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Improved Outcomes During Cardiac Surgery: A Multifactorial Enhancement of Cardiopulmonary Bypass Techniques

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Abstract: Patients presenting for cardiac surgery with cardiopulmonary bypass (CPB) are more likely to have pre-existing comorbidities, which has resulted in a steady increase in the risk associated with CPB. The resulting challenge has mandated the optimization of perfusion care. The purpose of this study was to retrospectively evaluate the impact of a number of simultaneous, evidence based perfusion care changes on patient outcome. After Institutional Review Board approval, two groups of patients were compared. The control group (n = 317) included all patients undergoing CPB in a 12-month period preceding a multifaceted change in perfusion techniques. The treatment group (n = 259) included all patients undergoing CPB in the 12-month period after the changes, which included the incorporation of updated continuous blood gas monitoring, biocompatible circuitry, updated centrifugal blood propulsion, continuous autotransfusion technology, new generation myocardial protection instrumentation, plasmapheresis, topical platelet gel application, excluding hetastarch while increasing the use of albumin, viscoelastographic coagulation monitoring, and implementing a quantitative quality improvement program. After univariate analysis, propensity scoring and multiple conditional logistical regression were used to control for demographic, preoperative, operative, and postoperative parameters. Results of the primary endpoints revealed a lower mortality rate in the treatment group (4% vs. 9% [95% confidence interval 1.33, 7.72], p = 0.009), lower transfusion rate (51% vs. 59% [1.00, 2.11], p = 0.048), and lower complication rate (55% vs. 65% [1.06,2.19], p = 0.025) despite having similar predicted mortality (11 [2,22] vs. 11[3,22], p = NS) and other preoperative and operative parameters. The lower mortality rate was concurrent with a trend towards a lower incidence of complications, consistent with the differences in primary outcomes. In conclusion, the patients treated after the implementation of a multifactorial improvement plan using evidence based changes in CPB care had decreased complication and mortality rates. **Keywords:** cardiopulmonary bypass, outcome, propensity analysis. *JECT. 2005;37:165–172*

A primary goal of research in the field of extracorporeal circulation is to make cardiopulmonary bypass (CPB) benign and unrecognizable to the human body. Methods of improving CPB have focused on two major areas: the reaction of blood to synthetic surfaces and the maintenance of homeostasis through the physical processes of fluid dynamics. During the first 50 years, there were numerous reports that identified CPB in the methodology for the treatment of heart disease but did specifically evaluate CPB. Significantly fewer studies have reported on the benefits of CPB, with most focused on improvements in *individual* components of the extracorporeal circuit. Most of these studies compared a treatment (newer technology) with a control (existing technology), examining physical or clinical endpoints for determining effect. In theory, a simple aggregate analysis of these studies could render a best-practice recommendation that could help standardize perfusion methodology (1). Unfortunately, no such plan has been devised, likely a result of the equivocal state of

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CPB data and a reflection of the overall lack of knowledge concerning this technique (2).

The question becomes: should we lose the rigidity of scientific scrutiny and embrace technologies that may empirically offer benefit, but have not been shown to be beneficial (3)? The new generation of coatings will not receive the investigative scrutiny that heparin-coated circuits received because the probability of multiple randomized clinical trials being conducted is low (4,5). These trials are very expensive to complete, and funding for this type of research is almost nonexistent. The multifactorial problem of improving extracorporeal circulation needs to be addressed with a multifaceted approach. The opportunity for one alteration in CPB conduct resulting in a significant improvement to patient outcome would depend on both a large number of observations *and* a homogeneous population, with validation occurring across multiple centers.

Patients presenting for cardiac surgery requiring CPB are more likely to have pre-existing comorbidities with a more involved operative plan, which has resulted in a steady increase in the risk associated this surgery (6). The resulting challenge has mandated the optimization of perfusion care despite the increased difficulty in evaluating new and existing technologies and techniques. The purpose of this study was to retrospectively evaluate the impact of a multifaceted perfusion improvement plan on patient outcome.

