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Factors That Influence the Ability to Perform Autologous Priming

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Abstract: The purpose of this study was to determine which factors impact the ability to perform autologous priming (AP) of the extracorporeal circuit. Second, the effects of differential AP on transfusion and volume requirements were evaluated. After institutional review board approval, demographic, operative, volumetric, and transfusion data were prospectively collected on 100 adult patients undergoing cardiopulmonary bypass (CPB). Two analyses were conducted: AP Taken and percent AP Given. For each analysis, three groups were created based on standard distribution. Group A included patients within less than mean – 1 SD (≤500 mL AP Taken or ≥90% AP Given back), group B included patients within mean ± 1 SD (501–1299 mL AP Taken or 11%–89% AP Given back), and group C included patients greater than mean + 1 SD (≥1300 mL AP Taken or ≤10% AP Given back). Weight, pre-CPB hematocrit, clinical severity, and pre-CPB volume balance did not differ between the groups. Significant differences existed in AP Taken and percent AP Given between individual perfusionists. More AP was given back with higher urine output (group A: 846 ± 700 mL, group B: 613 ± 414 mL, group C: 384 ± 272 mL; $p = .004$), more autotransfusion [group A: 0 (0,1300 mL), group B: 0 (0,500 mL), group C: 0 (0,250 mL); $p = .008$], and less AP Taken [group A: 800 (0,1300 mL), group B: 1000 (200,1600 mL), group C: 1000 (800,1600 mL); $p = .001$]. When more AP was taken, CPB hematocrit was higher (group A: 22.3% ± 4.8%, group B: 25.6% ± 4.7%, group C: 26.6% ± 4.3%; $p = .032$), and fewer patients received red blood cells (group A: 64.3%, group B: 28.3%, group C:14.3%; $p = .017$). Some perfusionists were able to remove more AP before CPB. When more AP was taken, CPB hematocrit was higher, fewer patients received a transfusion, and less AP was given back. More AP was also given back with higher urine output and higher blood loss to the autotransfusion device. **Keywords:** autologous prime, cardiopulmonary bypass. *JECT. 2008; 40:43–51*

The process of displacing crystalloid prime solution with the patient's own blood to reduce hemodilution during the onset of cardiopulmonary bypass (CPB), known as autologous priming (AP), is neither new nor novel. A prospective trial by Rosengart et al. (1) at the New York Hospital–Cornell Medical Center brought the technique into contemporary literature and led the way for other investigators (1). The study of Rosengart et al. was limited to first-time coronary artery bypass grafting patients and had a small sample size ($n = 60$), but established that AP limits hemodilution and reduces the number of patients needing red cell transfusions. Since the report of Rosengart et al., several groups have reported similar results in both randomized and observational trials (2–6), with reported benefits of reduced transfusion requirements and higher CPB hematocrits being consistent. However, one observational study concluded that AP does not offer a clinical benefit as a blood conservation technique. The trial was limited by design (retrospective cohort, single surgeon) and the restrained reporting of AP techniques and volume management strategies prevents replication (7). Given that the majority of reports, including all of the randomized trials, support the use of AP, the technique should be considered a standard blood conservation strategy during CPB.

Reducing transfusion use and exposure is a well-understood goal, but the importance of maintaining higher hematocrits during CPB is becoming more apparent. Several groups have reported that lower nadir hematocrit on CPB is exponentially associated with poor outcome. In a very large series of patients ($n = 3800$), Habib et al. (8)

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found that increased hemodilution during cardiac surgery (Hct = 22%–24%) was associated with higher incidences of perioperative organ dysfunction, increased resource use, and higher mortality (8). In a similar large, multicenter series (n = 6980), the Northern New England Study Group found that lower CPB hematocrits were significantly associated with increased post-CPB mechanical support and increased mortality (9). It is clear from these studies and others that the avoidance of anemia and avoiding transfusion triggers during CPB is critical, and AP is an effective method for supporting this goal.

Although AP techniques are known to reduce CPB volume balance, reduce transfusion of homologous red blood cells, and maintain higher hematocrits, most studies have compared AP vs. no AP in defined, limited patient populations. Therefore, it is not clear what level of AP is needed to achieve benefit or what impacts the ability to perform this procedure. The purpose of this study was to evaluate different levels of effective AP on hematocrit and transfusion requirements. A second goal was to identify any demographic or operative parameters that may influence the effectiveness of AP.

MATERIALS AND METHODS

After institutional review board approval, data on 100 adult patients undergoing cardiopulmonary bypass (CPB) were prospectively collected. Primary groups were defined by the amount of AP removed before initiation of CPB (AP Taken) or the percentage of AP given back during CPB (%AP Given). Eleven patients were removed from the study because of missing data.

