**SURVEY REPORT**

# Results from the Perfusion.com Cardiac Surgery Hematocrit Trend Survey: Observations and Evidence-Based Recommendations


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## BACKGROUND

In the face of a national shortage and increasing demand for blood products, it is imperative that those who care for patients undergoing cardiothoracic and vascular surgical procedures optimize the patient's red blood cell mass and coagulation prior to surgery. (1) Clinicians and supporting staff need to employ a multi-modality approach to conserve plasma proteins, clotting factors and red blood cells from being wasted perioperatively. (2,3)

Today's perfusionist is an integral member of a multidiscipline perioperative team (anesthesia, nursing, surgery, blood bank, pathology laboratory) approach with improved team communications for conservation of autologous blood and avoidance of allogeneic transfusions. (4,5,6) JCAHO, AABB, perfusion professional organizations and others alike recognize the need for increased diligence in perioperative blood management. (7)

Perfusion.com solicited various perfusionists to respond to an on-line survey regarding collecting hematocrit (Hct) measurements at certain time points during cardiac surgery. The goal of the survey was to describe the average change in hematocrit at six time points during adult cardiac surgical procedures to characterize hematocrit levels throughout the surgery. The second goal of the study was to provide perfusionists the ability to apply the results of the survey to benchmark their local clinical experiences.

## METHOD

During October and November in 2005, perfusionists were solicited at http://www.perfusion.com and volunteered to participate in the survey to collect hematocrit levels from each of five adult patients undergoing cardiopulmonary bypass (CPB). The perfusionists retrospectively reviewed the charts for hematocrit levels at six time points throughout the procedure. All data was kept confidential and abided by current 1996 Health Insurance Portability and Accountability Act (HIPAA) regulations.

**Table One: Description of six measurement points for Hct survey**

| Sample Point | Description |
|---|---|
| **Baseline** | Baseline from the chart, morning of surgery, pre-anesthesia or day before surgery |
| **Post- Intubation** | If your service draws an ABG sample after the ET tube is inserted |
| **Pre-CPB** | Immediately prior to initiating CPB usually during ACT sampling post-heparinization |
| **On-CPB** | Three to ten minutes into the initiation of CPB, post-ECC dilution (first gas on CPB) |
| **End-Surg** | Last hematocrit measurement prior to leaving the OR, post protamine or chest closed |
| **Nadir (Lowest)** | Record the lowest hematocrit value measured any time during the surgical procedure, at any time point |

**Note:** Hct is hematocrit; ABG is arterial blood gas; ET is endotrachial tube; Surg is surgery; CPB is cardiopulmonary bypass.

Data points were entered in an on-line form at Perfusion.com. Descriptive statistics were calculated employing SPSS 13.0 for Windows® (http://www.spss.com/). Hematocrit results from the six time events were statistically compared by analysis of variance. Trend information was plotted and differences calculated.

## RESULTS

Forty-nine perfusionists responded to the survey. Table two is a summary of the data for the Hct observations reported at the six time periods.

**Table 2:**
**Hematocrit levels at various time points during cardiac surgery**

| Measurement Point | Obs (n) | Hct (mean) | Hct (% BL) | Hct (Median) | Hct (Std Dev) | Hct (Min / Max) | Hct (95% CI LB) | Hct (95% CI UB) |
|---|---|---|---|---|---|---|---|---|
| **Baseline** | 245 | 38.7 | 100.0 | 39.0 | 5.7 | 14.3/55.0 | 38.1 | 39.5 |
| **Post- Intubation** | 215 | 35.7 | 91.5 | 36.0 | 5.0 | 22.0/47.0 | 35.0 | 36.3 |
| **Pre-CPB** | 206 | 33.6 | 87.9 | 33.0 | 5.2 | 20.0/48.0 | 32.8 | 34.3 |
| **On-CPB** | 245 | 24.8 | 64.9 | 25.0 | 4.2 | 14.0/36.0 | 24.3 | 25.4 |
| **End-Surg** | 240 | 27.8 | 73.0 | 27.0 | 4.8 | 14.0/41.0 | 27.2 | 29.4 |
| **Nadir (Lowest)** | 244 | 23.5 | 61.5 | 23.6 | 4.0 | 14.0/36.0 | 23.0 | 24.0 |