METHODS

After the Geisinger Medical Center Institutional Review Board approval, patients undergoing CPB within 1 year before the start of the new treatment regimen (control group) and patients with procedures occurring within 1 year after the start of the new treatment regimen (treatment group) were selected. To reduce bias due to learning curve(s), a 2-month buffer was established between the control and treatment groups. No pediatric patients (i.e., patients younger than 19 years of age) were included in the analysis. Demographic, preoperative, operative, and postoperative data were extracted from the local Society of Thoracic Surgeons Database, which was collected and maintained by an individual not affiliated with the study.

The initial phase of the study included selection of the perfusion care elements to be updated. An extensive review of the literature was conducted, and all studies were stratified according to the grade of evidence, a technique initially developed by the US Preventative Services Task Force (Table 1) (7,8). For each potential change, the decision was based on the highest grade of evidence available.

From this review, four main categories of change were identified, including technological, technical, physiological, and logistical (Tables 2–5). Technological changes included the incorporation of in-line blood gas monitoring (CDI 500; Terumo Cardiovascular, Ann Arbor, MI), biocompatible circuitry (SMARxT Tubing, Revolution Pump, Monolyth Integrated Oxygenator; Cobe Cardiovascular, Arvada, CO), dedicated myocardial protection system (MPS; Quest Medical, Allen, TX), continuous autotransfusion (CATS; Terumo Cardiovascular, Ann Arbor, MI), and point-of-care hemostasis monitoring (TEG; Haemoscope, Niles, IL) (Table 2). Technical changes included the complete elimination of Hetastarch, replaced by the use of albumin (12.5 g per liter crystalloid solution, or to achieve [Albumin] > 3.5 $g \cdot dL^{-1}$ or colloid oncotic pressure [COP] > 14 mmHg) (Table 3). Further technical changes included standardizing the methods of retrograde autologous priming, minimizing the use of ancillary vents and suction pumps, perioperative plasmapheresis, and platelet gel application to the sternal wounds (Table 3). Both plasmapheresis and platelet gel application were used on select patients, based upon surgeon preference and the absence of contraindications (active infection, critical aortic stenosis, hemodynamic instability). Physiological parameters were formalized to include maintaining the mean arterial pressure between 60 and 90 mmHg, maintaining a cardiac index greater than 1.8 $L \cdot min^{-1} \cdot m_2^{-1}$, using alpha-stat blood gas management (pH_a 7.35–7.45, P_aCO_2 35–45 mmHg, P_aO_2 150–250 mmHg), precisely controlling temperature (gradients < 6°C, maximum arterial temperature < 37°C, rewarming rate < $0.5°C \cdot min^{-1}$), and limiting vacuum assisted venous drainage (only used when required, never exceed –40 mmHg). To assure that the technical and physiological changes were implemented on a uniform and consistent basis, a logistical change was implemented. The change involved an independent review of perfusion performance (PDS Corporation, Philadelphia, PA) followed by monthly staff review of compliance and improvement.

Table 1. Grades of evidence for the quality of research designs.

I	Evidence obtained from at least one properly randomized, controlled trial.
II-1	Evidence obtained from well-designed controlled trials without randomization.
II-2	Evidence obtained from well-designed cohort or case–control analytic studies, preferably from more than one center or research group.
II-3	Evidence obtained from multiple time series with or without the intervention. Dramatic results in uncontrolled experiments (i.e., penicillin treatments in the 1940s) could also be regarded as this type of evidence.
III.	Opinions of respected authorities, based on clinical experience; descriptive studies and case reports; or reports of expert committees.

Statistics

To determine whether the new treatment regime was having an impact on patient outcomes, the following analyses were conducted. First, descriptive statistics (mea-

Table 2. Technological changes.