Two analyses were conducted: AP Taken and %AP Given. For each analysis, three groups were created based on standard distribution. Demographic, preoperative, operative, transfusion, and hematocrit data were recorded for each patient.

For AP Taken, group A included patients with 0–500 mL of AP removed, or less than mean – 1 SD of the entire population (n = 15). Group B included patients with 501–1299 mL removed, or mean – 1 SD to mean + 1 SD (n = 60). Group C included patients with ≥1300 mL removed, or greater than mean + 1 SD (n = 14). For %AP Given, group A included those with <10% returned (n = 26), group B included those with 11%–89% returned (n = 34), and group C included those with ≥90% returned (n = 28). Patients with 0 mL AP Taken (n = 10) were included in group C for %AP Given. A separate analysis was created comparing patients with 0 mL AP Taken (n = 7) vs. ≥1 mL AP Taken (n = 82).

Anesthesia Management

Patients received 0.5–5.0 mg of Versed in the preoperative care unit, followed by the placement of two 16-gauge intravenous lines. After arriving in the operative suite, a radial or brachial arterial line was placed, followed by a continuous cardiac output pulmonary artery catheter, inserted through an internal jugular introducer. Induction was accomplished by 5.0–10.0 mg Versed, 0.5–1.0 mg Fentanyl, and 7.0–10.0 mg of pancuronium (cisatracurium or vecuronium were occasionally used in lieu of Pavulon to maintain a heart rate <100 bpm).

Before CPB, formal anesthesia guidelines were in place to keep fluid administration <1200 ml. Blood pressures were maintained with either neosynephrine and ephedrine or epinephrine infusion through the central line. Fentanyl (as needed), ativan (2 mg), and versed (5–10 mg) were given before initiation of CPB at the discretion of the anesthesia staff. In addition, 1 g of cefazolin was given <60 minutes before skin incision, followed by repeat 1-g doses every 4 hours until closure.

Amicar or aprotinin was used on all cases, with selection based on surgeon preference. If amicar was used, 5 g was infused before CPB. If aprotinin was used, a 1-mL test dose was given, followed by 2,000,000 KIU infused over 30 minutes, followed by a 100,000-KIU/h drip continued through intensive care unit (ICU) arrival.

For circulatory arrest procedures, 30 mg/kg of solumedrol and 25 g of mannitol were given. During rewarming, additional fentanyl (12.5–25.0 μg/kg) and versed (5.0–12.0 mg) and additional muscle relaxant were given. Before cross-clamp removal, 100 mg lidocaine and 2 g magnesium sulfate were given.

CPB Management

The CPB circuit consisted of an oxygenator with integrated arterial line filter and cardiotomy reservoir (Synthesis; Cobe Cardiovascular, Arvada, CO), $SmART_x$-coated tubing (Cobe Cardiovascular), Myocardial Protection System (MPS; Quest, Allen, TX), in-line blood gas monitoring (CDI 500; Terumo Cardiovascular, Ann Arbor, MI), and a centrifugal pump (Revolution; Cobe Cardiovascular). The circuit was primed with 1400 mL of PlasmaLyteA, 35 mEq $NaHCO_3$, 5000 IU heparin, and 25 g mannitol.

Autotransfusion was used with every case (CATS; Terumo Cardiovascular). A ratio of 1 part anticoagulant (30 IU heparin/mL 0.9% NS) to 10 parts collected blood was used and was washed with 0.9% NaCl solution on the "Quality Wash" program.

During CPB, arterial pressure was maintained between 60 and 90 mmHg, cardiac index was maintained >1.8 L/min/m^2, and blood gases were managed with alpha-stat physiology (pH_a, 7.35–7.45; P_aCO_2, 35–45 mmHg; P_aO_2, 150–250 mmHg). Patients were cooled to a temperature specified by surgeon preference and surgical procedure, with temperature control according to institutional policy (gradients <6°C, maximum arterial temperature <37°C, rewarming rate <0.5°C/min). Vacuum-assisted venous

drainage was only used when needed and never exceeded −40 mmHg. Volume replacement during CPB was accomplished with PlasmaLyteA, with 12.5 g of albumin added per liter crystalloid solution or 5% albumin added to achieve [Albumin] >3.5 g/dL or colloid oncotic pressure (COP) >14 mmHg.

