

To RAP or Not to RAP: A Retrospective Comparison of the Effects of Retrograde Autologous Priming

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Abstract: Retrograde autologous priming (RAP) is a process used to reduce hemodilution associated with the initiation of cardiopulmonary bypass (CPB). Previous studies have reported potential benefits to RAP; however, many of these studies do not evaluate the benefits of RAP with limited preoperative fluid administration combined with a condensed CPB circuit. We examined clinical metrics of patients who underwent RAP versus those who did not undergo RAP prior to the initiation of CPB. This was a retrospective data review of 1,303 patients who underwent CPB in the setting of open-heart surgery for a 2-year period. RAP was used on all patients between June 1, 2017 and June 30, 2018 ($n = 519$) and not used on patients between July 1, 2018 and June 30, 2019 ($n = 784$). Both groups were subjected to a low-prime CPB circuit volume of 800–900 mL. We compared the clinical metrics for packed red blood cell (PRBC) transfusion, oxygen delivery, postoperative acute kidney injury (AKI), Albumin utilization, ventilator time, Intensive Care Unit length of stay (ICU LOS), and

30-day mortality between the two groups. Our data analysis showed there were no statistically significant differences between the two groups on the incidence of postoperative AKI, PRBC administration, ventilator time, ICU LOS or 30-day mortality. In the RAP group, there was a statistically significant lower oxygen delivery and a statistically significant increased volume of Albumin administered postoperatively, although those differences were so small, they were potentially not clinically significant. Our analysis revealed no significant benefit to performing RAP with limited preoperative fluid administration and minimized CPB circuit prime volume. We formalized a process that included limiting preoperative fluid administration and minimizing the CPB circuit volume so that we were not required to RAP and did not simultaneously sacrifice patient outcomes in other areas. **Keywords:** retrograde autologous priming (RAP), cardiopulmonary bypass (CPB), acute kidney injury (AKI), oxygen delivery (DO_2). *J Extra Corpor Technol. 2021;53:279–85*

Retrograde autologous priming (RAP) is a process a perfusionist uses prior to the initiation of cardiopulmonary bypass (CPB) to reduce hemodilution associated with initiating bypass (1). RAP is performed by replacing the crystalloid used to prime the circuit with the patient's own blood, via passive exsanguination from the patient's arterial and venous cannulation sites (1). Studies have indicated the potential benefits of RAP include reduction of sudden drop of hemoglobin, attenuation of capillary leak preventing the third spacing of fluid, improvement of cerebral perfusion

during initiation, and diminution of necessity for blood transfusions (1). However, this temporary exsanguination can result in transient hypotension resulting in decreased perfusion prior to initiation of CPB, eliciting multiple end organ damage, including acute kidney injury (AKI) (2,3). In this analysis, we examined the effects of RAP on our general cardiothoracic surgical patients. Specifically, we examined the incidence of packed red blood cell (PRBC) transfusion, oxygen delivery (DO_{2i}), postoperative AKI, Albumin administration, ventilator times, Intensive Care Unit length of stay (ICU LOS), and 30-day mortality.

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MATERIALS AND METHODS

After formal institutional IRB approval from Catholic Health Initiatives, all patients who underwent CPB during

cardiac surgery between June 1, 2017 and June 30, 2019 were retrospectively analyzed. The breakdown of case mix was as follows: isolated Coronary Artery Bypass (CAB) ($n = 779$), CAB/Aortic Valve Replacement (AVR) ($n = 91$), and CAB/MAZE ($n = 66$). The remaining 367 surgery types were a mixture and combination of valve repairs, valve replacements, MAZE procedures, aortic dissection repairs, aortic aneurysm repairs, and CAB/valve operations. All surgery types—elective, urgent, and emergent—were included. We chose to evaluate the consecutive patients who went on CPB during this time frame with no exclusions, regardless of surgery type and status, to avoid selection bias.

RAP was used on all patients from June 1, 2017 to June 30, 2018 ($n = 519$). From July 1, 2018 to June 30, 2019, RAP was not performed on any patient ($n = 784$). All other perfusion practices remained the same.