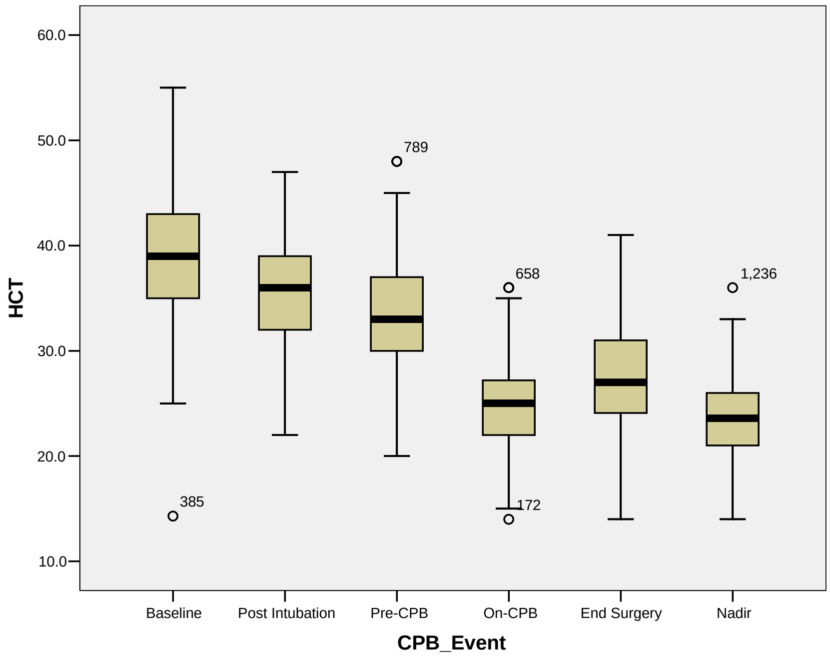
**Note:** BL is baseline; Std dev is one standard deviation; Min is minimum; Max is maximum; CI is confidence interval; LB is lower bounds; UB is upper bounds

All mean Hcts from each time period were significantly different from the others ($p < 0.004$) including nadir compared to On-CPB. Figure one is a boxplot that illustrates the drop in Hct and the deviation of the reported Hct values as the cardiac surgery proceeds.

The mean drop in hematocrit percent from baseline to Pre-CPB was –5.3 +/- 0.5 (1 SD) which was 12.1% of the Baseline Hct value. The mean drop from Pre-CPB to On-CPB was –8.7 +/- 0.5 Hct % which was 23.0% of the baseline Hct value. The drop in Hct with anesthesia control was significantly less than the drop in Hct with the initiation of CPB ($p < 0.001$). Figure Two compares the drop in Hct with anesthesia compared to the drop in Hct with the initiation of CPB.

**Figure 1:**

**Boxplot of reported hematocrits by measurement point**

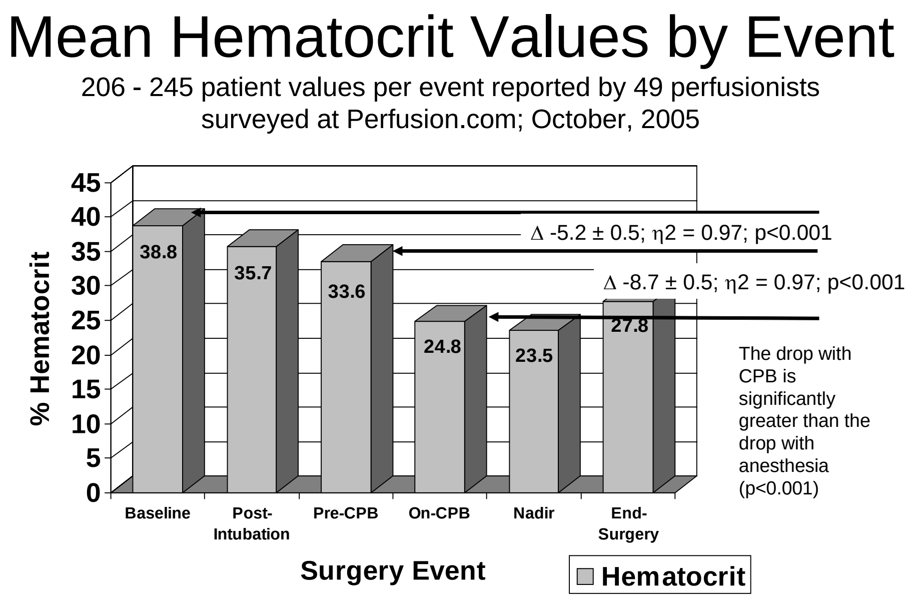



**Note:** Black bars are the median; Boxes are the 25th percentile to the 75th percentile; Whiskers are +/- 1.5 interquartile range values; Observations represented as circles are outliers which more than 1.5 interquartile range units from the median.

## DISCUSSION

It is exceedingly useful to describe the hematocrit levels at various time points from numerous institutions from across the United States during cardiac surgery. An interesting finding during this study was that the drop in Hct with introduction of CPB is significantly greater than the drop in Hct during the Pre-CPB anesthesia periods.

