

# Variation in Arterial Inflow Temperature: A Regional Quality Improvement Project

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**Abstract:** Peer-reviewed evidence (Class IIa, Level B) suggests that arterial blood temperature should be limited to 37°C during cardiopulmonary bypass. We implemented a regional quality improvement initiative to reduce regional variability in our performance around this recommendation at four northern New England medical centers between January 2006 and June 2010. Cardiovascular perfusionists at four medical centers collaborated by conference calls regarding blood temperature management. Evidence from the recommendations were reviewed at each center, and strategies to prevent hyperthermia and to improve performance on this quality measure were discussed. Centers submitted data concerning highest arterial blood temperatures among all isolated coronary artery bypass grafting procedures between 2006 through June 2010. Scope and focus of local practice changes were at the discretion of each center. The timing of each center's quality improvement initiatives was recorded, and adherence to thresholds of 37°C and 37.5°C were analyzed.

Data were collected prospectively through our regional perfusion registry. Data were available for 4909 procedures (1645 before interventions, 3264 after interventions). Prior to the quality improvement interventions, 90% of procedures had elevated arterial line temperatures (37°C or more), and afterwards it was 69% ( $p < .001$ ) for an absolute difference of 21%. Prior to the intervention, 53% of procedures had temperatures beyond a threshold of 37.5°C versus 19% subsequent to interventions, for an absolute difference of 34% ( $p < .001$ ). This regional effort to reduce patient exposure to elevated arterial line temperatures resulted in a significant sustained reduction in high arterial outflow temperatures at three of the four centers. A regional registry provides a means for assessing performance against evidence-based recommendations, and evaluating short and long-term success of quality improvement initiatives. **Keywords:** cardiopulmonary bypass, cerebral protection. *JECT. 2011;43:58–63*

Evidence-based clinical practice guidelines are frequently developed to assist clinicians in summarizing the depth and breadth of literature on important aspects of clinical care. In a recent evidence-based review of the liter-

ature relating to cardiopulmonary bypass (CPB) by Shann and colleagues, recommendations were published for the practice of CPB in adults undergoing isolated coronary artery bypass grafting surgery (1). Nonetheless, the effectiveness of such guidelines in changing practice has recently been called into question (2).

Perfusionists whose centers participate within The Northern New England Cardiovascular Disease Study Group (NNECDSG) reviewed the Shann et al. recommendations as a benchmark for assessing the quality of care provided within our region. To this end, we postulated that

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our regional cardiovascular perfusion registry could be used for tracking a medical center’s performance around each recommendation (3). Our regional data showed wide variability in practice, and our regional perfusion group identified one particular recommendation as an area for investigation and improvement, namely the avoidance of hyperthermia.

We sought to leverage our regional registry and our expertise in undertaking process improvement projects, to reduce the incidence of hyperthermia in the setting of CABG surgery. In January 2006, we conducted a regional quality improvement project among patients undergoing CABG at four of eight NNECDSG centers.

**METHODS**

**Data Collection**

The NNECDSG is a voluntary research consortium, composed of clinicians, research scientists, and hospital administrators, representing all medical centers in Maine, Vermont, and New Hampshire where cardiac surgery is performed. Since 1987, the NNECDSG has maintained a prospective registry of all patients undergoing cardiac surgery in the region. The group fosters continuous improvement in the quality of care of patients with cardiovascular disease in the region through collection and analysis of process and outcome data and the timely feedback of data to clinicians. Previous publications by the NNECDSG have discussed in detail our data collection methodology and definitions (4).

Since 1996, centers participating in the NNECDSG have collected data concerning the conduct and practice of CPB among coronary and valve procedures. The contents of this form may be downloaded from our website ([http://www.nnecds.org/data\\_forms\\_2.htm](http://www.nnecds.org/data_forms_2.htm)). Of interest to this study, highest arterial line temperature was defined as

“(H)ighest temperature reached by the arterial inflow during re-warming.” For this study, hyperthermia was defined as highest arterial line temperature greater than 37°C.