Phosphorylchorine-coated circuitry (COBE Cardiovascular, Arvada, CO)
Continuous arterial and venous in-line blood gas monitoring (Terumo Cardiovascular, Ann Arbor, MI)
Dedicated myocardial protection system (Quest Medical, Allen, TX)
Centrifugal Pump (COBE Cardiovascular, Arvada, CO)
Thromboelastograph whole blood coagulation monitoring (Haemoscope CO., Skokie, IL)
Continuous Autotransfusion System (Terumo Cardiovascular, Ann Arbor, MI)

Table 4. Physiological changes.

Mean arterial pressure	60–90 mmHg
Cardiac index/flow	>1.8 $L \cdot min^{-1} \cdot m_2$
Alpha-stat blood gas management	
pH_a	7.35–7.45
p_aCO_2	35–45 mmHg
p_aO_2	150–250 mmHg
Temperature control	
Maximum gradient	6°C
Maximum arterial temp	37°C
Maximum rate	$0.5°C \cdot min^{-1}$

sures of central tendency, measures of variation, and percentages) were used to describe the population. Second, the characteristics of the population that received the new treatment regimen were compared to the historical control. The comparisons were done using a two-sample *t* test, chi-square test, Fisher exact test, Cochran-Armitage trend test, or Wilcoxon rank-sum test, as appropriate. Finally, the impact of the new treatment regimen on patient outcomes was tested. The evaluation involved univariate and multivariate components. The univariate component evaluated differences in patient outcomes between the treatment and control groups using chi-square/Fisher exact tests and Wilcoxon rank sum tests. The multivariate component evaluated the effect of the changes on patient outcomes while controlling for patient age, gender, risk factors, existing cardiac disease, operative procedures, and other patient characteristics. This analysis was conducted using propensity scores and conditional logistic regression. Before conducting the multivariate analysis, tests for time trends were performed for each outcome by examining time as a linear predictor of outcome in the historical control group. Because time was not a significant factor, it was excluded from further analyses. SAS (Statistical Analysis Systems; version 8.0; Cary, NC) was used for statistical analyses. All tests were two-sided and $p \leq 0.05$ was considered significant.

RESULTS

A total of 586 cases were identified for inclusion in the study. Of these 586, 10 cases were removed from the analysis because of missing data. In the analyzable population, 317 were in the control group and 259 were in the treatment group. Patients in the control group were more likely to be male (66% vs. 56%; $p = 0.010$), less likely to have previous myocardial infarction (5% vs. 10%; $p = 0.034$), less likely to have congestive heart failure (19% vs. 26%; $p = 0.045$), and more likely to have angina (53% vs. 42%; $p = 0.009$) (Table 6a). The control group had fewer urgent cases (15% vs. 20%; $p = 0.029$), fewer left ventricular aneurysm repairs (0% vs. 3%; $p = 0.004$), more congenital repairs (6% vs. 3%; $p = 0.042$), and shorter cross clamp times (median = 79 vs. median = 92; $p = 0.003$) (Table 6b).

Table 3. Technical changes.

Albumin replaced high molecular weight starch ([Alb] > $3.5g \cdot dL^{-1}$, COP > 14 mmHg)
Intraoperative plasmapheresis (select patients)
Platelet gel application to sternal wounds (select patients)
Standardize retrograde autologous priming
Minimize the use of ancillary vents and suction

Table 7a contains the univariate comparison of the primary and secondary outcomes. The control group was more likely to have mortality (odds ratio [OR] 2.27; 95% confidence interval [95% CI] 1.11, 4.64) and any complication (OR 1.53; 95% CI 1.09, 2.14). The rate of blood product use trended lower in the treatment group (OR 1.38; 95% CI 0.99, 1.93). However, days to discharge and number of mechanical ventilation hours were greater in the treatment group.