Each chart was accessed via the Meditech Charting System. Each value analyzed was collected and organized in a Microsoft Excel spreadsheet. After all data was collected, the full spreadsheet was coded and sent to an independent statistician who transferred the spreadsheet into the SPSS Statistics Software (v25) for all descriptive statistics. The two groups were coded separately to allow for group comparison analyses. Chi square analysis was used to examine dichotomous variables while independent t tests were used for all continuous metrics to obtain p -values and determine significance. Due to multiple comparisons across variables between the groups, a Bonferroni correction was applied resulting in a corrected p -value of $<.002$ to determine statistically significant differences.

Preoperative and Intraoperative Anesthesia

Anesthesia was maintained by the anesthesia team based on individual anesthesiologist's preferences and current standards of practice. Preoperatively and intraoperatively prior to initiation of CPB, crystalloid was limited to keeping veins open (KVO) for IVs and central lines. On average, patients receive less than 250 mL of crystalloid between hospital admission and initiation of CPB.

CPB Circuit Selection, Priming, and RAP

The circuit used was a Terumo® FX (Terumo Cardiovascular Systems, Ann Arbor, MI) hollow fiber oxygenator with an integrated arterial filter. A-V Loop contained 6 feet of 3/8-inch tubing for the arterial line and 6 feet of 1/2-inch tubing for the venous line. All circuits were primed with Normosol or Plasmalyte A to de-air all components, including the Quest Myocardial Protection System™ (MPS; Quest, Allen, TX) Cardioplegia Delivery device. A Terumo FX15 W40 oxygenator and reservoir was used in patients whose flow was less than 5.0 LPM at a cardiac index (CI) of 2.2 L/min/m². For patients whose flow was greater than or equal to 5.0 LPM at a

CI of 2.2 L/min/m² a Terumo FX25 was used. The flow probe was positioned on the arterial line, distal to the oxygenator and all shunts.

In the non-RAP group, after sterilely passing lines to the sterile field, an average of 3 feet was removed from the AV Loop (1 foot from arterial line and 2 feet from venous line) to shorten the arterial and venous lines at the table, prior to cannulation. At that time, the extra fluid within the reservoir was displaced into an empty priming bag, and the prime drugs of Mannitol 12.5 g (50 mL), Sodium Bicarbonate 50 mEq (50 mL), and Albumin 5% 12.5 g (50 mL) were added to maintain minimum operating level within the reservoir. The average priming volume in the non-RAP group was 800 mL for the FX15 circuits and was 900 mL for the FX 25 circuits.

In the RAP group, the same amount of tubing was removed prior to cannulation. After arterial cannulation at the surgical field, the perfusionist would begin to RAP by isolating the oxygenator from the centrifugal head and opening the necessary clamps to create a passive connection from the patient to an empty priming bag. During RAP, the patient's own blood pressure and hydrostatic pressure would drive the crystalloid into the empty bag, replacing the crystalloid with blood. This process continued until the arterial line and the oxygenator were primed with the patient's own blood, or the patient became hemodynamically unstable including, but not limited to a mean arterial pressure (MAP) <60 mmHg, systolic blood pressure (SBP) <90 mmHg, cerebral oximetry $>20\%$ below baseline, and/or cerebral oximetry $<40\%$, for an average RAP volume of 566.94 ± 189.34 mL.

Once RAP was finished, the perfusionist closed all open clamps and the oxygenator was returned in sequence to the centrifugal head to prepare for initiation of CPB. While initiating CPB, the venous line was slowly drained while simultaneously displacing the crystalloid within the reservoir into an empty priming bag down to the minimum operating level in the reservoir prior to the venous line being fully unclamped. At this time, the Mannitol 12.5 g, Sodium Bicarbonate 50 mEq, and Albumin 5% 12.5 g were added to the circuit, and are not included in the prime volume of the RAP group.

Intraoperative CPB Protocols

Extracorporeal perfusion was maintained by using a nonpulsatile, centrifugal arterial pump head to maintain flows at a CI of 2.2–2.4 L/min/m² to maintain a venous saturation (SVO₂) greater than 70% and cerebral oximetry no less than 20% below baseline and/or greater than 40%. Target MAP was 55–70 mmHg with the use of flows and intravenous phenylephrine, norepinephrine, or nitroglycerine. Arterial blood gases (ABG) were measured every 30 minutes while on CPB using an Abbott CG8 + cartridge and i-STAT point of care laboratory system (Abbott Point

of Care, East Windsor, NJ). Sweep and circuit FiO₂ were adjusted to maintain a pH of 7.35–7.45 (Alpha Stat), with a carbon dioxide (CO₂) of 35–45 mmHg, and arterial oxygen tension at 180–300 mmHg.