Induction of cardioplegic arrest was accomplished with 1000–1500 mL cold (4°C) 4 blood:1 crystalloid. The MPS was set to deliver 20 mEq/L KCl and 15 mEq/L $NaHCO_3$, with the crystalloid component consisting of 1 L 0.9% saline with 12.5 g mannitol. Subsequent doses were given at 15- to 20-minute intervals and consisted of cold (4°C) blood with 10–16 mEq/L KCl (adjusted to ensure electrical quiescence and avoid hyperkalemia). Antegrade cardioplegia was delivered at a system pressure of 100–150 mmHg, and retrograde cardioplegia was delivered to a coronary sinus pressure of 30–40 mmHg. Antegrade vs. retrograde delivery was based on surgeon preference and surgical procedure. Before removal of the cross-clamp, warm blood (37°C) was delivered for 5 minutes, with additional [KCl] of 8 mEq for the first minute, 4 mEq for the second minute, and 0 mEq for the remaining 3 minutes.

If Amicar was used, 5 g of Amicar was added to the pump prime, the patient was anticoagulated with a loading dose of 300 IU/kg heparin, and additional heparin was given to during CPB to maintain an activated clotting time (ACT) >480 seconds (ACTII; Medtronic, Minneapolis, MN). If aprotinin was used, 2,000,000 KIU of aprotinin was added to the pump prime, the patient was anticoagulated with 400 IU/kg heparin, and additional heparin was given during CPB to maintain ACT >600 seconds. After termination of CPB and patient stability was assured, heparin was reversed with 0.6 mg of protamine per 100 IU heparin administered.

Autologous Priming Procedure

After adequate anticoagulation was confirmed by an ACT > 400 seconds, the arterial cannula was placed and AP started by slowly displacing the crystalloid prime with the patient blood, retrograde down the arterial line. All purges were closed, a clamp was placed distal to the outlet of the arterial filter, and a clamp was placed on the recirculation line proximal to the cardiotomy reservoir (Figure 1). With the centrifugal pump turning (>1300 rpm), the clamp located between the cardioplegia Y and the prime Y was opened, allowing the contents of the reservoir to empty into the bags. A clamp was placed distal to the centrifugal pump and proximal to the oxygenator. The clamp located between the cardioplegia Y and the prime Y was opened, and the clamp distal to the arterial filter was opened, allowing blood to travel down the arterial line, through the arterial filter, and into the bags through the recirculation line. The clamp distal to the arterial line filter was closed when the recirculation lines showed evidence of blood. The clamp located between the cardioplegia Y and the prime Y was closed.