**Figure Two**




**Note:** Δ is difference; $\eta^2$ is effect size; The drop in Hct with anesthesia was exceeded by the drop in Hct with initiation of CPB

While a survey such as this has limitations, absolute hematocrit values and trends can be easily established with this type of study. Perfusionists, anesthesiologists and cardiac surgeons will be able to draw information from this descriptive study to benchmark their own practice hematocrit levels.

Open-heart team members treat every patient with universal precautions because that is the standard for accepted care. Yet when it comes to blood conservation and avoidance we treat some patients and patient populations differently than others. We need to treat every patient as if they were of the Jehovah's Witness faith and not waste a drop of blood in order to maximally preserve the patient's native cell fractions and mass. (8) Clinical equations, garnered from the literature review, to minimize hemodilution and predict post-dilution Hct and protein levels are presented in Appendix One for use by the reader.

This model survey should be reproduced at a much greater level in the US. Perhaps more information could be collected to help interpret and understand the trends in Hct during cardiac surgery with CPB.

## OBSERVATIONS

The following observations are supported by the results of this descriptive survey:

- Perfusion.com perfusionist members are willing to submit clinical data on-line for survey purposes
- The Nadir Hct observed during cardiac surgery is significantly lower than the initial On-CPB Hct
- The End-surgery Hct is significantly greater than the observed On-CPB Hct and the Nadir Hct
- The drop in Hct associated with CPB is significantly greater than the drop in Hct associated with anesthetic induction

## RECOMMENDATIONS

There appears to be room for improvement in preventing drops in hematocrit during the Pre-CPB period and On-CPB period. Like other authors (9), upon completion of this analysis, we offer the following recommendations and evidence. ***However, these recommendations do not supersede the informed sound judgment of the clinicians caring for a particular patient.***

**Recommendation One:** Anesthesia, surgery and perfusion specialties should continue to work to improve on the multi-modality approach to preserve hematocrit. There is room for process improvement in both anesthesia and perfusion specialties, but of course, every team member is responsible to help preserve Hct.

**Evidence to Read:**

- Karkouti K, Djaiani G, Borger MA, Beattie WS, Fedorko L, Wijeysundera D, Ivanov J, Karski J. Low hematocrit during cardiopulmonary bypass is associated with increased risk of perioperative stroke in cardiac surgery. *Ann Thorac Surg.* 2005;80(4):1381-7.

- Dial S, Delabays E, Albert M, Gonzalez A, Camarda J, Law A, Menzies D. Hemodilution and surgical hemostasis contribute significantly to transfusion requirements in patients undergoing coronary artery bypass. *J. Thorac. Cardiovasc. Surg.* 2005;130:654.
- Belway D, Rubens FD, Wozny D, Henley B, Nathan HJ. Are we doing everything we can to conserve blood during bypass? A national survey. *Perfusion.* 2005;20(5):237-41
- Shander A, Moskowitz D, Rijhwani TS. The safety and efficacy of "bloodless" cardiac surgery. *Semin Cardiothorac Vasc Anesth.* 2005;9(1):53-63.
- Richard Merritt. US heart patients receive more transfusions than international patients Medical News Today. 18 Nov. 2005.
- Habib RH, Zacharias A, Schwann TA, Riordan CJ, et al. Adverse effects of low hematocrit during cardiopulmonary bypass in the adult: Should current practice be changed? *J Thorac Cardiovasc Surg.* 2003;125(6):1438-50.
- Van der Linden P, De Hert S, Daper A, Trenchant A, Jacobs D, De Boelpaepe C, Kimbimbi P, Defrance P, Simoens G. A standardized multidisciplinary approach reduces the use of allogeneic blood products in patients undergoing cardiac surgery. *Canadian Journal of Anesthesia.* 2001;48:894-901.
- Helm RE, Rosengart TK, Gomez M, Klemperer JD, DeBois WJ, Velasco F, Gold JP, Altorki NK, Lang S, Thomas S, Isom OW, Krieger KH. Comprehensive multimodality blood conservation: 100 consecutive CABG operations without transfusion. *Ann Thorac Surg.* 1998;65(1):125-36.

**Recommendation Two:** It is important to adopt a team approach to blood management with attainable goals to make red cell conservation a viable practice.

**Evidence to Read:**

- Hardy JF, Van der Linden P. Blood conservation and the management of perioperative blood transfusions in a patient undergoing major vascular surgery: a Self-Assessment Program. *Can J Anaesth.* 2005;52(3):344-5.
- Shander A, Moskowitz D, Rijhwani TS. The safety and efficacy of "bloodless" cardiac surgery. *Semin Cardiothorac Vasc Anesth..* 2005 Mar;9(1):53-63.
- Paiva P, Ferreira E, Antunes M. Bloodless open heart surgery: simple and safe. *Rev Port Cardiol.* 2005;24(5):647-54.