PRBCs were transfused if a combination of the following occurred: the patient's hemoglobin was less than 8 g/dL, hematocrit less than 24%, or SVO₂ less than 65%. If cerebral oximetry reading fell more than 20% below baseline, then PRBCs were transfused. Further, if the cerebral oximetry reading was less than 40% despite increased flows or increased MAP, then the patient was transfused.

In the RAP group, of the 21.38% ($n = 111$) of patients were hemoconcentrated, the average volume removed was 385.09 mL \pm 977.93. At the time we stopped performing RAP, Hemoconcentrators were eliminated from the CPB circuit, unless Custodial[®] Cardioplegia ($n = 258$, RAP 81, non-RAP 177; Custodial HTK Solution, Durham, NC) was delivered to arrest the heart. In that instance, volume removed using a hemoconcentrator was limited to only the amount of Custodial administered. Microplegia via the Quest MPS Cardioplegia Delivery Device was used to arrest the heart in the remaining 1,038 patients (433 in the RAP group, 605 in the non-RAP group). Patients were cooled to 34°C (potentially further depending on the case, i.e., circulatory arrest) and were rewarmed to a nasopharyngeal temperature no higher than 37°C with a bladder temperature of 36.5°C prior to termination of CPB.

A COBE Brat 2 Autotransfusion Device (COBE Cardiovascular, Arvada, CO) was used to process all salvaged blood and the CPB circuit volume after decannulation. Autologous blood was washed and then returned to the patient. Albumin 5% (250 mL) was administered after decannulation if the patient demonstrated signs of hypovolemia as evidenced on the transesophageal echocardiogram (TEE), pulmonary artery diastolic pressure (PAD) less than 12 mmHg, central venous pressure (CVP) less than 10 mmHg and/or SBP less than 90 mmHg. After the patient was closed and dressed, he or she was transferred to the ICU for postoperative care.

Postoperative Protocols

Postoperative ICU nursing protocols were as follows:

- A. Albumin 5% (12.5 g/250 mL bottle) was administered if SBP was less than 90 mmHg or MAP less than 55 mmHg, with a CVP less than 12 mmHg, as needed.
- B. PRBCs were transfused if Hemoglobin and Hematocrit decreased to less than 8.0 g/dL and 24%, respectively, and/or the patients showed signs of a clinical deficit, such as hypotension unresponsive to vasopressor administration or hypotension in the presence of excessive chest tube output.
- C. After admission to the ICU, an ABG was drawn and those results were communicated to the

Anesthesiologist who managed the case. If the ABGs were within an acceptable range, the ICU nurse and respiratory therapist began to wean the ventilator in accordance with the official weaning protocol (Appendix A).

Data Analysis and Definitions

We examined the following intra-operative and postoperative parameters: 1st Hgb on CPB, average Hgb on CPB, blood transfusion rates, indexed oxygen delivery (DO_{2i}) on CPB, urine output (UOP) on CPB, UOP in the operating room (OR), incidence of postoperative AKI based on creatinine, Albumin utilization, ventilator time, ICU LOS, and 30-day mortality.

Baseline lab data was recorded as the closest values drawn to day of surgery, prior to entry into the OR. The highest creatinine was recorded at baseline, day of ICU admission, through POD 3.

DO_{2i} was calculated retrospectively using the patient's actual weight to calculate Body Surface Area (BSA), the average flow on CPB, and the average hemoglobin on CPB. The formal equation for DO_{2i} is $DO_{2i} = \text{Indexed Flow} \times [(1.34 \times \text{Hgb} \times \text{SaO}_2) + (\text{PaO}_2 \times .003)]$ (4).

UOP on CPB was recorded as the total amount of urine via the Foley catheter while on CPB. UOP in the OR was recorded by anesthesia as the total amount of urine from Foley insertion until ICU admission. The Risk, Injury, Failure, Loss and End Stage (RIFLE) definition was used to determine the incidence of postoperative AKI (Appendix B, 5). In correlation with the RIFLE criteria, a rise in serum creatinine greater than twice the baseline was classified as kidney injury.

Intraoperative fluid administration was the total amount of mL of crystalloid anesthesia administered while in the OR. Intraoperative Albumin was reported as total mL given by perfusion on CPB (excluding the Albumin in the prime), plus total mL given peripherally by anesthesia. Postoperative Albumin was reported as the total mL given by the ICU nurse between ICU admission and through POD 2.