After controlling for the factors and characteristics in Table 6a and 6b, the control group was more likely to have mortality (OR 3.21; 95% CI 1.33, 7.72), blood product use (OR 1.45; 95% CI 1.00, 2.11), and complications (OR 1.52; 95% CI 1.06, 2.19) (Table 7b). Table 8 contains the univariate comparison of other miscellaneous outcomes. None of these were significantly different, although trends consistent with the differences in primary outcomes were evident.

DISCUSSION

Patients undergoing CPB continue to present with higher preoperative risk stratifications while requiring increasingly complex surgeries (6). Several reasons exist for this evolution. First, the relative proportion of low-risk patients is decreasing, a direct result of the avoidance of CPB in the lowest-risk patients. Because the techniques of off-pump revascularization (OPCAB) procedures have improved, the capability to perform them has shifted away

Table 5. Logistical changes.

Quality Improvement Process
Independent data review
Monthly analysis
Monthly review
Cleveland Clinic Risk Stratification

Table 6a. Patient demographics and characteristics in control and treatment groups.

	Control	Treatment	*p* Value
N, sample size	317	259	
Age, mean (SD)	64 (13)	63 (16)	0.28*
Gender, male (%)	210 (66%)	144 (56%)	0.010†
Body surface area, mean (SD)	2.0 (0.3)	2.0 (0.2)	0.92*
Risk factors			
Smoker—ever (%)	127 (40%)	106 (41%)	0.83†
Smoker—current (%)	40 (13%)	35 (14%)	0.75†
Family history CAD (%)	62 (20%)	40 (15%)	0.20†
Diabetes (%)	82 (26%)	73 (28%)	0.531†
Insulin (%)	23 (7%)	15 (6%)	0.48†
Hypercholesterol (%)	145 (46%)	112 (43%)	0.55†
Renal failure (%)	21 (7%)	25 (10%)	0.18†
Hypertension (%)	192 (61%)	166 (64%)	0.39†
Cerebralvascular accident (%)	22 (7%)	17 (7%)	0.86†
Infectious endocarditis (%)	16 (5%)	16 (6%)	0.56†
Chronic Lung Disease (%)	37 (12%)	34 (13%)	0.60†
Immunosuppressive therapy (%)	1 (<1%)	0 (0%)	0.99†
Peripheral vascular disease (%)	43 (14%)	37 (14%)	0.80†
Cerebral vascular disease (%)	35 (11%)	30 (12%)	0.84†
Redo (%)	57 (18%)	49 (19%)	0.77†
Cardiac status			
Previous MI (%)	17 (5%)	26 (10%)	0.034†
Congestive heart failure (%)	61 (19%)	68 (26%)	0.045†
Angina (%)	167 (53%)	108 (42%)	0.009†
Unstable angina (%)	31 (10%)	24 (9%)	0.84†
Cardiogenic shock (%)	4 (1%)	6 (2%)	0.36‡
Arrythmia (%)	53 (17%)	46 (18%)	0.74†
Cardiac disease			
Number of diseased vessels:			
0 (%)	124 (39%)	115 (44%)	0.13§
1 (%)	25 (8%)	21 (8%)	
2 (%)	37 (12%)	33 (13%)	
3 (%)	131 (41%)	90 (35%)	
Left main disease (%)	36 (11%)	24 (9%)	0.41†
Ejection fraction, mean (SD)	50 (14)	49 (14)	0.51*
Aortic stenosis (%)	80 (25%)	80 (31%)	0.13†
Mitral stenosis (%)	14 (4%)	17 (7%)	0.26†
Tricuspid stenosis (%)	1 (<1%)	1 (<1%)	0.99‡
Pulmonary stenosis (%)	0 (0%)	0 (0%)	–
Aortic insufficiency (%)	40 (13%)	44 (17%)	0.14†
Mitral insufficiency (%)	99 (31%)	100 (39%)	0.064†
Tricuspid insufficiency (%)	15 (5%)	22 (8%)	0.067†
Pulmonary insufficiency (%)	1 (<1%)	2 (<1%)	0.59‡