- American Association of Blood Banks (AABB). Standards for perioperative autologous blood collection and administration. Proposed 2nd edition of Standards for Perioperative Autologous Blood Collection and Administration for Comment Purposes October 29-December 29, 2004. Downloaded January 15, 2005 from: www.aabb.org/
- Martyn V, Farmer SL, Wren MN, Towler SC, Betta J, Shander A, Spence RK, Leahy MF. The theory and practice of bloodless surgery. *Transfus Apher Sci.* 2002;27(1):29-43.
- Souza MHL, Elias DO. Guidelines for blood conservation during adult cardiac surgery and cardiopulmonary bypass. Downloaded January 9, 2006 from: http://perfline.com/guidelines/bloodless.shtml

**Recommendation Three:** Cardiac surgery patients should be screened for blood indices, protein concentration, and treated preoperatively to maximize conservation of their red blood cell mass and blood fractions. Perfusionists should calculate post-dilution Hct, protein concentration and expected colloidal osmotic pressure (COP) to treat the patient accordingly. See the Clinical Equations Appendix for the clinical algorithms to estimate post dilution Hct, total protein concentration and COP.

**Evidence to Read:**

- Blome M, Isgro F, Kiessling AH, Skuras J, Haubelt H, Hellstern P, Saggau W. Relationship between factor XIII activity, fibrinogen, haemostasis screening tests and postoperative bleeding in cardiopulmonary bypass surgery. *Thromb Haemost.* 2005;93(6):1101-7.
- Goodnough LT, Shander A, Spivak JL, Waters JH, Friedman AJ, Carson JL, Keating EM, Maddox T, Spence R. Detection, evaluation, and management of anemia in the elective surgical patient. *Anesth Analg.* 2005;101(6):1858-61.
- Russell JA, Navickis RJ, Wilkes MM. Albumin versus crystalloid for pump priming in cardiac surgery: meta-analysis of controlled trials. *J Cardiothorac Vasc Anesth.* 2004;18(4):429-37.
- Yukl RL, Bar-Or D, Harris L, Shapiro H, Winkler JV. Low albumin level in the emergency department: a potential independent predictor of delayed mortality in blunt trauma. *J Emerg Med.* 2003;25(1):1-6.
- Delgado-Rodriguez M, Medina-Cuadros M, Gomez-Ortega A, Martinez-Gallego G, Mariscal-Ortiz M, Martinez-Gonzalez MA, Sillero-Arenas M.Cholesterol and serum albumin

levels as predictors of cross infection, death, and length of hospital stay. *Arch Surg.* 2002;137(7):805-12.

- Marinella MA, Markert RJ. Admission serum albumin level and length of hospitalization in elderly patients. *South Med J.* 1998;91(9):851-4.

**Recommendation Four:** CPB circuits should be safely condensed to primes of 1500 mls or less for adults to decrease the effects of obligatory hemodilution and hypoproteinemia from the ECC. See the clinical equations in the Clinical Equations Appendix to assess the impact of circuit prime volume.

**Evidence to Read:**

- Karkouti K, Djaiani G, Borger MA, Beattie WS, Fedorko L, Wijeysundera D, Ivanov J, Karski J. Low hematocrit during cardiopulmonary bypass is associated with increased risk of perioperative stroke in cardiac surgery. *Ann Thorac Surg.* 2005;80(4):1381-7.
- Lilly KJ, O'Gara PJ, Treanor PR, Reardon D, Crowley R, Hunter C, Shapira OM, Aldea GS, Lazar HL, Shemin RJ. Cardiopulmonary bypass: it's not the size, it's how you use it! Review of a comprehensive blood-conservation strategy. *J ExtraCorpor Technol.* 2004;36(3):263-8.
- Zelinka ES, Ryan P, McDonald J, Larson J. Retrograde autologous prime with shortened bypass circuits decreases blood transfusion in high-risk coronary artery surgery patients. *J ExtraCorpor Technol.* 2004;36(4):343-7.
- Norman MJ, Sistino JJ, Acsell JR. The effectiveness of low-prime cardiopulmonary bypass circuits at removing gaseous emboli. *J ExtraCorpor Technol.* 2004;36(4):336-42.
- Jansen PG, te Velthuis H, Bulder ER, Paulus R, Scheltinga MR, Eijsman L, Wildevuur CR. Reduction in prime volume attenuates the hyperdynamic response after cardiopulmonary bypass. *Ann Thorac Surg.* 1995;60(3):544-9.

**Recommendation Five:** Retrograde Autologous Priming is an excellent technique to minimize the effects of hemodilution from the ECC and should be considered for use with all CPB cases with the help of Anesthesia and the surgical team.