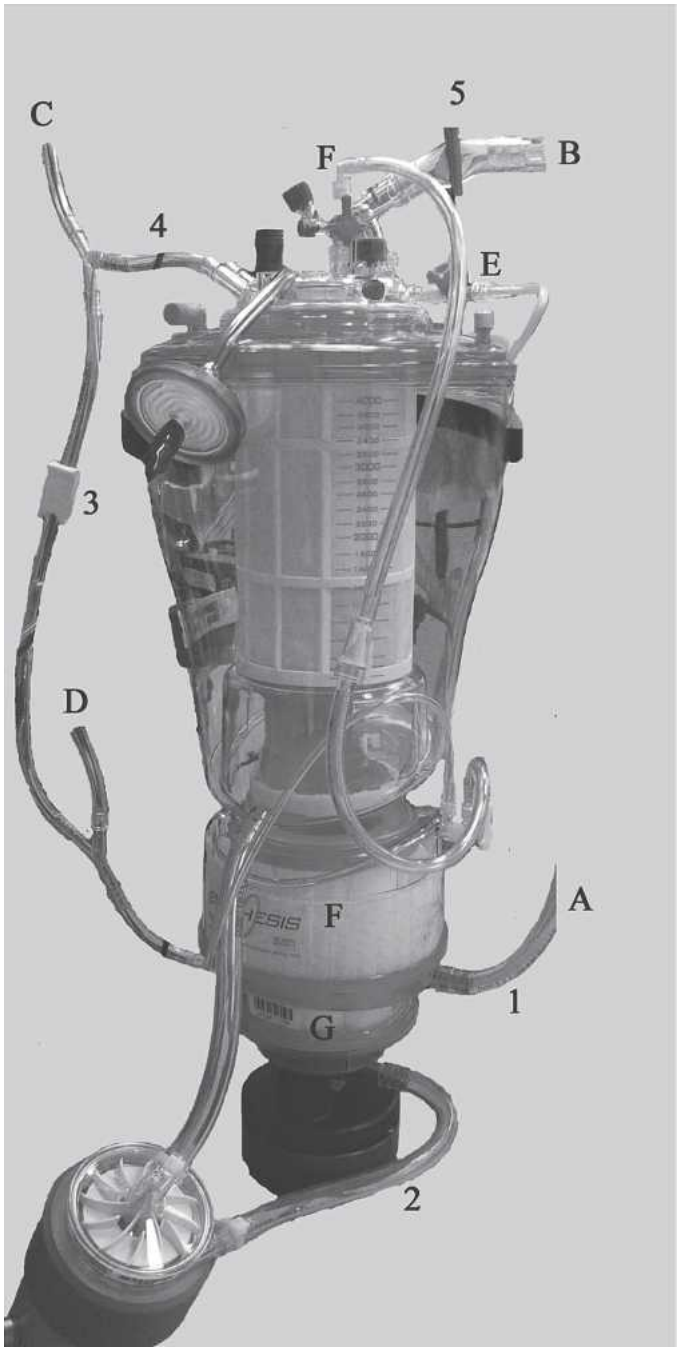

Figure 1. A, Arterial line. B, Venous line. C, Line to prime bags, which has a male–female fitting to attach to stopcocks. D, Blood source line for cardioplegia. E, Cardioplegia purge. F, Arterial filter. G, Oxygenator. Clamp positions: 1, distal to arterial filter; 2, proximal to oxygenator, distal to centrifugal pump; 3, recirculation line, proximal to prime line Y; 4, recirculation line distal to prime line Y, proximal to cardiotomy reservoir; 5, venous line clamp proximal to Luer lock connector.

The clamp distal to the arterial line filter was opened, and the purge on the arterial filter was opened to high flow, allowing blood to flow down the arterial line and into the cardiotomy reservoir. After a sufficient volume of blood was collected, the arterial line was reclamped, and

the purge was closed. Alternatively, a large amount of cardiotomy suction blood would be used instead of blood removed from the arterial line. The clamp distal to the centrifugal pump was opened, and the clamp located between the cardioplegia Y and the prime Y was opened, allowing the blood in the cardiotomy to be pumped through the centrifugal pump and the oxygenator and out the recirculation line.

When the venous line was placed, a clamp was located between the pressure monitoring stopcock and the reservoir. The prime bags were connected to this stopcock and opened to the patient. When the venous line was blood filled, the stopcock was closed. The prime bags were connected to the cardioplegia vent line, and the cardioplegia was turned on "Vent, Blood," and blood filled from the cardiotomy.

If sufficient time was available after the venous line was placed, an alternative method was used. The arterial line and arterial filter were primed as above. The venous line was emptied into reservoir, and the venous reservoir was emptied as above. The cardiotomy was filled with blood from the venous line and pumped through the centrifugal pump and oxygenator as above. The cardioplegia was primed as above.

During the AP procedure, systolic blood pressures were maintained >100 mmHg. When a drop in pressure was noted, volume removal was slowed. Neosynephrine boluses (0.1 mg/mL, not to exceed 1.0 mg) were used to increase systemic vascular resistance (SVR) to no higher than 1400 dyn/s/cm^5. If the SVR was ≥1400 dyn/s/cm^5 and the systolic blood pressure fell below 100 mmHg, AP was discontinued. If the systolic blood pressure fell below 90 mmHg with an SVR ≥ 1400 dyn/s/cm^5, or if the surgeon, anesthesiologist, or perfusionist felt the status of the patient was compromised, CPB was initiated or volume was reinfused into the patient in 50-mL boluses until a blood pressure >90 mmHg was achieved. After the AP was complete, CPB was initiated.

Transfusion decisions were based on an institutional algorithm. Packed red blood cells (RBCs) were transfused for hemocrits <22% for patients ≤65 years old and 24% for patients >65 years old. If non-surgical bleeding occurred, other blood products were used. Fresh frozen plasma (FFP) was transfused when the thromboelastograph R-time was >16 minutes, or 12–16 minutes with a fibrinogen level <100 mg/dL. Platelets (Plt) were transfused if the thromboelastograph maximum amplitude (MA) was <49 mm or if the platelet count was <100,000. Cryoprecipitate (CRYO) was transfused if the R-time was >16 minutes and the fibrinogen level was <100 mg/dL.

Statistical Analysis

All data were loaded on a secure Microsoft Excel file. The Geisinger Health System, Center for Health Research and Rural Advocacy, Statistical Support Section provided consultation and analysis using SAS (version 8.0; SAS, Cary, NC). Tests included χ^2, Fisher exact, ANOVA, and Kruskal-Wallis tests, as appropriate. Data are expressed as percent yes, mean ± SD, or median (minimum, maximum). All tests were two-sided, and $p < .05$ was considered significant.

RESULTS

For AP Taken, there were no differences between groups A, B, or C for age, weight, body surface area (BSA), body mass index (BMI), sex, clinical severity, post-induction hematocrit, or pre-anesthesia volume balance (Tables 1–3). Some perfusionists were able to achieve significantly higher AP Taken than their peers (Table 1). When more AP was taken, the first hematocrit on CPB was higher (22.3 ± 4.8 vs. 25.6 ± 4.7 vs. 26.6 ± 4.3; $p = .032$), fewer patients received RBCs during CPB (64.3% vs. 28.3% vs. 14.3%; $p = .017$), and additional volume added was less (Table 3). Of particular interest, when more AP was taken, less was given back (80.0 ± 41% vs. 48 ± 40% vs. 31 ± 34%; $p = .006$).

