Occasional Review

Transfusions in patients undergoing cardiac surgery with autologous blood

Jean-François Hardy MD*
François Harel MSc,†
Sylvain Bélisle MD*

Purpose: Determinants of allogeneic blood use in cardiac surgery include preoperative factors such as female sex, age, body weight, hematocrit and red cell volume. We verified if these variables also predicted the need for allogeneic transfusions when autologous blood is predonated.

Methods: Demographic and intraoperative variables, hemoglobin concentrations and transfusion requirements in patients undergoing cardiopulmonary bypass with autologous blood predonation were reviewed. Multivariate logistic regression and RECPAM tree-growing analyses were applied to identify the preoperative predictors of allogeneic transfusion in these patients.

Results: Data from 230 patients included in our autologous blood program between 1995 and 1998 were analysed. Patients undergoing complex/reoperative surgical procedures and patients over age 64yr with a low red cell volume (<2070ml) undergoing simple procedures were more likely to require allogeneic red cells. Younger patients with a low red cell volume undergoing simple procedures carried an intermediate risk. Allogeneic transfusion was avoided in 95% of patients undergoing simple procedures when red cell volume $\geq$ 2070ml.

Conclusions: In our institution, complex/reoperative surgery, low red cell volume and increased age are the main factors associated with the need for allogeneic red cell transfusion despite autologous blood predonation. Knowledge of the factors that limit the effectiveness of predonation with respect to allogeneic blood exposure should help clinicians decide which cardiac surgical patients should be included in autologous blood programs.

Objectif : Parmi les déterminants de l'utilisation de sang allogénique en cardiochirurgie, on retrouve des facteurs préopératoires comme le sexe féminin, l'âge, la masse corporelle, l'hématocrite et le volume globulaire. Nous avons voulu vérifier si ces variables prédisaient aussi le besoin de transfusions allogéniques dans les cas d'un don autologue préopératoire.

Méthode : Les variables démographiques et peropératoires, les concentrations d'hémoglobine et les conditions de transfusion ont été révisées chez des patients qui subissent une circulation extracorporelle avec du sang autologue prélevé avant l'opération. Des analyses de régression logistique multifactorielle et de partition et amalgamation récursive ont été appliquées pour identifier les facteurs prédictifs préopératoires de transfusion allogénique chez ces patients.

Résultats : Des données sur 230 patients admis dans notre programme de sang autologue entre 1995 et 1998 ont été analysées. Les patients qui subissent une intervention chirurgicale complexe ou une réopération et ceux qui ont plus de 64 ans, présentent un faible volume globulaire, (<2070 ml), et subissent une intervention simple ont davantage besoin de globules rouges allogéniques. Les jeunes patients qui présentent un faible volume globulaire et subissent une opération simple sont moyennement à risque. La transfusion allogénique a été évitée chez 95 % des patients qui subissent une opération simple et ont un volume globulaire $\geq$ 2070 ml.

Conclusion : Dans notre institution, une intervention complexe ou une réopération, un volume globulaire faible et un âge avancé sont les principaux facteurs associés au besoin de transfusion de globules rouges allogéniques malgré un don préopératoire de sang autologue. La connaissance des facteurs qui limitent l'efficacité d'un don préopératoire de sang en regard d'une exposition au sang allogénique devrait aider les cliniciens à décider quels patients de cardiochirurgie doivent faire partie de programmes de sang autologue.

From the Departments of Anesthesiology,* and Biostatistics,† Montreal Heart Institute, University of Montreal, Montreal, Quebec, Canada.

Address correspondence to: Jean-François Hardy MD, Montreal Heart Institute, 5000 Bélanger Street East, Montreal, Quebec, Canada H1T 1C8. Phone: 514-376-3330; Fax: 514-376-8784; E-mail: jean-francois.hardy@umontreal.ca

Supported in part by the Department of Anesthesiology, Montreal Heart Institute.

Accepted for publication March 24, 2000.