CAD, coronary artery disease; MI, myocardial infarction.
*Two-sample t-test.
†Chi-square test.
‡Fisher exact test.
§ Cochran-Armitage trend test.

from *select* patients with *talented* surgeons towards *most* patients with *most* surgeons. However, the implementation of OPCAB is influenced by factors beyond simple capability, and there is not a uniform application of the procedure. Therefore, the actual impact on CPB demographics varies widely. At institutions such as ours, where OPCABs represent more than 95% of the CAB surgery, the impact was dramatic. With limited or no OPCAB use, the impact is less noticeable. Under these circumstances, the relative contribution of more aggressive nonsurgical interventions may be more noticeable, but the trend is not unique to circumstances of limited OPCAB use. However, the end result is the same. The lowest-risk patients treated with CPB a decade ago are less likely to require CPB today. In more general terms, cardiac surgery patients as a group (both CPB and OPCAB) are at a higher risk than just 10 years ago (3). The increasing age and rates of comorbidity is also a result of medical advancements, many beyond the scope of cardiac care. Patients are living longer and accumulating more preexisting conditions before undergoing cardiac surgery, which appears to be a trend that will continue into the foreseeable future (6). The result is evident in the predicted mortality of the study groups presented here, with predicted mortality rates of 9% (control) and 10% (treatment). Although these values reflect the complexity of the cases performed on-pump, our coronary

Table 6b. Patient demographics and characteristics in control and treatment groups.

	Control	Treatment	*p* Value
N, sample size	317	259	
Surgeon			
A (%)	92 (29%)	63 (24%)	0.19*
B (%)	79 (25%)	84 (32%)	
C (%)	73 (23%)	61 (24%)	
D (%)	73 (23%)	51 (20%)	
Status			
Elective (%)	244 (77%)	194 (76%)	0.029*
Emergent (%)	27 (9%)	10 (4%)	
Urgent (%)	46 (15%)	51 (20%)	
Operative procedure			
Any coronary artery bypass (%)	183 (58%)	131 (51%)	0.089*
Any aortic valve operation (%)	123 (39%)	113 (44%)	0.24*
Any mitrial valve operation (%)	105 (33%)	105 (41%)	0.066*
Any tricuspid valve operation (%)	26 (8%)	30 (12%)	0.17*
Any pulmonary valve operation (%)	14 (4%)	10 (4%)	0.74*
Grouping: No CAB or valve (%)	28 (9%)	17 (7%)	0.58‡
CAB, no valves (%)	79 (25%)	42 (16%)	
Single valve, no CAB (%)	73 (23%)	81 (31%)	
CAB and single valve (%)	86 (27%)	68 (26%)	
Multiple valves, no CAB (%)	33 (10%)	30 (12%)	
CAB and multiple valves (%)	18 (6%)	21 (8%)	
Procedures			
Minimally invasive (%)	7 (2%)	2 (1%)	0.20†
Other cardiac procedure (%)	63 (20%)	47 (18%)	0.60*
Other noncardiac procedure (%)	27 (9%)	12 (5%)	0.065*
Left ventricular aneurysm repair (%)	0 (0%)	7 (3%)	0.004†
Ventricular septal defect repair (%)	5 (2%)	1 (<1%)	0.16*
Atrial septal defect repair (%)	4 (1%)	6 (2%)	0.34*
Congenital repair (%)	20 (6%)	7 (3%)	0.042*
Laser revascularization (%)	0 (0%)	1 (1%)	0.45*
Traumatic repair (%)	0 (0%)	0 (0%)	–
Aortic aneurysm repair (%)	20 (6%)	12 (5%)	0.38*
Carotid endarterectomy (%)	3 (1%)	0 (0%)	0.26†
Other vascular procedure (%)	0 (0%)	1 (<1%)	0.45†
Other thoracic procedure (%)	4 (1%)	3 (1%)	0.99†
Cross clamp time			
Median [Q1, Q3]	79 [50, 113]	92 [62,123]	0.003§
Perfusion time			
Median [Q1, Q3]	110 [82, 149]	124 [89, 154]	0.059§
Cleveland clinic, Median [Q1, Q3]	11 [3, 22]	11 [2, 22]	0.28§

*Chi-square test.
†Fisher exact test.
‡Cochran-Armitage trend test.
§Wilcoxon Rank Sum test.

artery bypass grafting only patients (95% OPCAB) also are increasing steadily in predicted mortality.