Institutional review board approval has designated the NNECDSG as a quality improvement registry at three of the member centers and therefore patient consent was not required. The fourth center required patient consent.

**Development and Execution of a Regional Quality Improvement Study**

Representatives from each participating center meet three times per year in person in conjunction with our standing regional conferences and listserves. During these meetings, our perfusion group discusses a variety of topics including variability in practice patterns. These discussions are informed by previous analyses of our regional registry and an annual perfusion report.

All NNECDSG centers were invited to participate in this regional quality improvement project concerning reducing the rate of hyperthermia. Ultimately, four centers elected to participate in this quality improvement study. Additionally, one of the four centers had already adopted the practices recommended by Shann et al. and served as our internal benchmark.

Perfusionists collaborated by conference call regarding blood temperature management. A stepwise process was undertaken, whereby participating perfusionists first shared their rewarming process, followed by calibration of equipment, and subsequent improvement interventions (Table 1). In all cases, interventions were not centrally dictated, but were chosen through local census by medical center-specific teams.

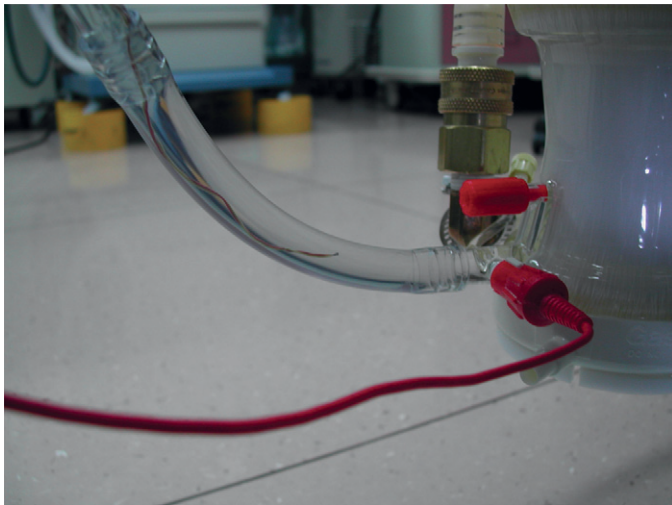
**Calibration of Outflow Temperature Monitoring System**

A process for validation and calibration of the coupled temperature ports as recommended in the guideline

**Table 1.** Temperature monitoring site and warming strategy at each medical center.

	Medical Center			
	One	Two	Three	Four
Monitoring site	Bladder on most cases, although nasopharyngeal alternatively	Bladder	Nasopharyngeal and pulmonary artery	Bladder
Rewarming strategy	In most cases rewarming is started as soon as bypass is initiated (the patient might have drifted down to 35 degrees at that point). In other cases, patients may be cooled to as low as 30 degrees for non-deep hypothermic circulatory arrest procedures).	Core temperature is allowed to drift 34.5 degrees after initiation of CPB by setting the heater cooler to 34.5 degrees	Core temperature is left to drift between 33–35 degrees.	After going on pump the blood is cooled to 32–33 degrees and bladder is let to drift down. Upon re-warming, the heater cooler is set to 37.5 degrees.
Target core temperature at separation	Bladder temp is usually in mid-36 degrees at the end of bypass. Timing for ending bypass is not determined by the patient’s core temperature.	Patient is separated from bypass at a core of no lower than 36 degrees	Patient is separated from bypass at a core temperature of 36.5–37.0 degrees.	Patient is separated from bypass at a bladder temperature of 36 degrees, or sometimes 35.5 degrees.

published by Shann et al. was discussed and each center agreed to independently validate the temperature measurement accuracy of the arterial blood temperature monitoring port of the CPB circuit. Previous studies have shown that the standard membrane oxygenator arterial outlet temperature probe underestimates the perfusate temperature (5). A precision biomedical-grade temperature analyzer (Fluke Corporation, Everett, WA) was used at each center, with the probe being placed into the tubing adja-