There were also differences in %AP Given between individual perfusionists (Table 4). A higher percentage of AP was given back when less was taken [800 (0,1300) vs. 1000 (200,1400) vs. 1000 (800,1400); $p = .001$], when more autotransfusion was used during CPB [0 (0,1300) vs. 0 (0,500) vs. 0 (0,250); $p = .008$], and when more urine was produced during CPB (846 ± 700 vs. 613 ± 414 vs. 384 ± 272; $p = .004$). When more AP was given back, more additional crystalloid was used [550 (0,3900) vs. 300 (0,2600) vs. 0 (0,2500); $p = 0.0001$] and more RBCs were transfused [0 (0,7) vs. 0 (0,3) vs. 0 (0,2); $p = .04$).

DISCUSSION

Increasing the effectiveness of AP resulted in fewer patients receiving RBCs during CPB, with fewer total unit exposures. When examining AP Taken in isolation, more AP Taken resulted in significantly higher first CPB hematocrit, but the results were equivalent by the last CPB hematocrit. The hematocrit values were similar between %AP Given groups, with more RBC transfusions with more AP Given. Combined, these results suggest that in the absence of effective AP (AP Taken – AP Given), transfusions are used to raise hematocrit levels to the desired level. Thus, more effective AP results in fewer patients reaching the transfusion trigger.

Higher Hct and fewer transfusions with AP have been reported elsewhere and were not surprising (1–6). From these data, it seems that optimizing the effectiveness of AP may be as critical as whether it is performed. Therefore, it was important to identify factors that limit or com-

Table 1. AP Taken: demographic and operative variables.

Demographics and Operative Category	Group A RAP Taken (n = 14) (0–500 mL)	Group B RAP Taken (n = 60) (501–1299 mL)	Group C RAP Taken (n = 14) (≥1300 mL)	$p < .0001$*
Age (yr)	66.4 ± 16.1	65.8 ± 11.4	65.1 ± 12.7	NS†
Weight (kg)	79.0 ± 24.6	81.6 ± 17.1	80.8 ± 18.5	NS†
Height (cm)	160.7 ± 12.7	167.6 ± 13.8	168.7 ± 12.6	NS†
BSA (m^2)	1.85 ± 0.30	1.93 ± 0.30	1.92 ± 0.20	NS†
BMI (kg/m^2)	41.8 ± 5.5	41.9 ± 4.0	41.6 ± 5.1	NS†
CCCS score (points)	7.5 ± 4.3	5.3 ± 4.1	6.2 ± 4.2	NS†
Male	42.9%	61.7%	71.4%	NS‡
Surgeon				
A	28.6%	33.3%	14.3%	NS§
B	35.7%	51.7%	64.3%	
C	7.1%	0.0%	0.0%	
D	28.6%	15.0%	21.4%	
Perfusionist				
A	0.0%	16.7%	7.1%	<.0001§
B	7.1%	26.7%	35.7%	
C	21.4%	16.7%	50.0%	
D	7.1%	31.7%	0.0%	
E	64.3%	8.3%	7.1%	
Valve				
None	35.7%	15.0%	7.1%	.188§
AVR	50.0%	46.7%	35.7%	
MVR	7.1%	23.3%	35.7%	
AVR, MVR	0.0%	6.7%	7.1%	
AVR, MVR, TVR	7.1%	0.0%	0.0%	
Other combo	0.0%	8.3%	14.3%	
CABG				
None	50.0%	63.3%	78.6%	.055§
OPCAB conventional	14.3%	3.3%	0.0%	
CABG only	14.3%	0.0%	0.0%	
CABG combined	21.4%	33.3%	21.4%	
Aorta				
None	100.0%	93.0%	79.0%	.153§
Ascend	0.0%	6.7%	21.4%	
Other				
None	64.3%	78.3%	78.6%	NS§
ASD/PFO	0.0%	6.7%	7.1%	
A-Fib	7.1%	1.7%	7.1%	
TMR	7.1%	0.0%	0.0%	
Salvage	7.1%	1.7%	0.0%	
Other	14.3%	11.7%	7.1%	

Values are means ± SD or percentages.
*Kruskal-Wallis test.
†ANOVA test.
‡χ^2 test.
§Fisher exact test.
NS, not significant.

promise the effectiveness of AP vs. those that promote it. Obviously, how much volume is removed from the patient before initiation of CPB and how much is returned during CPB determine the effectiveness of AP. Both were analyzed separately, because parameters effecting one may, or may not, influence the other.