Unfortunately, as the demographic status of CPB patients continues towards a higher risk population, the ability to effectively accommodate them and maintain similar or improved outcomes is decreasing. Although debatable, a decrease in the ability to implement improvements in CPB is related more to our ability to critically evaluate new technologies and techniques rather than their slow development and introduction (9). The tools for improvement may very well be in place, but implementation is hampered by the lack of scientific scrutiny, the economic pressures of capitated health plans, and the lack of appreciation for the importance of modern CPB care. The failure of recent technological developments in CPB, such as the Cardiovations CORX™ System, may be attributable to two related issues. First, the ability to independently evaluate them was not exercised, likely because of the lack of funding necessary for outcome studies. Second, these developments are based on either existing technologies or techniques, in which risks versus benefits have yet to be resolved. Further evidence towards the impediments posed to new and existing technology is provided by the OPCAB debate. Although it is well recognized that the OPCAB versus on-pump CAB literature is dominated by lower power, nonprospective investigation, the apathy towards the conduct of CPB in the on-pump CAB groups is also evident. The Methods sections in these articles typically identify whether CBP was used but do not identify which technologies, techniques, and strategies were used. There-

Table 7a. Univariate analysis of primary and secondary outcomes.

	Control	Treatment	OR	95% CI	*p* Value
N, sample size	317	259			
Primary					
Mortality, deaths (%)	29 (9%)	11 (4%)	2.27	[1.11, 4.64]	0.021†
Blood products, yes (%)	187 (59%)	132 (51%)	1.38	[0.99, 1.93]	0.054†
Any complication, yes (%)	206 (65%)	142 (55%)	1.53	[1.09, 2.14]	0.013†
Any re-operation, yes (%)	49 (15%)	30 (12%)	1.40	[0.86, 2.27]	0.18†
Readmit within 30 days, yes (%)	47 (15%)	26 (10%)	1.56	[0.94, 2.60]	0.086†
Secondary					
Reop-bleeding, yes (%)	23 (7%)	12 (5%)	1.61	[0.79, 3.30]	0.19†
Reop-valve, yes (%)	1 (<1%)	1 (<1%)	0.82	[0.05, 13.11]	0.99‡
Reop-graft, yes (%)	2 (1%)	1 (<1%)	1.64	[0.15, 18.17]	0.99‡
Reop other cardiac, yes (%)	14 (4%)	11 (4%)	1.04	[0.46, 2.34]	0.92†
Reop noncardiac, yes (%)	15 (5%)	6 (2%)	2.09	[0.80, 5.48]	0.12†
Ventilation Hours					
Hrs ≥ 48, (%)	24 (8%)	37 (17%)	0.47	[0.27, 0.81]	0.006†
Hrs < 48, mean (SD)	9 (7)	11 (9)			0.026*
Days to discharge					
Median [Q1, Q3]	5 [4, 8]	6 [4, 11]	–	–	0.027§
Mean (SD)	7.5 (8.0)	8.1 (5.7)	–	–	0.32*

*Two-sample t-test.
†Chi-square test.
‡Fisher exact test.
§Wilcoxon Rank Sum test.
Survivors only were included in these analyses (n = 288 controls, n = 248 treatment).

Table 7b. Multivariate analysis of primary outcomes.