**Figure 1.** A Fluke temperature probe was inserted in-line just distal to the oxygenator outlet temperature probe site measuring the actual temperature of the perfusate simultaneously with temperature measurements from the heart-lung machine.

cent to the arterial temperature port of the oxygenator (Figure 1). Clear crystalloid priming solution was recirculated at 4 liters per minute (LPM) in a closed loop, with the heater-cooler thermostat being set variously at 30°C, 38°C, and 40°C. Measurements were taken when the temperatures were judged to be at a steady state. Results ranged from a displayed temperature on the heart-lung console that was one degree lower than that seen on the thermistor to readings that were .05 degrees higher than the thermistor. For the center with a one degree variance between displayed temperature and actual inflow temperature, the readings and recorded temperatures were corrected. The site of core temperature measurement in the body was also noted for each patient.

### Process Improvement

Evidence related to high arterial blood temperature was distributed prior to the second conference call (references 1,5–8). Participants focused on how they might disseminate this evidence internally within their medical centers, including to surgeons, anesthesiologists, and perfusionists. Methods for reducing high inflow temperatures were discussed including lowering the target temperature for separation from CPB, reducing the rate of rewarming, resetting heater-cooler thermostats to prevent hyperthermia, and employment of an audible high temperature alarm. The scope of the project and the interventions to be performed was at the discretion of each medical center. Table 2

**Table 2.** Changes undertaken by each medical center.

Medical Center			
One	Two	Three	Four
Discussion of Shann et al. recommendations with perfusion staff	Discussion of Shann et al. recommendations with perfusion staff	Discussion of Shann et al. recommendations with perfusion staff	Talked with perfusionists about avoidance of hyperthermia and calibrating coupled ports
Discussion with surgeons about the Shann et al. recommendations; Surgeons don't typically inquire about outflow temperature	Discussion with surgeons about the Shann et al. recommendations and revised target separation temperature from 37–36 degrees; Edited surgeons CPB guideline protocols	Set audible outflow temperature alarm at 38 degrees	Discussed limitations of bladder as a core temp. and decreased separation temp. from 36.0–35.5 on some cases
Set audible outflow temperature alarm at 37 degrees	Set audible outflow temperature alarm at 37 degrees	Used a tympanic probe to check the probes but not the accuracy of the temperature probe site	Implemented temperature alarm initially at 36.5 reflecting true temp of 37.5
Used a Medtronic BioCal heater cooler (Medtronic Corp., Minneapolis, MN) that did not have preset temperature limits	Shared temperature performance data with senior leadership and obtained approval to purchase heater cooler with .5 degree temperature adjustments	Validated coupled temp port with Fluke thermometer	Purchased new heater-coolers but not until June 2009
Validated coupled temp port with Fluke thermometer	Validated coupled temp port with Fluke thermometer		Talking about adopting different core temperature measurement, NP
Set arterial temp >37 as a quality indicator in the Databahn DMS software (Stöckert Instrumente GmbH, Munich, Germany)	Set arterial temp >37 as a quality indicator in the Databahn DMS software		Validated coupled temp port with Fluke thermometer

NP, neuropsychological.

summarizes the process improvement actions adopted at each medical center.

**Statistical Analysis**

The authors used STATA 11.0 program (Stata Corporation, College Station, TX) to analyze the data and standard methods for comparing continuous versus categorical data (9). The timing of each center’s quality improvement initiatives was recorded to denote cut-points in the data set. Performance against thresholds of 37°C and 37.5°C was analyzed. Authors had full access to the data and take

responsibility for its integrity. All authors have read and agree to the manuscript as written.

**RESULTS**

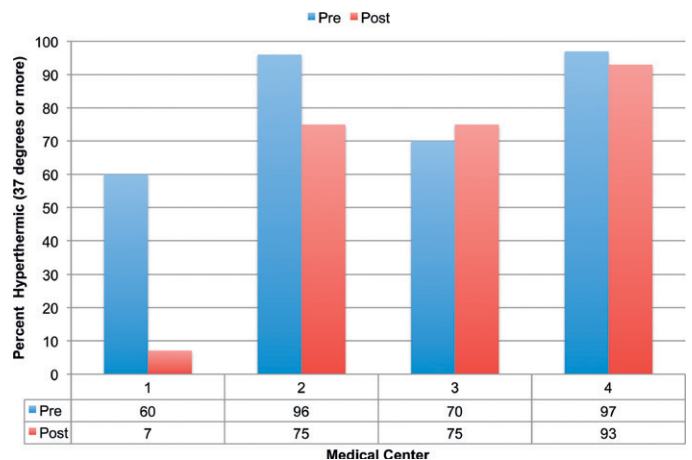
Data was available for 4909 procedures (1645 before interventions, 3264 after interventions). With some exceptions, most patient and disease characteristics were similar across the two time periods (Table 3). Patients in the post-intervention period had more chronic obstructive pulmonary disease (11.6 vs. 15.4,  $p < .001$ ), although less extensive coronary artery disease,  $p < .001$ .

Prior to the quality improvement interventions, 90% of procedures had elevated arterial line temperatures (37°C or more), and afterwards it was 69%,  $p < .001$ , for an absolute difference of 21% (Figure 2). Two of the four medical centers made statistically significant reductions in the percentage of patients experiencing hyperthermia ( $p < .001$ ). Medical center three had a small, non-significant increase in hyperthermia (70 vs. 75%,  $p = .35$ ). The two centers with the greatest absolute improvement were those where (1) the published guideline was discussed with the surgeon and (2) surveillance of high blood temperature as a quality indicator was aided with the use of a data acquisition system.

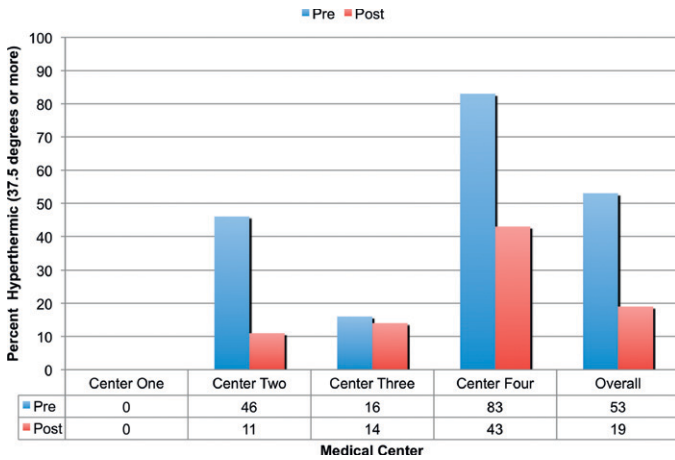
Prior to the intervention, 53% of procedures had temperatures beyond a threshold of 37.5°C, versus 19% subsequent to interventions, for an absolute difference of 34%,  $p < .001$  (Figure 3). None of medical center one’s patients were exposed to hyperthermia before the intervention, versus .4% post-intervention. Center two and four had statistically significant reduction in exposure to hyperthermia,  $p < .001$ , while center three had a non-significant reduction in exposure to hyperthermia,  $p = -.64$ .

**Table 3.** Characteristics of study population before and after intervention.

Variable	Before Intervention	After Intervention	<i>p</i> -value
Patients (number)	1645	3264	
<b>Demographics</b>			
Age (years, %)			
<65	48.6	47.3	
65–74	31.9	33.7	
≥75	19.5	19.0	
		<i>ptrend</i>	.73
Female gender (%)	25.6	22.5	.01
<b>Body mass index (kg/m<sup>2</sup>) (%)</b>			
<31	64.0	63.4	
31–36	25.1	25.0	
37+	10.9	11.6	
		<i>ptrend</i>	.55
<b>Comorbid disease</b>			
Diabetes, % yes	36.3	37.2	.52
Vascular disease, % yes	25.1	26.1	.41
Chronic obstructive pulmonary disease, % yes	11.6	15.4	<.001
Dialysis or creatinine ≥2, % yes	3.8	4.7	.18
<b>Cardiac anatomy and function</b>			
Left main stenosis (%)			
<50%	64.3	62.2	
59–89%	30.2	31.0	
≥90%	5.5	6.8	
		<i>ptrend</i>	.08
<b>Diseased vessels (#)</b>			
1	10.1	28.9	
2	36.6	43.2	
3	53.3	28.0	
		<i>ptrend</i>	<.001
<b>Priority (%)</b>			
Elective	29.9	27.5	
Urgent	60.5	65.2	
Emergent	9.6	78.1	
		<i>ptrend</i>	.99



**Figure 2.** Pre- and post-intervention rates of hyperthermia (defined as 37°C or more).



**Figure 3.** Pre- and post-intervention rates of hyperthermia (defined as  $37.5^{\circ}\text{C}$  or more).

## DISCUSSION

In this regional prospective quality improvement study, we sought to improve adherence to evidence-based recommendations concerning the prevention of hyperthermia. Four medical centers undertook changes to reduce the rate of hyperthermia, including inter-disciplinary discussions regarding the level of evidence supporting the deleterious effects of hyperthermia, validation, and calibration of the coupled temperature ports to improve the accuracy and reliability of temperature measurement, lowering the target temperature for separation from CPB, reducing the rate of rewarming, resetting heater-cooler thermostats to prevent hyperthermia, and employment of audible temperature alarms. While performance varied across medical centers, regional rates of hyperthermia significantly dropped, irrespective of using either  $37^{\circ}\text{C}$  or  $37.5^{\circ}\text{C}$  as the threshold for defining hyperthermia.

### Hyperthermia and Neurologic Injury

Neurocognitive dysfunction is a common complication after CPB, and an important cause of morbidity and mortality. Possible causes of neurocognitive dysfunction include microembolization, macroembolization, and inadequate cerebral perfusion (10). It is common practice to cool patients (hypothermia) on the heart-lung machine for tissue preservation and cerebral protection at times of low flow or inadequate tissue oxygenation. Hypothermia is unique among neuroprotective modalities in that it reduces energy consumption (about 7% per  $^{\circ}\text{C}$ ) associated with both electrophysiological function and maintenance of cellular integrity (11). Hypothermia does however have several distinct disadvantages, not the least of which is the requirement for rewarming the patient at the end of the procedure. Cerebral hyperthermia may occur during the rewarming period as an unintended sequelae of high

cerebral blood flow and the proximity of the carotid origins to the aortic cannulation site (6). The duration and degree of hyperthermia, especially in the cerebral territories may influence the incidence of neurologic morbidity (7). This relationship may be mediated by one or more of the following: release of excitotoxic neurotransmitters (glutamate), increase of oxygen-derived free radical production, increase of blood-brain barrier permeability and intracellular acidosis, and delay of neuronal metabolic recovery (6).

### Temperature Monitoring and Hyperthermia

The rate of hyperthermia may be influenced not only by processes of clinical care, but location of temperature monitoring. While there is no standardized temperature monitoring site for cardiac surgery, some of the following are commonly used: pulmonary arterial, nasopharyngeal, esophageal, bladder, and rectal. Unfortunately, each of these sites may variably reflect an accurate representation to “real” brain temperature (8,12). Nasopharyngeal temperature is considered by many centers to be the standard site for estimation of brain temperature due to its proximity to the cerebral circulation, although many centers still use core rectal or bladder temperatures.

Nussmeier (13) estimated the degree of variability in commonly used temperature monitoring sites relative to an approximation of cerebral temperature jugular bulb venous temperature. The investigators placed monitoring ports at: blood exiting the oxygenator, nasopharyngeal, esophagus, bladder, and rectum. During the rewarming period, temperature measured at nasopharyngeal, esophagus, bladder, and rectum sites underestimated jugular bulb venous temperature. As such, if rectum or bladder temperatures are used to guide rewarming practice, patients may be exposed to periods of cerebral hyperthermia while at the same time the perfusionists presumes to be practicing normothermic bypass. Based on these findings, only the temperature of the blood exiting the oxygenator and entering the patient provides an accurate approximation of jugular bulb venous temperature during rewarming. As such, the perfusionist must be attentive in limiting the arterial-inflow temperature to  $37^{\circ}\text{C}$  to prevent cerebral hyperthermia.

### Process Improvement to Reduce Hyperthermia

Recently, Shann and colleagues published recommendations for the practice of cardiopulmonary bypass in adults undergoing isolated CABG (1). In this document, the authors report on the evidence supporting the avoidance of hyperthermia. DioDato reported wide variability across eight medical centers participating in the NNECDSG in regional CPB practice concerning the rate of hyperthermia when utilizing a regional perfusion registry (3). As a consequence our regional perfusion group committed to analyzing practices relating to temperature management as

a mechanism for improving quality and patient safety. Although our results show that we decreased the number of patients exposed to hyperthermia on cardiopulmonary bypass, additional opportunities exist to reduce further rates of hyperthermia in this setting.

To effect these changes in practice, perfusionists must reflect upon their current systems, beliefs, and practices. Familiarization of the perfusionist and the surgeon with the evidence-based literature is essential. Current methods for measuring temperature must be assessed and validated. Our present findings suggest that a number of interventions may be helpful in reducing the rate of hyperthermia, including: verifying the accuracy of the coupled temperature ports to truly protect the patient from excessive inflow temperatures (on a routine basis), evaluating different sites and methods for measuring core temperature, and purchasing of new heater cooler water sources to enable precise rewarming strategies.

Regional quality improvement collaboratives may be used to leverage collective clinical and epidemiologic expertise and experience to reduce unwanted variability in practice as a mechanism for improving clinical outcomes. These efforts are accomplished not only through the collection of large sample sizes, but the aggregation, synthesis, and analysis of practice patterns, and timely feedback to the front-line clinicians. As an example, Pronovost and colleagues conducted a regional quality improvement effort to reduce blood stream infections (BSI) secondary to central line placement in intensive care units throughout Michigan (14). Because BSIs are fortunately rare (and thus difficult to study at an individual center level), Pronovost developed and implemented bundles of best practices at each participating medical center. Our work differed from that of Pronovost in two important ways. First, Pronovost standardized the intervention across centers and investigators measured both process-level variables (adherence to bundles of interventions) and outcome measures (BSIs). Second, Pronovost measured and reported on clinical sequelae of BSIs and cost. In our own work, regional practice standards were not developed or implemented, but rather in our study clinical teams designed unique local improvement efforts to reduce unwanted variability in technology or practice. The tests of change were not standardized across medical centers. Nonetheless, statistically significant improvements over time were realized in three of the four medical centers. One limitation of the study was that the interventions were left to the discretion of individual centers and were thus not standardized. Future regional efforts will focus on the development and adoption of standardized bundles of best practices for reducing rates of hyperthermia and associated clinical sequelae.

These changes in practice might include acceptance of a lower core temperature for separation from CPB, moderation of hypothermic practices for routine procedures, earlier commencement of rewarming, and decreased rates of rewarming. Each of these changes should be made in a collegial manner with all members of the team reaching agreement on the proposed changes.

Given the increasing public and private sector demands for the measurement and reporting of clinical practice, regional improvement collaboratives may provide a unique opportunity to shed light on unwanted variability, and opportunities for improving patient care. Further, registries afford clinicians with the ability to assess whether efforts to improve clinical care result in short and long-term improvements.

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