**Evidence to Read:**

- Zelinka ES, Ryan P, McDonald J, Larson J. Retrograde autologous prime with shortened bypass circuits decreases blood transfusion in high-risk coronary artery surgery patients. *J ExtraCorpor Technol.* 2004;36(4):343-7.

- Eising GP, Pfauder M, Niemeyer M, Tassani P, Schad H, Bauernschmitt R, Lange R. Retrograde autologous priming: is it useful in elective on-pump coronary artery bypass surgery? *Ann Thorac Surg.* 2003;75(1):23-7.
- Balachandran S, Cross MH, Karthikeyan S, Mulpur A, Hansbro SD, Hobson P. Retrograde autologous priming of the cardiopulmonary bypass circuit reduces blood transfusion after coronary artery surgery. *Ann Thorac Surg.* 2002;73(6):1912-8.
- Shapira OM, Aldea GS, Treanor PR, Chartrand RM, DeAndrade KM, Lazar HL, Shemin RJ. Reduction of allogeneic blood transfusions after open heart operations by lowering cardiopulmonary bypass prime volume. *Ann Thorac Surg.* 1998;65(3):724-30.

**Recommendation Six:** Anesthesia should reduce the amount of crystalloid volume given as much as possible, and increase the patient's systemic vascular resistance as tolerated by afterload.

**Evidence to Read:**

- Dial S, Delabays E, Albert M, Gonzalez A, Camarda J, Law A, Menzies D. Hemodilution and surgical hemostasis contribute significantly to transfusion requirements in patients undergoing coronary artery bypass. *J. Thorac. Cardiovasc. Surg.* 2005;130:654.
- Karkouti K, Djaiani G, Borger MA, Beattie WS, Fedorko L, Wijeysundera D, Ivanov J, Karski J. Low hematocrit during cardiopulmonary bypass is associated with increased risk of perioperative stroke in cardiac surgery. *Ann Thorac Surg.* 2005;80(4):1381-7.
- Chandler WL. Effects of hemodilution, blood loss, and consumption on hemostatic factor levels during cardiopulmonary bypass. *J Cardiothorac Vasc Anesth.* 2005;19(4):459-67.
- Habib RH, Zacharias A, Schwann TA, Riordan CJ, et al. Role of hemodilutional anemia and transfusion during cardiopulmonary bypass in renal injury after coronary revascularization: Implications on operative outcome. *Crit Care Med.* 2005;33(8):1749-17.
- Green JA. Blood conservation in cardiac surgery: the Virginia Commonwealth University (VCU) experience. *J Cardiothorac Vasc Anesth.* 2004;18(4 Suppl):18S-23S.

**Recommendation Seven:** Colloid solution is an acceptable alternative to avoid excessive hemodilution from overload crystalloid infusion during surgery. See the equations in the Clinical Equations Appendix to estimate colloidal osmotic pressure during CPB.

**Evidence to Read:**

- Rex S, Scholz M, Weyland A, Busch T, Schorn B, Buhre W. Intra- and extravascular volume status in patients undergoing mitral valve replacement: crystalloid vs. colloid priming of cardiopulmonary bypass. *Eur J Anaesthesiol.* 2006;23(1):1-9.
- Trowbridge CC, Stammers AH, Wood GC, Murdock JD, Klayman M, Yen BR, Woods E, Gilbert C. Improved outcomes during cardiac surgery: a multifactorial enhancement of cardiopulmonary bypass techniques. *J Extra Corpor Technol.* 2005;37(2):165-72.
- Russell JA, Navickis RJ, Wilkes MM. Albumin versus crystalloid for pump priming in cardiac surgery: meta-analysis of controlled trials. *J Cardiothorac Vasc Anesth.* 2004;18(4):429-37.
- Kuitunen AH, Hynynen MJ, Vahtera E, Salmenpera MT. Hydroxyethyl starch as a priming solution for cardiopulmonary bypass impairs hemostasis after cardiac surgery. *Anesth Analg.* 2004;98(2):291-7.
- Sedrakyan A, Gondek K, Paltiel D, Elefteriades JA. Volume expansion with albumin decreases mortality after coronary artery bypass graft surgery. *Chest.* 2003;123(6):1853-7.
- Haynes GR, Navickis RJ, Wilkes MM. Albumin administration--what is the evidence of clinical benefit? A systematic review of randomized controlled trials. *Eur J Anaesthesiol.* 2003;20(10):771-93.
- Molter GP, Soltesz S, Larsen R, Baumann-Noss S, Biedler A, Silomon M. [Haemodynamic effects following preoperative hypervolemic haemodilution with hypertonic hyperoncotic colloid solutions in coronary artery bypass graft surgery] Anaesthesist. 2003;52(10):905-18.
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- Hoeft A, Korb H, Mehlhorn U, Stephan H, Sonntag H. Priming of cardiopulmonary bypass with human albumin or Ringer lactate: effect on colloid osmotic pressure and extravascular lung water. Br J Anaesth. 1991;66(1):73-80.