For both analyses, height, weight, BSA, and BMI were not significantly different between groups, indicating that patient size does not impact how much AP is taken, how much must be returned during CPB, and what the net result of both is. Although other groups have reported similar findings, the results were surprising enough that a second analysis on weight was conducted (Figure 2) (6). Note that there is very little correlation between weight and the amount of AP taken (correlation coefficient = 0.1058).

Likewise, pre-CPB volume balance was similar between all groups in both analyses. The removal of whole blood for the production of platelet gel was also similar between all groups and all analyses, suggesting that this treatment does not negatively affect our ability to perform AP. Perhaps these results are a reflection of limited patient-specific alterations in patient care before the initiation of CPB. However, both weight and pre-CPB volume balance may have a more limited impact on the ability to perform AP than would be assumed by intuition alone.

In a similar manner, age and clinical severity [as measured by the Cleveland Clinic Clinical Severity (CCCS)

Table 2. AP Taken: miscellaneous variables.

	Group A RAP Taken (n = 14) (0–500 mL)	Group B RAP Taken (n = 60) (501–1299 mL)	Group C RAP Taken (n = 14) (≥1300 mL)	$p < .0001$*
Operative techniques				
Redo	14.3%	26.7%	14.3%	NS†
Min Inv	14.3%	16.7%	42.9%	NS†
IABP				
None	85.7%	88.3%	71.4%	NS†
Pre-operative	7.1%	1.7%	14.3%	
Intra-operative	0.0%	10.0%	14.3%	
Post-operative				
Hematocrit (%)				
Postinduction	32.7 ± 5.8	35.1 ± 4.3	34.6 ± 4.3	NS‡
First CPB	22.3 ± 4.8	25.6 ± 4.7	26.6 ± 4.3	.032‡
Last CPB	24.7 ± 3.1	25.8 ± 4	25.4 ± 3.7	NS‡
Plasmapheresis (mL)				
WB removed	0 (0, 475)	109 (0, 675)	109 (0, 180)	NS*
PrP	0 (0, 100)	12.5 (0, 100)	20 (0, 40)	NS*
RBC	0 (0, 375)	7 (0, 245)	16.5 (0, 93)	NS*
PpP	0 (0, 200)	40 (0, 350)	40 (0, 87)	NS*
Autotransfusion returned (mL)				
Pre CPB	0 (0, 1000)	0 (0, 420)	0 (0, 100)	.106*
CPB	0 (0, 1300)	0 (0, 505)	0 (0, 250)	NS*
Post CPB	621.4 (494)	749.5 (737.5)	837.7 (470)	NS
Bypass times (min)				
CPB time	195.8 ± 130.6	161.2 ± 69.7	180.6 ± 53.7	NS‡
XC time	102 ± 68	114.6 ± 62.1	125.4 ± 68.8	NS‡
Circ arrest	0 (0, 60)	0 (0, 30)	0 (0, 31)	NS*
Pharmacology				
Aprotinin	50.0%	70.0%	64.3%	NS§
rFVIIa	7.1%	3.3%	7.1%	NS†

Values are means ± SD, percentages, or median (minimum, maximum).
*Kruskal-Wallis test.
†Fisher exact test.
‡ANOVA test.
§χ^2 test.
NS, not significant.

score] did not influence effective AP, AP Taken, or %AP Given. The finding is important, given the changing demographics of cardiac surgery patients and the fact that most published reports have limited the enrollment of sicker, more complicated patients.

Although intra-group variability may contribute to some of these results, they are likely a reflection that other factors may be more important in determining the effectiveness of AP. The assumption that small patients, sick patients, or "dry" patients preclude the use of AP is flawed. The data from this trial indicate that operative characteristics impact the ability to perform AP more significantly. For example, blood loss to the cell saver before initiation of CPB may limit the amount of AP Taken, and blood loss to the cell saver during CPB may result in higher amounts of AP given back. Combined, blood loss to the cell saver trends toward decreasing the amount of effective AP. Perhaps as important, the perfusionist doing the case may have a large bearing on the effective AP volume. By way of example, perfusionist E was more likely to have low AP Taken (<500 mL) and more likely to give that volume back than perfusionist C. At the local level, these finding were important and prompted a review and standardization of AP techniques. At a global level, these findings emphasize the limitation of using a small number of practitioners in the study of AP, as Murphy et al. (7) did in their study.