Ventilator times represent the time in minutes between intubation in the operating suite and the postoperative extubation in the ICU. ICU LOS was defined as the time in hours between the patient's arrival in the ICU and transfer to the floor or discharge from hospital. 30-Day Mortality was gathered from the Quality Department.

RESULTS

This retrospective analysis assessed the postoperative outcomes for 1,303 patients who underwent cardiac surgery requiring the use of CPB. Preoperative variables

including age, BSA, baseline hemoglobin, baseline hematocrit, baseline creatinine, preexisting Chronic Kidney Disease (CKD), preexisting End Stage Renal Disease (ESRD), time on CPB, and cross clamp times were collected on both RAP and non-RAP groups (Table 1). There were no statistically significant differences between the two groups on baseline parameters.

We theorized the non-RAP group would be hemodiluted due to the excess crystalloid administered, requiring an increase in PRBC administration. The average hemoglobin first hemoglobin on CPB was 10.09 ± 1.56 g/dL in the RAP group and 9.90 ± 1.54 in the non-RAP group with an insignificant p -value of .026. The change in hemoglobin from the first value intraoperatively to the first level on CPB was a decrease of 1.71 ± 1.25 g/dL in the RAP group and 2.23 ± 1.14 g/dL in the non-RAP group with a statistically significant p -value of $<.001$. The average hemoglobin on CPB was 10.07 ± 1.44 g/dL in the RAP group and 9.93 ± 1.37 g/dL in the non-RAP group and was also not significant between the two groups ($p = .076$). The change in hemoglobin from the first intraoperative value to the average hemoglobin on CPB was 1.73 ± 1.16 g/dL in the RAP group, compared to 2.19 ± 1.09 g/dL in the non-RAP group with a statistically significant p -value of $<.001$. However, we observed no statistically significant difference between the PRBC transfusion rate between the two groups intraoperatively (RAP $n = 53$, 10.2%; non-RAP $n = 78$, 10.0%, $p = .937$) or postoperatively (RAP $n = 54$, 10.4%; non-RAP $n = 80$, 10.2%; $p = .966$).

The average calculated indexed flow in each group was $2.09 \pm .22$ mL/min/m² in the RAP group and $2.19 \pm .20$ mL/min/m² in the non-RAP group with a statistically significant p -value of $<.001$. Using the average indexed flow and average hemoglobin on CPB, we calculated the DO_{2i} on CPB for each patient. We observed a statistically insignificant lower DO_{2i} in the RAP group compared to the non-RAP group (RAP 283 ± 47 mL O₂/min/m², non-RAP 289 ± 47 mL O₂/min/m², $p = .024$). This suggests that the increased crystalloid in the non-RAP group did not lower oxygen delivery to the patient.

The UOP on CPB resulted in 510 ± 166.93 mL in the RAP group and 760 ± 225.98 mL in the non-RAP group

with a statistically significant p -value of $<.001$. The total UOP in the OR was 517 ± 304.81 mL in the RAP group and 781 ± 329.09 in the non-RAP group with no statistical significance ($p = .30$). Using the RIFLE definition, our incidence of postoperative AKI was 4.9% in the RAP group and 4.8% in the non-RAP group, revealing no statistically significant change ($p = .949$).

There was no statistically significant difference in the amount of fluids administered by anesthesia in the OR (RAP $1,350.98 \pm 432.63$ mL, non-RAP $1,369.90 \pm 454.54$ mL, $p = .454$). Intraoperatively, we noted no significant difference between the Albumin administered between the two groups (RAP 157 ± 185 mL, non-RAP 157 ± 211 mL, $p = .939$). However, there was a statistically significant increase in the amount of postoperative Albumin given to the RAP patients (RAP 526 ± 363 mL, non-RAP 460 ± 331 mL, $p = .001$).

The analysis showed no statistically significant difference to the ventilator times (RAP $489 \pm 2,196$ minutes, non-RAP $534 \pm 2,590$ minutes, $p = .740$), ICU LOS (RAP 61 ± 68 hours, non-RAP group 63 ± 91 hours, $p = .676$), or 30-day mortality (RAP 2.3%, non-RAP 3.0%, $p = .417$).