	OR	95% CI	*p* Value
Mortality	3.21	[1.33, 7.72]	0.009
Any blood products use	1.45	[1.00, 2.11]	0.048
Any complication	1.52	[1.06, 2.19]	0.025
Any re-operation	1.60	[0.93, 2.77]	0.090
Readmit within 30 days	1.41	[0.82, 2.42]	0.21

fore, it is unknown how best-evidence based CPB compares with OPCAB.

It can be argued that evidence-based CPB cannot exist because of the paucity of the randomized, controlled trial with definitive conclusions (2). However, implementing *best*-evidence practices cannot be debated, provided the risks and costs associated with the practice changes are low. The relative cost (or risk) must reflect the level of evidence supporting its use (see Table 1), as higher inherent risk must be supported by high grades of evidence.

Often, best-evidence based practices are already in place, as were the physiological guidelines in this study for mean arterial pressure, cardiac index, blood gas management, and temperature control. The requirement for these changes was relatively simple: standardize, track performance, implement improvement mechanisms, and a periodically update the ranges. The costs associated with the technical aspect of the changes were minimal, although technological updates allowed the required level of improvement to be achieved. For example, achieving optimal blood gas management involved a technological update in addition to the technical update. Using the latest in-line blood gas monitoring technology involved additional cost, offset by a series of Level I studies that established the technology would improve blood gas management and this improvement would result in an incremental improvement in outcome (10,11). In addition, the technology facilitates performance tracking efforts while offsetting cost by reducing the number of laboratory samples from every 30 minutes to two per case.

Other changes were facilitated by price changes. With the advent of intravenous immunoglobin production, which produces albumin as a byproduct, the price of albumin had dropped precipitously at our institution. The incorporation of more aggressive colloid use was well appreciated by the peer-reviewed literature, as a COP less than 15 mmHg has been associated with a less than 50% survival (12). Albumin, being the most abundant protein in plasma, is a major component of COP, and decreasing serum albumin levels ([Alb]) were shown to be an independent predictor of death in a wide range of clinical and research settings (13). The increased odds of mortality ranged from 24% to 56% for every 0.25 $g \cdot dL^{-1}$ [Alb] below normal (3.5 $g \cdot dL^{-1}$) (13). Synthetic volume expansion solutions (Hetastarch) can effectively maintain COP but have the capacity to reduce hemostatic function, leading to increased bleeding in the postcardiotomy period (14). Furthermore, the use of albumin in the CPB prime may coat the artificial surfaces, potentially reducing the adsorption of fibrinogen and reducing the activation and adhesion of platelets (15).

The evidence to support certain changes, such as the use

Table 8. Univariate analysis of other outcomes.