**Recommendation Eight:** Acute normovolemic hemodilution (ANH), either prior to heparinization or during the onset of CPB may help preserve autologous whole blood. ANH should be performed as tolerated through the use of calculations and nomograms. See the Clinical Equations Appendix for clinical algorithms to estimate safe ANH sequester volume.

**Evidence to Read:**

- Taketani T, Motomura N, Toyokawa S, Kotsuka Y, Takamoto S. Beneficial effect of acute normovolemic hemodilution in cardiovascular surgery. *Jpn J Thorac Cardiovasc Surg* 2005;53(1):16-21.
- Licker M, Ellenberger C, Sierra J, Christenson J, Diaper J, Morel D. Cardiovascular response to acute normovolemic hemodilution in patients with coronary artery diseases: Assessment with transesophageal echocardiography. *Crit Care Med.* 2005;33(3):591-7.
- Shander A, Rijhwani TS.Acute normovolemic hemodilution. *Transfusion.* 2004;44(12 Suppl):26S-34S.
- Monk TG, Goodnough LT. Acute normovolemic hemodilution. Clin Orthop Relat Res. 1998;(357):74-81.

**Recommendation Nine:** Meticulous surgical technique should be employed throughout the surgical procedure. When ever there is obvious surgical bleeding the surgeon should stop to tie down or cauterize the area to reduce waste.

**Evidence to Read:**

- Dial S, Delabays E, Albert M, Gonzalez A, Camarda J, Law A, Menzies D. Hemodilution and surgical hemostasis contribute significantly to transfusion requirements in patients undergoing coronary artery bypass. *J. Thorac. Cardiovasc. Surg.* 2005;130:654.
- The National Blood Resource Education Program Expert Panel. The use of autologous blood. [Article] JAMA. 1990;263(3):414-7. [Abstract]
- NHLBI. The National Blood Resource Education Program Expert Panel. The use of autologous blood. Downloaded January 10, 2006.
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- Network for Advancement of Transfusion Alternatives. Information downloaded from http://www.nataonline.com/ on January 10, 2006.
- Society for the Advancement of Blood Management. Information downloaded from: http://www.sabm.org/ on January 10, 2006.

- Bloodless Medicine Research. Information downloaded from http://www.med.unipi.it/patchir/bloodl/bmr.htm on January 11, 2006.
- Farmer S, Webb D. Your Body, Your Choice: The layman's complete guide to bloodless medicine and surgery. Singapore: Media Masters: 2000.

**Recommendation Ten:** Cell washing should be kept to a minimum and limited to the pre- and post-heparinization period. Coronary suckers are a safe alternative to use during the heparinization period to preserve frank autologous whole blood and return it back to circulation. A waste sucker should be kept in the field for undesirable shed blood and irrigant solutions.

**Evidence to Read:**

- Shander A, Moskowitz D, Rijhwani TS. The safety and efficacy of "bloodless" cardiac surgery. *Semin Cardiothorac Vasc Anesth.* 2005;9(1):53-63.
- Guo XY, Duan H, Wang JJ, Luo AL, Ye TH, Huang YG, et al. Effect of intraoperative using cell saver on blood sparing and its impact on coagulation function [Chinese]. *Zhongguo Yi Xue Ke Xue Yuan Xue Bao.* 2004;26(2):188-91.
- Tanemoto K, Hamanaka S, Morita I, Masaki H. Platelet activity of residual blood remained in the cardiopulmonary bypass circuit after cardiac surgery. *J Cardiovasc Surg (Torino).* 2004;45(1):27-30.
- Cross MH. Autotransfusion in cardiac surgery. *Perfusion.* 2001;16:391-400.
- von Bormann B, Weidler B, Holleufer R, Muller-Wiefel H, Trobisch H. Alternative mechanical autotransfusion. Hemofiltration vs. hemoseparation [German]. *Anasthesiol Intensivmed Notfallmed Schmerzther.*1992;27(1):11-7.
- Boldt J, Zickmann B, Fedderson B, Herold C, Dapper F, Hempelmann G. Six different hemofiltration devices for blood conservation in cardiac surgery. *Ann Thorac Surg.* 1991;51(5):747-53.
- Nakamura Y, Masuda M, Toshima Y, Asou T, Oe M, Kinoshita K, et al. Comparative study of cell saver and ultrafiltration nontransfusion in cardiac surgery. *Ann Thorac Surg.* 1990;49(6):973-8.
- Boldt J, Kling D, Zickmann B, Jacobi M, Dapper F, Hempelmann G. Acute preoperative plasmapheresis and established blood conservation techniques. *Ann Thorac Surg.* 1990;50(1):62-8.