Table 2 outlines the results for average first hemoglobin, average hemoglobin on CPB, change in hemoglobin, PRBC transfusion, indexed flows, DO_{2i} on CPB, postoperative AKI, UOP on CPB, total UOP in OR, Albumin utilization, ventilator time, ICU LOS, and 30-day mortality.

DISCUSSION

The purpose of this analysis was to try and determine whether RAP was beneficial in our patient population. Prior to 2017, we performed RAP on almost every patient because we supported the previously published studies that suggest RAP can potentially limit hemodilution, PRBC transfusions, decrease third spacing, and immediately increase cerebral and end organ perfusion to reduce morbidity and mortality associated with CPB (6–14). In the middle of 2018, we anecdotally noted there were some negative postoperative consequences to performing RAP on every patient. We suspected that RAP in the OR was

Table 1. Preoperative and CPB comparison \pm SD.

Description	RAP ($n = 519$) \pm SD	No RAP ($n = 783$) \pm SD	p Values
Patient age (years)	65.93 ± 9.97	65.74 ± 10.10	.735
BSA	$2.07 \pm .28$	$2.08 \pm .26$.472
Hemoglobin (g/dL)	12.96 ± 1.87	12.71 ± 1.85	.015
Hematocrit (%)	38.67 ± 5.26	37.64 ± 5.49	.001
Creatinine (mg/dL)	$1.20 \pm .95$	$1.15 \pm .82$.364
Preoperative history of CKD (number of patients and percentage)	27 (5.20%)	37 (4.72%)	.935
Preoperative history of ESRD (number of patients and percentage)	7 (1.34%)	8 (1.02%)	.586

BSA, body surface area; CKD, chronic kidney disease; CPB, cardiopulmonary bypass; ESRD, end stage renal disease; RAP, retrograde autologous priming.

Table 2. Full analysis results \pm SD.

	RAP \pm SD	Non-RAP \pm SD	<i>p</i> Values*
CPB time (minutes)	110.95 \pm 41.01	114.52 \pm 51.06	.165
Cross clamp time (minutes)	85.02 \pm 33.72	88.15 \pm 38.74	.123
Indexed flow (mL/min/m ²)	2.09 \pm .22	2.17 \pm .20	<.001
Custodial cardioplegia (number of patients and percentage)	81 (31.4%)	177 (68.6%)	N/A
Microplegia (number of patients and percentage)	433 (41.7%)	605 (58.3%)	N/A
Fluid administration by anesthesia (mL)	1,350.98 \pm 432.63	1,369.90 \pm 454.54	.454
First hemoglobin (g/dL) on CPB	10.07 \pm 1.56	9.90 \pm 1.54	.026
Hemodilution of hemoglobin (g/dL) from intraop to first Hgb on CPB	1.71 \pm 1.25	2.23 \pm 1.14	<.001
Average hemoglobin (g/dL) on CPB	10.07 \pm 1.44	9.93 \pm 1.37	.076
Hemodilution of Hemoglobin (g/dL) from intraop to average on CPB	1.73 \pm 1.16	2.19 \pm 1.09	<.001
PRBCs intraop (<i>n</i> > 0) (% patients in this group)	53 (10.21%)	78 (10.0%)	.937
PRBC postoperative (<i>n</i> > 0) (% patients in this group)	54 (10.40%)	80 (10.21%)	.966
Indexed oxygen delivery (mL O ₂ /min/m ²)	283.56 \pm 47.44	289.65 \pm 47.50	.024
AKI (% patients in this group)	25 (4.9%)	37 (4.8%)	.949
Urine output on CPB (mL)	510 \pm 166.93	760 \pm 225.98	<.001
Total UOP in OR (mL)	517 \pm 304.81	781 \pm 329.09	.30
Intraoperative Albumin 5% (12.5 g in 250 mL) (mL)	157.03 \pm 185.62	157.91 \pm 211.85	.939
Postoperative Albumin 5% (12.5 g in 250 mL) (mL)	526.16 \pm 363.56	460.14 \pm 331.51	.001
Ventilator time (minutes)	489.10 \pm 2196.08	534.96 \pm 2590.18	.740
ICU LOS (hours)	61.91 \pm 68.92	63.89 \pm 91.77	.676
30-day mortality	12 (2.3%)	24 (3.0%)	.417

AKI, acute kidney injury; CPB, cardiopulmonary bypass; ICU LOS, intensive care unit length of stay; PRBCs, packed red blood cell; OR, operating room; UOP, urine output.