	Control	Treatment	OR	95% CI	*p* Value
N, sample size	317	259			
Intraaortic ballon pump					
Preop (%)	15 (5%)	5 (2%)	2.52	[0.90, 7.04]	0.068*
Intraop (%)	4 (1%)	5 (2%)	0.65	[0.17, 2.44]	0.74†
Postop (%)	4 (1%)	6 (2%)	0.54	[0.15, 1.93]	0.36†
Ventricular assist device, yes (%)	2 (1%)	0 (0%)	–	–	0.50†
Peri-operative myocardial infarction, yes (%	4 (1%)	0 (0%)	–	–	0.13†
Deep sternal infection, yes (%)	10 (3%)	4 (2%)	2.07	[0.64, 6.70]	0.21*
Thoracic infection, yes (%)	0 (0%)	0 (0%)	–	–	–
Leg infection, yes (%)	7 (2%)	5 (2%)	1.15	[0.36, 3.66]	0.82*
Septicemia, yes (%)	9 (3%)	6 (2%)	1.23	[0.43, 3.51]	0.70*
Urinary tract infection, yes (%)	1 (<1%)	5 (2%)	0.16	[0.02, 1.38]	0.10†
Permanent stroke, yes (%)	11 (3%)	5 (2%)	1.83	[0.63, 5.32]	0.26*
Transient stroke, yes (%)	2 (1%)	2 (1%)	0.82	[0.11, 5.83]	0.99†
Coma, yes (%)	1 (<1%)	0 (0%)	–	–	0.99†
Pulmonary embolism, yes (%)	1 (<1%)	0 (0%)	–	–	0.99†
Pneumonia, yes (%)	15 (5%)	5 (2%)	2.52	[0.90, 7.04]	0.068*
Renal failure, yes (%)	19 (6%)	17 (7%)	0.91	[0.46, 1.78]	0.78*
Aortic Dissection, yes (%))	0 (0%)	0 (0%)	–	–	–
Valvular dysfunction, yes (%)	0 (0%)	0 (0%)	–	–	–
Heart Block, yes (%)	18 (6%)	19 (7%)	0.76	[0.39, 1.48]	0.42*
Cardiac Arrest, yes (%)	13 (4%)	5 (2%)	2.17	[0.76, 6.18]	0.14†
Tamponade, yes (%)	6 (2%)	4 (2%)	1.23	[0.34, 4.41]	0.99†
Gastro-intestinal complication, yes (%)	9 (3%)	9 (3%)	0.81	[0.32, 2.08]	0.66*
Multisystem failure, yes (%)	2 (1%)	2 (1%)	0.81	[0.11, 5.83]	0.99†
Atrial fibrillation, yes (%)	94 (30%)	78 (30%)	0.98	[0.68, 1.40]	0.90*

*Chi-square test.
†Fisher exact test.

of coated circuitry, may not have been sufficient to outweigh the costs, although the relative risks were exceedingly low. In the case of coated circuitry, strategic partnerships with industry were developed to lower the cost of incorporation to a sufficient level to justify use. A similar approach was used when the implied benefits were sufficient for a change to be justified. In the case of continuous autotransfusion, the chosen device allows the reinfusion of red blood cells *independent* of the volume to be processed, while generally providing superior product (16,17). Both features imply patient benefit, but in the diverse cardiac surgery population, establishing benefit is exceedingly difficult.

This observational study has shown that through technological and practical changes in the conduct of CPB, significant improvement in patient outcomes can be achieved. The improvements were obtained using techniques and technologies readily available to all perfusionists. Although a time trend analysis revealed that time was not a predictor of outcome, the progression of time resulted in changes in patient risk factors, consistent with national trends. The control group, operated on before the multifaceted change, were less likely to have a previous myocardial infarction and congestive heart failure and trended towards less renal failure, less mitral insufficiency, and less tricuspid insufficiency. Further, the control group was less likely to present urgently, have a left ventricular aneurysm repaired, and had shorter cross clamp times and trended towards being less likely to have a valve or multiple procedure performed and having shorter CPB times. Despite these differences, the control patients were 3.2-fold more likely to die before discharge, 1.45-fold more likely to be transfused, 1.52-fold more likely to experience any complication(s), and trended towards being more likely to need additional surgery, to suffer an intraoperative myocardial infarction, to have cardiac arrest, pneumonia, or to have sternal infection. Interestingly, the treatment patients spent slightly more time on mechanical ventilation and more time in the hospital. It cannot be discerned if this was a true effect, a statistical anomalies, or a reflection of the lack of specificity of these measures.

The study lacked the objectivity of randomization and does not include a prospective control group. Although the use of advanced statistics, including propensity scoring and multiple conditional regression, raise the power of the conclusions that can be made, the prospective, randomized study remains the gold standard for scientific investigation (18). Further, multiple changes were tested concurrently and it is not possible to discern what impact the individual components had made.

In conclusion, the patients treated with a best-practice care plan, which implemented multiple changes simultaneously, had significantly fewer complications and a decreased mortality rate. Multiple changes in perfusion prac-

tice should be implemented to improve patient outcomes, even when individual benefit has not been unequivocally established.

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