Equally important may be the type of surgery performed. It did not make a difference if the procedure was a redo sternotomy, included a CAB, involved the aorta, or included an "other" procedure such as an ASD closure or atrial fibrillation correction. However, a clear trend exists between the occurrence of mitral valve and aortic valve surgery. As the occurrence of aortic valve surgery declined and mitral valve surgery increased, effective AP increased. Perhaps these differences were the result of the higher incidence of regurgitant/insufficient valve disease in the mitral valve patients and a higher proportion of stenotic lesions in the aortic valve patients. Unfortunately, the type of valvular disease was not prospectively collected (as were the other data), and the power of the sample size precludes further analysis.

Less effective AP was associated with higher positive CPB volume balances, beyond the contribution of AP. The CPB volume balance was 2638 + 1737 mL in the lowest effective AP group compared with 1031 + 1216 mL

Table 3. AP Taken: volume management.

	Group A RAP Taken (n = 14) (0–500 mL)	Group B RAP Taken (n = 60) (501–1299 mL)	Group C RAP Taken (n = 14) (≥1300 mL)	$p < .0001$*
Pre-CPB volume balance				
Albumin (mL)	0 (0, 1750)	0 (0, 1700)	0 (0, 1250)	NS*
Crystalloid (mL)	1417.9 ± 712.4	1482.3 ± 729.1	1785.7 ± 774.5	NS†
RBCs (units)				
None	78.6%	96.7%	100.0%	.02*
1 unit	14.3%	1.7%	0.0%	
2 units	0.0%	1.7%	0.0%	
3 units	7.1%	0.0%	0.0%	
Urine (mL)	393.9 ± 351.9	337.2 ± 234.6	368.9 ± 254.1	.734†
Volume balance	1606.1 ± 1320.5	1382.5 ± 834.5	1577.5 ± 119.1	.621†
CPB volume balance				
Crystalloid (mL)	500 (0, 3900)	0 (0, 3000)	0 (0, 2600)	.022*
Albumin (mL)	575 (0, 3250)	500 (0, 1500)	375 (0, 1250)	NS*
RBC (units)	1.5 (0, 7)	0 (0, 3)	0 (0, 1)	.001*
RBC Y/N	64.3%	28.3%	14.3%	.017‡
Other volume (mL)	50 (0, 800)	105 (0, 1185)	227.5 (0, 817)	NS*
Total volume (mL)	3622.2 ± 2032	2245.6 ± 935	2107.7 ± 1450	.001†
Urine (mL)	553.2 ± 433.5	638.6 ± 566.1	602.5 ± 422.8	NS†
Ultrafiltration (mL)	0 (0, 800)	0 (0, 1250)	0 (0, 1400)	NS*
Ultrafiltration Y/N	21.4%	11.7%	28.6%	NS‡
Volume balance (mL)	2933.3 ± 2195	1509.5 ± 819	1273.1 ± 1648	.001†
Post-CPB volume requirements				
Crystalloid (mL)	550 (0, 1200)	400 (0, 4700)	400 (0, 3500)	NS*
Colloid (mL)	0 (0, 500)	0 (0, 1000)	0 (0, 2000)	NS*
RBC (units)	1 (0, 6)	0 (0, 12)	0 (0, 6)	NS*
RBC Y/N	57.10%	23.30%	15.10%	.032§
FFP (units)	0 (0, 9)	0 (0, 18)	0 (0, 6)	NS*
FFP Y/N	21.40%	16.70%	21.40%	NS‡
CRYO (units)	0 (0, 20)	0 (0, 20)	0 (0, 10)	NS*
CRYO Y/N	21.40%	13.30%	14.30%	NS‡
Plt (units)	0 (0, 4)	0 (0, 12)	0 (0, 6)	NS*
Plt Y/N	21.40%	16.70%	35.70%	NS‡

Values are means ± SD, percentages, or median (minimum, maximum).
*Kruskal-Wallis test.
†ANOVA test.
‡Fisher exact test.
§χ^2 test.
NS, not significant.

Table 4. Percent AP Given: significantly different variables.

	Group A (n = 26) (≥90%)	Group B (n = 35) (11%–89%)	Group C (n = 28) (≤10%)	p
Perfusionist				
A	3.6%	14.3%	19.2%	.002*
B	14.3%	31.4%	26.9%	
C	21.4%	25.7%	23.1%	
D	17.9%	28.6%	19.2%	
E	42.9%	0.0%	11.5%	
CPB cell saver (mL)	0 (0, 1300)	0 (0, 500)	0 (0, 250)	.008†
RAP Taken	800 (0, 1300)	1000 (200, 1400)	1000 (800, 1400)	.001†
CPB volumes (mL, units)				
Crystalloid (mL)	550 (0, 3900)	300 (0, 2600)	0 (0, 2500)	<.0001†
RBC (units)	0 (0, 7)	0 (0, 3)	0 (0, 2)	.04†
Total volume given	4000 ± 1947	2121 ± 883	2014 ± 999	<.0001‡
Urine (mL)	846 ± 700	613 ± 414	384 ± 272	.004‡
Volume balance (mL)	3072 ± 2078	1325 ± 968	1542 ± 1064	<.0001‡