*Bonferroni Corrected *p*-value .002.

resulting in an increased amount of fluids in the postoperative ICU, whether it was crystalloid or Albumin. Additionally, we suspected RAP may be impacting the incidence of postoperative AKI. To further examine these outcomes, we compared the previously mentioned clinical metrics of patients who we did RAP versus those we did not.

We theorized the increased hemodilution in the non-RAP group would increase PRBC transfusion rates. Our analysis did note a larger amount of hemodilution in the non-RAP group; however, the difference between the two groups is only .5 g/dL, which is not clinically significant and correlates with the insignificant difference in PRBC transfusion rates between the two groups. In conjunction, Nanjappa et al. showed there was no decrease in PRBC transfusion between RAP and no RAP group (15). In a similar study, Murphy et al. showed there was no reduction in any blood product transfusion between RAP and non-RAP groups (16). Our results were similar with both of these article's findings that the process of RAP did not assist in PRBC conservation. Further, our PRBC transfusion rate in our low prime circuit is only 10% in both groups.

Adequate DO_{2i} is essential for optimal organ function (4,17–19). In the kidneys, research has suggested that a DO_{2i} >270 mL O₂/min/m² on CPB is optimal to avoid postoperative AKI (4,17–19). AKI following cardiac surgery with the use of CPB is a common complication associated with longer hospital stay, increased cost, morbidity, and mortality (4,13,14,17–27). We thought the benefit of RAP would be to improve DO_{2i}, thereby reducing the

incidence of postoperative AKI. The mean indexed flow was higher in the non-RAP group, but the average hemoglobin was higher in the RAP group. However, our results were not significantly higher DO_{2i} in either group. Although, the difference was 6 mL O₂/min/m², the result is still not clinically significant since oxygen delivery was maintained above the recommended optimal level of 270 mL O₂/min/m² in both groups. This may suggest why we did not observe an improvement in our incidence of postoperative AKI.

Fluid balance is reportedly an important factor in providing hemodynamic stability (28–30). A positive fluid balance has been associated with many postoperative complications such as increased ventilator times, AKI, delayed wound healing, poor gastrointestinal function, and an overall increase in morbidity and mortality (28–30). Hemodynamic instability is a risk factor following cardiac surgery that is typically treated with some combination of vasoactive drips, inotropic agents, IV fluid administration, and/or Albumin or PRBC administration, and is especially crucial to maintain adequate preload, cardiac output, and systemic vascular resistance (25,30). While Albumin is very effective in volume resuscitation, increased Albumin administration has been linked to a two-fold increased risk of AKI in postoperative cardiac surgery patients (21,26,28). We theorized the RAP group would be subjected to more fluid resuscitation secondary to the hypovolemia from the exsanguination during RAP. This analysis partially validated our theory by showing there was no difference in the amount of fluid

administered by anesthesia in the OR or intra-operative Albumin administered; however, there was statistical significance showing that patients in the RAP group received more Albumin in the postoperative period. However, since Albumin 5% (12.5 g/250 mL bottle) was administered postoperatively when indicated, a difference of 66 mL in an adult population is potentially not clinically significant.

Extended ventilator times can occur due to a multitude of reasons such as preoperative chronic obstructive pulmonary disease (COPD) smoking, low ejection fraction, low hematocrit, and CHF, but can additionally occur due to volume overload related to the amount of fluids given during and after surgery, and is associated with increased morbidity and mortality (3,20,22). Studies have suggested a linear relationship between extended ventilator times, prolonged ICU LOS, and 30-day mortality (3,29,31). In correlation with the linear relationship between the three, we observed no statistically significant difference in ventilator times ($p = .740$), ICU LOS ($p = .676$), and 30-day mortality ($p = .417$), indicating that RAP did not significantly improve these clinical parameters.