**Recommendation Eleven:** Hemoconcentration should be considered for use to reverse excess fluid administration, eliminate undesirable byproducts including antiplatelet medications and concentrate the patient's red cell mass and plasma proteins.

**Evidence to Read:**

- Samolyk KA, Beckmann SR, Bissinger RC. A new practical technique to reduce allogeneic blood exposure and hospital costs while preserving clotting factors after cardiopulmonary bypass: the Hemobag. *Perfusion.* 2005;20(6):343-9.
- Belway D, Rubens FD, Wozny D, Henley B, Nathan HJ. Are we doing everything we can to conserve blood during bypass? A national survey. *Perfusion.* 2005;20(5):237-41.
- Koster A, Chew D, Merkle F, Gruendel M, Jurmann M, Kuppe H, Oertel R. Extracorporeal elimination of large concentrations of tirofiban by zero-balanced ultrafiltration during cardiopulmonary bypass: an in vitro investigation. *Anesth Analg.* 2004;99(4):989-92.
- Raman JS, Hata M, Bellomo R, Kohchi K, Cheung HL, Buxton BF. Hemofiltration during cardiopulmonary bypass for high risk adult cardiac surgery. *Int J Artif Organs.* 2003;26(8):753-7.
- Lee LY, DeBois W, Krieger KH, Girardi LN, Russo L, McVey J, et al. The effects of platelet inhibitors on blood use in cardiac surgery (review). *Perfusion.* 2002;17(1):33-7.
- Leyh RG, Bartels C, Joubert-Hubner E, Bechtel JF, Sievers HH. Influence of modified ultrafiltration on coagulation, fibrinolysis and blood loss in adult cardiac surgery. *Eur J Cardiothorac Surg.* 2001;19(2):145-51.
- Kamada M, Niibori K, Akimoto H, Yokoyama H, Tofukuji M, Iguchi A, et al. Efficacy of modified ultrafiltration in coronary artery bypass grafting. *Kyobu Geka.* 2001;54(6):463-7.
- Kiziltepe U, Uysalel A, Corapcioglu T, Dalva K, Akan H, Akalin H. Effects of combined conventional and modified ultrafiltration in adult patients. *Ann Thorac Surg.* 2001;71(2):684-93.
- Luciani GB, Menon T, Vecchi B, Auriemma S, Mazzucco A. Modified ultrafiltration reduces morbidity after adult cardiac operations: a prospective, randomized clinical trial. *Circulation.* 2001;104(12 Suppl 1):I253-9.
- Catala Bauset JC, de Andres Ibanez J, Grau Real F, Bengtsson A, Bengtson JP. Comparative study of two methods for salvaging red blood cells: centrifugation techniques (cell-saver) versus filtration through a 100,000-dalton filter. *Rev Esp Anestesiol Reanim.* 1999;46(8):338-43.

**Recommendation Twelve:** On-site coagulation monitoring (i.e., thromboelastography and heparin concentration determination) along with targeted pharmacotherapy (antifibrinolytics and desmopressin acetate) are an integral part to prevent empiric transfusions of allogenic blood and blood products.

**Evidence to Read:**


- Santos AT, Kalil RA, Bauemann C, Pereira JB, Nesralla IA.A randomized, double-blind, and placebo-controlled study with tranexamic acid of bleeding and fibrinolytic activity after primary coronary artery bypass grafting. *Braz J Med Biol Res.* 2006 Jan;39(1):63-9.
- Shore-Lesserson L. Evidence based coagulation monitors: heparin monitoring, thromboelastography, and platelet function. *Semin Cardiothorac Vasc Anesth.* 2005;9(1):41-52.
- Sedrakyan A, Treasure T, Elefteriades JA. Effect of aprotinin on clinical outcomes in coronary artery bypass graft surgery: a systematic review and meta-analysis of randomized clinical trials. *J Thorac Cardiovasc Surg.* 2004;128(3):442-8.
- Shore-Lesserson L. Monitoring anticoagulation and hemostasis in cardiac surgery. *Anesthesiol Clin North America.* 2003;21(3):511-26.
- Despotis GJ, Levine V, Saleem R, et al.: Use of point-of-care test in identification of patients who can benefit from desmopressin during cardiac surgery: a randomised controlled trial. *Lancet.* 1999;354:106-10.
- Jobes DR, Aitken GL, Shaffer GW: Increased accuracy and precision of heparin and protamine dosing reduces blood loss and transfusion in patients undergoing primary cardiac operations. *J Thorac Cardiovasc Surg.* 1995;110:36-45.


**Recommendation Thirteen:** Remember that transfusion of any allogeneic blood product is an "organ transplant" and not just a medication that is without side-effects. Everyone (surgeons, anesthesiologists, perfusionists and nurses) needs to think of a blood product infusion for what it actually is an "organ transplant" and not another medication that they can order from a menu.

**Evidence to Read:**


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# Appendix One: Clinical Equations

**Acute Normovolemic Hemodilution**

Ovrum (1), Moskowitz, Vinas (2) and others employ the following three equations to estimate the safe ANH volume to remove prior to CPB. The first step is to estimate the patients circulating blood volume (Eq. 1). Find the necessary pre-CPB Hct with Eq. 2 given a desired on-CPB Hct: then calculate the safe ANH volume with Eq. 3.

$$EBV = f_{BV}\ x\ Kg \qquad \textbf{Eq. 1}$$

$$Hct_{preCPB} = \frac{Hct_{onCPB}\ x\left(EBV + \Pr ime\ Volume\right)}{EBV} \qquad \textbf{Eq. 2}$$

$$ANH\ Volume = \frac{EBV\ x\left(Hct_{initial} - Hct_{preCPB}\right)}{Hct_{initial}} \qquad \textbf{Eq. 3}$$

Where:

- EBV is the patient's estimated blood volume in cc
- $f_{BV}$ is the blood volume factor in cc blood per kilogram: typically 70-90 cc/kg
- Kg is body weight in kilograms
- $Hct_{preCPB}$ is the percent estimated patient Hct required before CPB to achieve the desired $Hct_{onCPB}$
- $Hct_{onCPB}$ is the desired percent Hct after initiating CPB
- Prime Volume is the extracorporeal circuit prime volume in cc
- $Hct_{initial}$ is the patient percent Hct after hemodilution after anesthetic induction
- ANH Volume is the whole blood volume in cc to be sequested prior to CPB.

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1. Ovrum E, Holen EA, Abdelnoor M, Oystese R. Conventional blood conservation techniques in 500 consecutive coronary artery bypass operations. *Ann Thorac Surg.* 1991;52:500-505.

2. Vinas MS. The volume allowance formula as a guide to non-haemic solution administration. *J Extra Corpor Technol.* 1990;22(2):70-72.

**Post-Dilutional Hematocrit ($Hct_{onCPB}$)**

Once the ANH volume has been sequested; the post-dilutional, on-CPB Hct may be more accurately estimated. Using the same estimated blood volume (Eq. 1), the patient red blood cell mass ($RCM_{pt}$ in cc) is estimated with Eq. 4 The on-CPB Hct is then estimated from the $RCM_{pt}$, EBV and extracorporeal circuit prime volume (cc). DeFoe, et al. recommend that the on-CPB Hct be predicted for all CPB patients and action taken to avoid the patient experiencing low Hct on CPB which leads to undesirable post operative outcomes. (2,3)

$$EBV = f_{BV}\ x\, Kg \qquad \textbf{Eq. 1}$$

$$RCM_{pt} = EBV\ x\, Hct_{initial} \qquad \textbf{Eq. 4}$$

$$Hct_{onCPB} = \frac{RCM_{pt}}{(EBV + Prime\,Volume)} \qquad \textbf{Eq. 5}$$

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1. Vinas MS. The volume allowance formula as a guide to non-haemic solution administration. *J Extra Corpor Technol.* 1990;22(2):70-72.

2. DeFoe GR, Ross CS, Olmstead EM, Surgenor SD, et al. Lowest hematocrit on bypass and adverse outcomes associated with coronary artery bypass grafting. Northern New England Cardiovascular Disease Study Group. Ann Thorac Surg. 2001;71(3):769-76.

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**Post-Dilutional Total Protein and Colloidal Osmotic Pressure (COP)**

Blackwell, et al. and Beshere, et al. provide guidance to predict, measure and estimate on-CPB total protein concentration ([TP] in gm/dL) and the resulting colloidal osmotic pressure (COP in mmHg). (1,2) Normal COP is 18 to 22 mmHg, during CPB the COP falls to 8-15 mmHg.

$$[TP]_{onCPB} = \frac{[TP]_{preCPB} \; x \, EBV}{EBV + \mathrm{Pr}\,imeVolume} \quad \textbf{Eq. 6}$$

$$COP\,mmHg = (3.32 \, x \, [TP_{onCPB}]) - 2.0 \quad \textbf{Eq. 7}$$


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2. Beshere GA, Camerlengo LJ, Dearing JP. Estimation of colloid osmotic pressure during hemodilutional cardiopulmonary bypass. *J Extra Corpor Technol.* 1982;14(3):381-84.

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