion will increase the safety and improve the care of these patients.

**Experimental Design:** Subjects less than 6 months of age will undergo the routine post-operative care in the Pediatric Cardiac Critical Care unit at Vanderbilt Children’s Hospital. Initial imaging will include the entire, uncovered body. Subsequently a minimum of one arm and one leg will remain exposed and thermographs will be taken every minute for the first 24 hours using a pole-mounted camera set above the patients bed. This will generate a thermographic movie consisting of 1440 frames. These data will be retrospectively correlated with recorded changes in lactate acid, urinary output, cerebral Near Infrared Spectroscopy (NIRS), vasoactive inotropic score, and arterial/venous blood gases as documented in the electronic medical record. Core temperatures will be recorded by rectal thermistor on a continuous basis.

**SA2a. Hypothesis:** Temperature changes on thermographs will correlate to changes in cardiac output and tissue perfusion after corrective or palliative cardiac surgery.

**Expected Outcome:** A widening temperature differential noted on proximal to distal thermographs will represent adverse changes in tissue perfusion and correlate with increased lactate acid production, decrease urinary output, decrease NIRS, increase vasoactive inotropic score, and metabolic acidosis as exhibited on arterial/venous blood gases. The converse will be true for narrowing temperature differentials noted on proximal to distal thermographs.

**Statistical Consideration:** Nonparametric statistical methods will be used to assess differences between groups for continuous variables. Spearman’s correlation and linear regression will be used to show relationship between continuous variables.

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**Specific Aim 3**

**Rationale:** The gold standard for cardiac output measurement is either Fick method, particularly used in patients with intra-cardiac shunts, or thermal dilution. Both methods are invasive requiring cardiac catheterization and often sedation and intubation for infants and toddlers adding further risk to the procedure. Noninvasive methods of accurately calculating cardiac output would reduce the need for invasive measurement modalities that place patients at albeit small but increased risk.

**Experimental Design:** Continuous thermal images will be captured from a non-instrumented extremity of patients undergoing routine hemodynamic cardiac catheterization. Inclusion criteria will include patients status post heart transplantation with otherwise normal cardiac function by echocardiogram who are undergoing routine hemodynamic catheterization. Patients with decreased cardiac function by echocardiogram will be excluded.

**SA3a. Hypothesis:** Data from cardiac catheterizations will validate the utility of thermographic imaging as a surrogate for cardiac output.

**Expected Outcome:** A logarithmic mathematical model of cardiac output will be created using body surface thermographic temperature differentials and validated against gold standard measurements such as the Fick method or thermal dilution.

**Statistical Consideration:** Spearman’s correlation and linear regression modeling will be sued to show relationship between measured thermographic temperatures and cardiac output measured by Fick or thermal dilution.

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**E. Significance and Future Directions:**
As surgical techniques advance and the ability to intervene on patients with congenital heart disease improves, there is shifting focus on the ability of specialized pediatric cardiac intensive care units to support and treat these patients during their period of highest vulnerability, the first 24-hours post operative. Modalities that increase the provider’s awareness of subtle but often ominous changes ultimately lead to earlier therapeutic interventions and improved outcomes. If the proposed hypotheses are proven correct, this research will not only mark a key advance in pediatric cardiac intensive care but also establish the relevance of a key technology that to date has been grossly under utilized in the pediatric population.

Much like modern telemetry monitoring systems, the latest thermographic cameras have Bluetooth and Wi-Fi capabilities that allow them to easily interact with established wireless networks. Consequently, patients’ thermographic images may be viewed, monitored, and processed remotely. As this proposed research establishes baseline normative data and defines the correlation between thermographic changes and cardiac output/tissue perfusion, it is easy for one to perceive a thermographic camera in every intensive care room remotely projecting multi-patient thermographic images to a central monitoring station observing for adverse changes in tissue perfusion just as current telemetry monitors for changes in rhythm and respiratory patterns.

References Cited:
