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Cardiopulmonary Bypass Recommendations in Adults: The Northern New England Experience

Christian P. DioDato, CCP;* Donald S. Likosky, PhD;† Gordon R. DeFoe, CCP;‡ Robert C. Groom, MS, CCP;§ Kenneth G. Shann, CCP;¶ Charles F. Krumholz, CCP, MSA;** Craig S. Warren, CCP;†† John W. Pieroni, CCP;‡‡ Arnold Benak, CCP;§§ Kevin McCusker, PhD, CCP;¶¶ Elaine M. Olmstead, BA;† Cathy S. Ross, MS;† Gerald T. O'Connor, PhD, DSc;† for The Northern New England Cardiovascular Disease Study Group

**Concord Hospital, Concord, New Hampshire; †Dartmouth Medical School, Hanover, New Hampshire; ‡Dartmouth-Hitchcock Medical Center, Lebanon, New Hampshire; §Maine Medical Center, Portland, Maine; ¶Montefiore-Einstein Heart Center, Bronx, New York; **Fletcher Allen Health Care, Burlington, Vermont; ††Eastern Maine Medical Center, Bangor, Maine; ‡‡Catholic Medical Center, Manchester, New Hampshire; §§Central Maine Medical Center, Lewiston, Maine; and ¶¶Portsmouth Regional Hospital, Portsmouth, New Hampshire*

Abstract: Using a regional cardiopulmonary bypass (CPB) registry, we compared the practice of CPB at eight northern New England institutions to recently published recommendations. We examined CPB practice among 3597 adult patients undergoing isolated coronary artery bypass grafting surgery from January 2004 to June 2005. Registry variables were used to compare regional CPB practice to recommendations on topics of neurologic protection (pH management, avoidance of hyperthermia, minimizing return of pericardial suction blood, aortic assessment, arterial line filtration), maintenance of euglycemia, reduction of hemodilution, and attenuation of the inflammatory response. We report overall regional practice (regional minimum, maximum). All centers used alpha-stat pH management and arterial line filters. Avoidance of hyperthermia (temperature <37°C) was achieved during 23.4% of procedures (regional minimum, 1.5%; maximum, 83.2%). Minimizing return of pericardial suction blood was achieved in 23.7% of cases (0.7%, 93.6%). Aortic assessment was performed during 45.7% of procedures (1.3%, 98.9%). Maintenance of euglycemia (<200 mg/dL) was accomplished in 82.7% (57.1%, 97.9%) of cases. Hemodilution (hematocrit <23% on CPB) was lower for men 32.4% (20.6%, 52.3%) than women 77.9% (64.7% 88.9%). Men were less likely to receive red blood cell transfusions in the operating room (11.0%; 1.8%, 20.9%) than women (54.6%; 30.1%, 70.6%). In an effort to attenuate the inflammatory response, surface coated circuits were used in 83.3% of procedures (8.8%, 100%). During this time, gaps existed between regional CPB practice and recently published recommendations. We continue to prospectively measure CPB practice relating to these recommendations to monitor and improve the care provided to our patients.
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Cardiopulmonary bypass (CPB) grafting (CABG) surgery, while undoubtedly effective for prolonging life and relieving angina, has previously been associated with adverse sequelae, such as mortality, atrial fibrillation, and stroke (1–4). A variety of groups have made efforts, through development of clinical practice guidelines, to review and synthesize the peer-reviewed medical literature to assist clinicians in identifying opportunities to reduce a patient's risk of developing these adverse sequelae (4,5).

Recently, Shann et al. (6) published recommendations for the practice of CPB in adults undergoing isolated CABG. These recommendations focused on the topics of neurologic protection (pH management, avoidance of hyperthermia, minimizing return of pericardial suction blood, aortic assessment, arterial line filtration), maintenance of euglycemia, reduction of hemodilution, and attenuation of the inflammatory response. Although this document afforded clinicians in our region and elsewhere with a synthesis of the literature on these particular topics, it was unclear the extent to which patient care during a contemporary time period was consistent with these recommendations.

This prospective, observational study was conducted within the Northern New England Cardiovascular Disease

Address correspondence to: Donald S. Likosky, PhD, Department of Surgery, Dartmouth-Hitchcock Medical Center, Lebanon, NH 03756. E-mail: Donald.likosky@dartmouth.edu
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Study Group. The practice of CPB from January 2004 to June 2005 was compared as a region to recently published recommendations by Shann et al. (6).

MATERIALS AND METHODS

The recommendation paper of Shann et al. (6) was distributed to practicing perfusionists in northern New England. After reviewing the document, representatives from each of the eight northern New England medical centers decided to examine regional perfusion practice from January 2004 to June 2005 (n = 3597 patients). Regional registry variables were used to track CPB practice as it related to published recommendations.

Data were obtained from the registries of the Northern New England Cardiovascular Disease Study Group (NNECDSG), a voluntary research consortium composed of clinicians, research scientists, and hospital administrators (http://www.nnecdsg.org/). The goal of the group is to foster continuous improvement in the quality of care, safety, and effectiveness of cardiovascular interventions through the analysis of process and outcomes data and the timely feedback of this data to the clinicians involved in providing these services. Data were collected prospectively on all CABGs in the region and are periodically validated using administrative data sources. The data collected included patient demographics, co-morbidities, cardiac history, cardiac anatomy, cardiac function, procedural indication and priority, procedural details, and outcomes.

Institutional review board approval was obtained for data collection at each participating medical center.

Overall regional practice, along with regional minimum and regional maximum values by medical center, was calculated for each published recommendation. Analyses were performed using the STATA 9.0 program (Stata Corp., College Station, TX) (7).

RESULTS

A wide variation in regional CPB practice existed as it relates to the recommendations (Table 1). Registry variables were available to describe all but two recommendations (pH management and arterial filtration). These two recommendations, however, were standard of practice within North America, and the sole use of alpha-stat pH management and arterial line filters during this time period among patients undergoing CPB was verified with Chief Perfusionists at each of our institutions.

Avoidance of hyperthermia (arterial blood temperature, as measured in the arterial line port of the oxygenator, ≥37°C) occurred during 23.4% of procedures (regional minimum, 1.5%; regional maximum, 83.2%). Minimizing return of pericardial suction blood into the CPB circuit through the cardiotomy reservoir was achieved in 23.7% of procedures (0.7%, 93.6%). Aortic assessment (with transesophageal or epiaortic echocardiography) was performed in 45.7% of procedures (1.2%, 98.9%). Maintenance of euglycemia (blood glucose level < 200 mg/dL) was accomplished in 82.7% (57.1%, 97.9%) of cases. Occurrence of hemodilution (hematocrit <23% on CPB) was lower for men (32.4%; 20.6%, 52.3%) than women (77.9%; 64.7% 88.9%). Men were less likely to receive red blood cell transfusions in the operating room (11.0%; 1.8%, 20.9%), whether as part of CPB prime or during the course of CPB than women (54.6%; 30.1%, 70.6%). Attenuation of the inflammatory response was achieved in 85.3% (8.8%, 100.0%) of operations.

Figures 1 and 2 show variation within and between medical centers with regard to the use of coated bypass circuits and highest and last glucose level in the operating room, respectively. Figure 1 shows wide variation in the use and extent of coated circuits across our region. All of center 1's procedures were performed with circuits that were fully coated except for the cannula, whereas most of center 2's procedures were performed without coated circuits, and center 6's cases were performed with partially coated circuits (oxygenator only). Figure 2 shows similar variability in glucose values, with highest glucose values at center 7 > 100 mg/dL higher than center 4. Similarly, last glucose values for center 5 were nearly 50 mg/dL higher than for center 7.

DISCUSSION

Gaps between regional CPB practice and recently published recommendations (6) were noted. Additionally, wide variability across our region existed on nearly all recommendations.

At least three reasons may account for gaps between current knowledge and clinical practice. First, a plethora of new articles appear in the peer-reviewed literature every year focused on the topic of CABG surgery (33,574 from 1950 through 2006; 1524 during 2006 alone), The pace of this generation of new knowledge is staggering. The synthesis of this literature occurs periodically through a number of sources: Cochrane Collaborative, meta-analyses, review articles, and clinical practice guidelines. Unfortunately, many of these, although covering the topic of CABG surgery, do not adequately reflect key technical aspects of configuring and operating the heart lung machine, i.e., "CPB practice." Accordingly, although new knowledge is generated in the peer-reviewed literature, its incorporation into practice is often less than optimal.

Second, a lack of clarity of ownership for some aspects of CPB practice may exist during handoffs. For example, one of the current recommendations focuses on the topic of preventing hemodilution and subsequent allogenic blood transfusions. Pre-operative preservation and management of a patient's hematocrit may be influenced by a number of processes, such as surgical technique, delivery

Table 1. Regional CPB practice characteristics across eight institutions in Northern New England (2004–2005).

Recommendation	Region (min, max)
pH Management: The clinical team should manage adult patients undergoing moderate hypothermic CPB with alpha-stat pH management (Class I, Level A)	
Patients who received alpha-stat pH management (%)	**100.0** (100.0, 100.0)
Avoidance of Hyperthermia: Limiting arterial line temperature to 37°C may be useful for avoiding cerebral hyperthermia (Class IIa, Level B). *Coupled temperature ports for all oxygenation should be checked for accuracy and calibrated	
Patients with blood temperature ≤37°C (%)	**23.4** (1.5, 83.2)
Minimizing Return of Pericardial Suction Blood: direct reinfusion to the CPB circuit of unprocessed blood exposed to pericardial and mediastinal surfaces should be avoided (Class I, Level B). Blood cell processing and filtration may be considered to decrease the deleterious effects of reinfused shed blood (Class Iib, Level B)	
No cardiotomy sucker (%)	**23.7** (0.7, 93.6)
Cardiotomy sucker with Cell Saver (%)	**62.7** (6.4, 99.3)
Cardiotomy sucker without Cell Saver (%)	**13.6** (0.0, 61.8)
Aortic Assessment: in patients undergoing CPB at increased risk of adverse neurologic events, strong consideration should be given to intraoperative TEE or epiaortic ultrasound scanning of the aorta	
1. to detect nonpalpable plaque (Class I, Level B)	
2. for reduction of cerebral emboli (Class IIa, Level B)	
Not done (%)	**27.5** (0.3, 97.5)
TEE (%)	**40.2** (1.2, 98.9)
Epiaortic ultrasound (%)	**5.5** (0.0, 41.2)
Palpation (%)	**26.8** (0.0, 96.3)
Arterial Filtration: arterial line filters should be incorporated in the CPB circuit to minimize the embolic load delivered to the patient (Class I, Level A)	
Arterial line filter used (%)	**100.0** (100.0, 100.0)
Maintenance of Euglycemia: the clinical team should maintain perioperative blood glucose concentration within an institution's normal clinical range in all patients including non-diabetics (Class I, Level B)	
Patients with highest glucose ≤200 mg/dL*	**55.1** (3.2, 79.6)
Patients with last glucose ≤200 mg/dL* (%)	**80.8** (50.0, 97.9)
Reduction of Hemodilution: efforts should be made to reduce hemodilution including reduction of prime volume to avoid subsequent allogenic blood transfusion (Class I, Level A)	
Patients with nadir Hct < 23% on CPB (%)	**43.7** (30.5, 60.7)
Men	**32.4** (20.6, 52.3)
Women	**77.9** (64.7, 88.9)
Patients with ≥1 RBC unit in CPB prime (%)	**7.4** (0.3, 18.1)
Men	**3.3** (0.0, 9.3)
Women	**19.6** (1.3, 54.9)
Patients given ≥1 RBC unit intraoperatively	**18.8** (8.3, 29.5)
Men	**9.8** (1.8, 16.4)
Women	**45.9** (28.0, 63.4)
Patients given ≥1 RBC unit in CPB prime or intraoperatively (%)	**22.0** (8.8, 30.5)
Men	**11.0** (1.8, 20.9)
Women	**54.6** (30.1, 70.6)
Attenuation of the Inflammatory Response: reduction of circuit surface area and the use of biocompatible surface modified circuits may be useful/effective at attenuating the systemic inflammatory response to CPB and improve outcomes (Class IIa, Level B)	
Coated circuit (%)	**85.3** (8.8, 100.0)

*Practice at each center was to keep a patient's glucose <200 mg/dL.

of fluids, and priming of the CPB circuit. Although these processes take place at different aspects of the patient's care delivery system and involve several clinicians, no one individual owns the entire process of managing the patient through the course of their pre- and intra-operative care.

Nonetheless, clear examples of ownership during cardiac surgery do exist. Use of arterial line filters in the CPB circuit is standard of care throughout North America. Although their use is potentially of interest to anesthesiologists and surgeons, their incorporation into the CPB circuit is under the domain of the perfusion team and influenced by practice guidelines from perfusion societies (AmSECT Essential IX, www.amsect.org). External forces coupled with clear ownership of this domain and

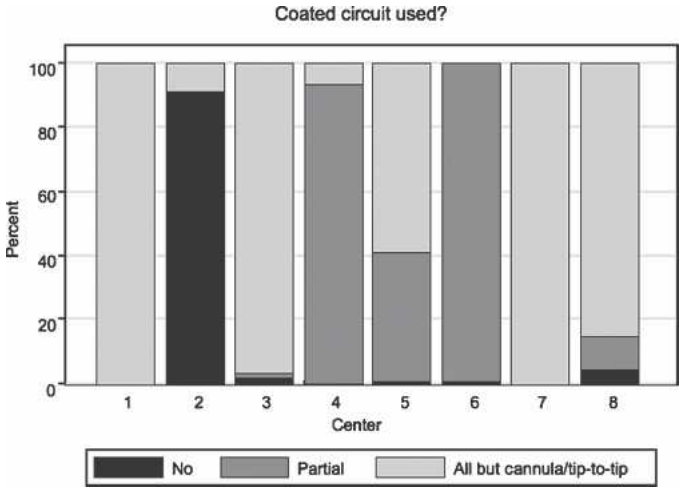

Figure 1. Use of coated circuits.

evidence from randomized trials (Class I, Level A evidence) of care has resulted in the near-universal incorporation of these filters in the CPB circuit. All centers in northern New England use arterial line filters for patients undergoing CABG surgery.

Third, we cannot discount the monetary factors at work. Some improvements to CPB practice, such as the conversion to surface-modified bypass circuits, may result in increased institutional costs. Material/business managers may be resistant to this advancement without a demonstrated benefit to costs elsewhere in the care delivery system, such as decreased length of stay or reduction in transfusion expenses. It will be important to provide the evidence of the efficacy and effectiveness of these circuits to these managers to promote their utilization in care. Additionally, there may be a temporal delay after the adoption of a new technology as the institution consumes existing stocks of older components.

How does a profession progress toward the incorporation of evidence-based principles into practice? There are likely four key steps to this desired goal. First, synthesis of the data concerning the effect of CPB practice techniques on clinical outcomes should be generated and periodically revisited. Several authors have recently completed such documents (6,8). Second, clinicians must view themselves as part of a complete system of care, with handoffs across clinicians needing attention, such as is the case with hemodilution. Third, teams should assess the delivery of the care they provide as it relates to scientific evidence and articulate clearly each team member's role. Fourth, when gaps exist between current practice and the evidence base, steps should be taken to reduce these gaps.

Centers in northern New England have embraced this opportunity to improve the quality of care delivered for patients undergoing CPB. First, the CPB recommendations were shared at regional conferences, where multidisciplinary representatives from all eight participating institutions convene. The current manuscript outlines performance in this region to date compared with the evidence base. The NNECDSG regional perfusion group has committed to track performance longitudinally around these recommendations and feed the information back to the centers. In areas where practice deviates from the evidence base, regional quality improvement projects will develop to reduce this gap.

This study used a regional prospective registry of patients undergoing CABG surgery in northern New England. Data reflecting the care provided to each patient were used to compare practice in northern New England

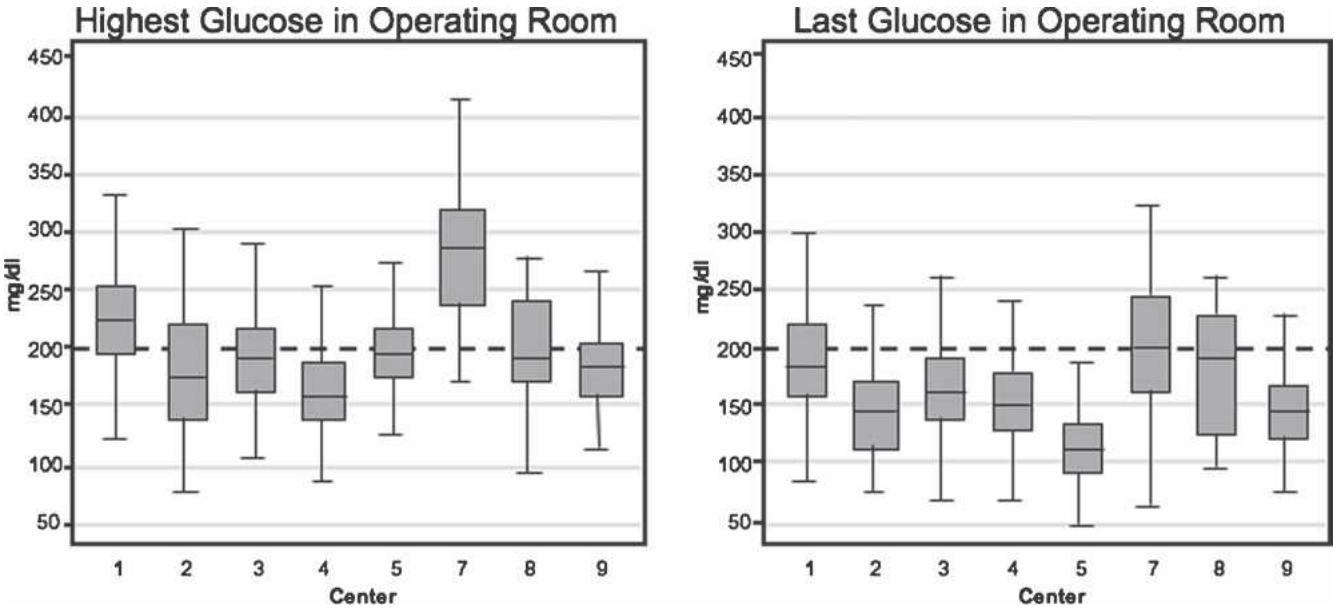

Figure 2. Glucose levels in the operating room.

vs. evidence-based guidelines. It is unclear whether similar findings would persist if data were collected through a survey of providers' reflections of how they imagine that they practice. Additionally, this study reflects practice in one region of the country. Additional studies outside of our region would need to be conducted to determine whether our findings are generalizable to centers outside of northern New England.

In conclusion, wide variation in regional CPB practice existed compared with current published recommendations. These findings suggest that some recommendations are fully implemented, whereas others are not. Future work will evaluate regional efforts to improve the practice of CPB through reduction in variation around evidence-based guidelines.

REFERENCES

1. Crystal E, Connolly SJ, Sleik K, Ginger TJ, Yusuf S. Interventions on prevention of postoperative atrial fibrillation in patients undergoing heart surgery: a meta-analysis. Circulation. 2002;106:75–80.
2. Charlesworth DC, Likosky DS, Marrin CA, et al. Development and validation of a prediction model for strokes after coronary artery bypass grafting. Ann Thorac Surg. 2003;76:436–43.
3. O'Connor GT, Plume SK, Olmstead EM, et al. A regional prospective study of in-hospital mortality associated with coronary artery bypass grafting. The Northern New England Cardiovascular Disease Study Group. JAMA. 1991;266:803–9.
4. Eagle KA, Guyton RA, Davidoff R, et al. ACC/AHA 2004 Guideline Update for Coronary Artery Bypass Graft Surgery: A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1999 Guidelines for Coronary Artery Bypass Graft Surgery). Circulation. 2004;110:1168–76.
5. Edwards FH, Ferraris VA, Shahian DM, et al. Gender-specific practice guidelines for coronary artery bypass surgery: perioperative management. Ann Thorac Surg. 2005;79:2189–94.
6. Shann KG, Likosky DS, Murkin JM, et al. An evidence-based review of the practice of cardiopulmonary bypass in adults: a focus on neurologic injury, glycemic control, hemodilution, and the inflammatory response. J Thorac Cardiovasc Surg. 2006;132:283–90 e3.
7. Stata. Stata Statistical Software: Release 9.0. College Station, TX: Stata Corp.; 2005.
8. Bartels C, Gerdes A, Babin-Ebell J, et al. Cardiopulmonary bypass: Evidence or experience based? J Thorac Cardiovasc Surg. 2002;124:20–7.

APPENDIX 1. VARIABLES USED TO MAP CPB RECOMMENDATIONS TO THE NNECDSG CARDIAC REGISTRY

Recommendation for pH management: alpha or pH stat management

Recommendation for avoidance of hyperthermia: highest temperature reached by the arterial blood inflow during re-warming

Recommendation for minimizing return of pericardial suction blood: use of cardiotomy suction, with or without concomitant Cell Saver

Recommendation for aortic assessment: Performed by transesophageal echocardiography, epiaortic echocardiography, or palpation

Recommendation for arterial line filtration: arterial line filter of the following approximate pore size: 20, 27, or 40 μm

Recommendation for maintenance of euglycemia: highest and last glucose measurements in the operating room

Recommendation for reduction in hemodilution:

Static volume: the minimum volume of fluid necessary to prime a given bypass circuit from tip-to-tip at a no-flow state and minimal acceptable reservoir level to initiate bypass. This value is independent of the net priming volume after RAP, draining the venous line, or other maneuvers to minimize hemodilution.

Lowest nadir hematocrit on CPB: lowest measured value, before transfusion (if any), during initial pump run

Transfusion of red blood cells: any transfusion of RBCs intraoperatively.

Recommendation for attenuation of the inflammatory response: if a "biocompatible" circuit was used, was it partial, all but cannula, or tip-to-tip?