Values are means ± SD, percentages, or median (minimum, maximum).
*Fisher exact test.
†Kruskal-Wallis test.
‡ANOVA test.

in the highest effective AP group. When the reduction in volume balance from AP is removed, the lowest AP group still required more volume than the highest AP group (1057 ± 1691 vs. 594 ± 1206; $p = .003$). Thus, less effective

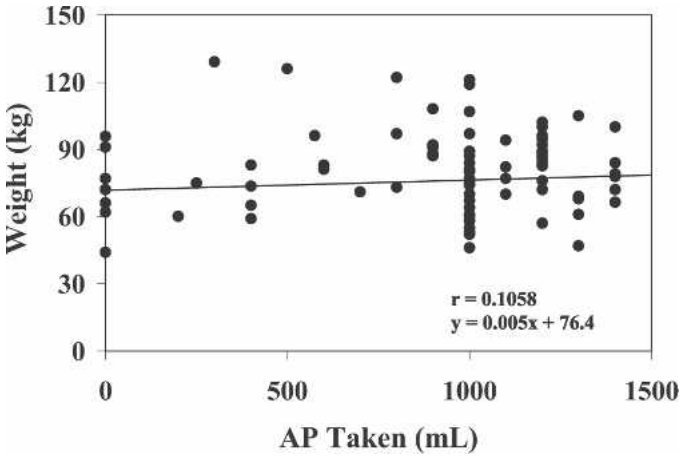

Figure 2. Weight vs. AP Taken.

AP may result in higher volume requirements during CPB, above and beyond the prime volume reduction achieved by AP. Likewise, when more AP is taken at the beginning of the case, less is returned during the procedure. These results suggest that AP may positively affect the intravascular–extravascular fluid dynamics during CPB, resulting in less third-space accumulation of fluid. Indeed, Eising et al. (3) reported higher colloid oncotic pressures (COPs) in patients receiving AP, with concomitant decreases in extravascular lung water. However, specific measures of plasma protein levels, COP, or extravascular water were not made in this study, so the reduction in volume requirements must be inferred and may be confounded by other variables.

The different groups in both analyses were similar in all post-CPB parameters, including volume balance and transfusion requirements (with the exception of RBC requirements). In part, these results may be because of the inclusion of all patient and operative categories. In addition, consistent perfusion management and adjustment of deviations resulting from differential effective AP would be expected to yield similar results. However, decreased hemodilution with the use of AP would be expected to result in higher concentrations of elements of blood, including clotting factors and platelets. No reduction in transfusion requirements were noted for post-CPB allogeneic non-RBC blood products, most likely a reflection of the diversity of factors impacting these needs. Future study should examine the role AP plays in hemostasis, which will require a larger sample and a more homogenous study population than this report.

Of the 89 patients included in this study, AP was not attempted in 7 (7.9%). To determine the characteristics of this subset of patients, a separate analysis was performed to compare them with the rest of the population. The circumstances all included emergent initiation of CPB: two failed OPCABs (28.6% vs. 2.4%), one massive hemorrhage (14.3% vs. 2.4%), and four acute hemodynamic collapse (57.1% vs. 0.0%). Other operative and demographic parameters were similar. It should be noted that AP was successfully performed in two failed OPCABs and two massive hemorrhage patients (by using salvaged blood to displace prime).

The groups are underpowered to perform a multivariate analysis, so it is difficult to account for the impact of other variables. For example, surgeon B more frequently had patients with an effective AP > 1300 mL, and he performed more minimally invasive procedures. Minimally invasive procedures were also associated with higher effective AP volumes. It is not possible to determine cause and effect. Does surgeon B have higher effective AP volumes because he performs more minimally invasive procedures or because he loses less blood regardless of the approach? The prospective observational study design further limits the ability to establish cause–effect from this data set.

The data related to AP volumes were not recorded for 11 patients in the defined study interval, which made inclusion of these patients in the study impossible. The data that were available from these 11 patients were compared to the study population, and no differences were detected. Thus, it is expected, but not assured, that these missing patients do no affect the results.

AP was safely performed in all patients but was not attempted in patients suffering acute hemodynamic collapse in the immediate pre-CPB interval. When more AP was taken before initiating CPB, the first CPB hematocrits were higher, fewer patients received fewer transfusions, and less AP was given back. Patient size, clinical severity, and pre-CPB volume balance did not impact the ability to perform AP. The most significant influences on effective AP were blood loss, perfusionist, and whether the aortic valve or mitral valve was being operated on.

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