Our analysis showed when preoperative fluid administration and CPB circuit prime volume are limited, there was no significant benefit to performing RAP. When considering the clinical outcomes we evaluated, we observed the benefits of RAP by using a low prime CPB circuit. Using the SCOPE registry, Sun et al. defined prime volume as the total amount of crystalloid given to patients after RAP (32). The overall volume of the CPB circuits in that study was 847.7 ± 354.3 mL (32). This was the same prime volume of our non-RAP CPB circuit. Further, the prime volume of our non-RAP circuit was equal to, or less than the volume of the RAP circuits in several published studies that showed RAP to be beneficial (6,7,15,16,32). In a randomized study, Sakwa et al. showed that a minimized CPB circuit with a prime volume of approximately 900 mL resulted in higher hemoglobin levels and lower red blood cell usage after the initiation of CPB (33). In this same study, RAP was used on all patients (33). Since hemoglobin was higher at all points in the study, Sakwa et al. noted that RAP could not be the only contributing factor to an increased hemoglobin (33). Further analysis should be concluded regarding the benefit of RAP in a minimized CPB circuit as most published studies that show favor to condensed circuitry, also performed RAP (33,34).

Overall, there are limitations to this analysis. Using the average flows and average hemoglobin to get the average DO_{2i} on CPB did not give us the lowest DO_{2i} supplied to each patient during the pump runs and therefore the exposure to the minimum DO_{2i} is not defined. The larger sample sizes and multiple comparisons between groups made interpretation of statistical significance, and more specifically clinical significance, a nuanced process. Also,

we had a heterogeneous group of patients to look at the effects of RAP on postoperative outcomes. We realized that this heterogeneous group may have confounded the data because of the inclusion of redo sternotomy, circulatory arrest, emergent, and salvage cases that may have erroneously extended the ventilator times, ICU LOS and 30-day mortality. We plan to narrow our focus to the isolated elective and urgent CAB cases and those results will be published in the future.

CONCLUSION

In this retrospective study, we examined the impact of RAP in a heterogeneous population of two consecutive patient groups undergoing CPB. Data analysis showed that the RAP and non-RAP group had equal demographic, preoperative, and CPB characteristics. Our investigation indicated there was no statistically significant impact of RAP on PRBC transfusion rates, DO_{2i} , incidence of postoperative AKI, intraoperative Albumin administration, ventilator times, ICU LOS, and 30-day mortality. We did observe a statistically significant increase in Albumin infusion in the ICU postoperatively in the RAP group, although the small volume difference was not clinically significant. While several published studies show there are potential benefits to RAP, our all-inclusive analysis in an active cardiac surgery program found that there was no significant benefit to RAP the condensed CPB circuit in our patient population. We suspect that limiting preoperative fluid administration and minimizing our CPB circuit volume eliminated the need for RAP.

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APPENDIX A.

ICU ventilator weaning policy.

Patient easily aroused, neurologically intact, and able to follow commands/lift head off pillow?
 Discussion of fluid status, hemodynamics, arrhythmias, and pain between nurse and respiratory therapist?
 Chest tube drainage <100 mL/h?
 Temperature was $\geq 36.2^{\circ}\text{C}$ (97.2°F) and $\leq 38.2^{\circ}\text{C}$ (101°F)?
 Clear, bilateral breath sounds?
 Minimal endotracheal secretions?
 Positive End Expiratory Pressure (PEEP) $\leq +5$ mmHg?
 $\text{FiO}_2 < 50\%$ with oxygen saturation $>92\%$?
 Rapid Shallow Breathing Index <100 ?
 Negative Inspiratory Force < -20 (more negative)?
 Arterial blood gases (ABGs) adequate after 30 minutes of Continuous Positive Airway Pressure (CPAP)?

If all of the above criteria were met, the patient was extubated to 6–8 L of Oxygen via Nasal Cannula. If there was failure to meet any of the above criteria, he or she was returned to full ventilator support and another attempt was made one hour later.

APPENDIX B.

Risk, injury, failure, loss of kidney function, and end-stage kidney disease (RIFLE) classification (4).

Class	GFR	Urine Output (UOP)
Risk	$\uparrow \text{SCr} \times 1.5$ or $\downarrow \text{GFR} >25\%$	$< .5 \text{ mL/kg/h} \times 6$ hours
Injury	$\uparrow \text{SCr} \times 2$ or $\downarrow \text{GFR} >50\%$	$< .5 \text{ mL/kg/h} \times 12$ hours
Failure	$\uparrow \text{SCr} \times 3$ or $\downarrow \text{GFR} >75\%$	$< .3 \text{ mL/kg/h} \times 24$ hours or anuria $\times 12$ hours
Loss of kidney function	Complete loss of kidney function	>4 weeks
End-stage kidney disease	Complete loss of kidney function	>3 months

GFR, glomerular filtration rate.