As stated in the Guidelines for Red Blood Cell and Plasma Transfusion for Adults and Children of the Canadian Medical Association, "Predonation of autologous blood should be considered a therapeutic option for adolescents and adults undergoing elective surgery in which the likelihood of transfusion is substantial (i.e. 10% or more)".¹ Results of a recent meta-analysis reveal that predeposition of autologous blood decreases allogeneic transfusion considerably and that the benefit of autologous blood donation (ABD) is greatest when the expected use of blood is highest.² In cardiac surgery, autologous blood programs are similarly successful. The probability of receiving allogeneic blood decreased from 82% to 27%, and from 69% to 32% in the studies by Owings *et al.* and Dzik *et al.* respectively.^{3,4}

Thus, autologous blood reduces, but does not completely eliminate^{3,5,6} exposure to allogeneic transfusions, especially in patients of small body habitus or with a low predonation hematocrit.⁷ In the absence of predonation, determinants of allogeneic blood use during myocardial revascularization have been identified to include preoperative factors such as female sex, age, body weight, preoperative hematocrit and red blood cell volume.⁸⁻¹³ Given the potential risks of conducting ABD in patients about to undergo cardiac surgery, we thought it would be important to verify if these or other preoperative determinants of allogeneic blood use applied to our ABD patient population. We postulate that identification of factors determining the need for allogeneic blood despite ABD may help clinicians decide which patients are most likely to benefit (with respect to allogeneic blood exposure) from this blood sparing strategy. Therefore, we conducted a retrospective review to determine which factors predict the need for allogeneic red cell transfusion in cardiac surgical patients undergoing ABD.

Methods

With Ethics Committee approval, computerized data from 230 patients undergoing cardiopulmonary bypass surgery with autologous blood predonation between initiation of the program in 1995 and mid 1998 were reviewed for demographic variables, predonation hemoglobin concentration ([Hb]), type of operation and transfusion requirement during their hospital stay. All data are reviewed by an anesthesiologist (Dr Raymond Martineau) prior to being entered in the computerized database. After being entered, the data are reviewed systematically by the same anesthesiologist to detect outliers and correct erroneous entries as required.

Patients enrolled in our autologous blood program are scheduled to predonate three units of blood (one

unit per week for three weeks), inasmuch as their initial hematocrit is > 34% (and subsequent hematocrit > 32%). Their cardiac condition must be stable. Patients with left main coronary artery stenosis, aortic valve disease and uncontrolled congestive heart failure are excluded from the program. Antifibrinolytics were not used routinely during the study period and no patient received recombinant erythropoietin. The protocol for transfusion of allogeneic red blood cells during and after CPB, prepared by the Transfusion Committee of this institution, was presented to anesthesiologists, surgeons, fellows and residents involved in the care of these patients. In summary, we maintain a [Hb] of approximately 60 G·l⁻¹ during CPB and [Hb]s as low as 80 G·l⁻¹ are tolerated after CPB as long as hemodynamic stability is maintained. Human albumin and/or pentastarch are used when volume expansion alone is desired.

Standard formulae were used to calculate red blood cell volume:¹⁴

Red blood cell volume = Estimated blood volume
x Body hematocrit

Where estimated blood volume = 70 ml·kg⁻¹ in men and 63 ml·kg⁻¹ in women; Body hematocrit = 0.91 x venous hematocrit

Statistical analyses

Chi-Square and Wilcoxon tests were used to compare simple and complex/reoperative operations with respect to frequency and number of units of allogeneic red cells transfused respectively. The red blood cell volume at which patients were at increased risk of receiving allogeneic transfusions was identified with the help of receiver operating characteristic (ROC) curves. A *P* < 0.05 was considered statistically significant.

Subsequently, a logistic regression analysis was performed to select the best predictors of allogeneic red cell transfusion. As suggested by Hosmer and Lemeshow,¹⁵ the selection process began with univariate analysis of each variable. Any variable with a *P* value < 0.30 by univariate analysis was considered a candidate for the multivariate analyses. Then, we applied two multivariate statistical techniques to investigate the impact of the candidate variables on allogeneic red cell transfusion. First, we performed a step-wise logistic regression. Second, we performed a RECURSIVE Partitioning and Amalgamation (RECPAM) tree-growing analysis¹⁶ which led to classification of patients into homogeneous classes characterized by different prognoses. The RECPAM is a generalization of the well known Classification And Regression Trees (CART) algorithm¹⁷ for building regression trees to fit more general outcome data.

TABLE I Evolution of hemoglobin concentrations

	Group	n	Mean $\pm$ SD	Min	Max	95% CI	P*
Baseline [Hb]	No Allo RC	194	148.6 $\pm$ 12.21	113	184	[146.8 ; 150.3]	0.1146
	Allo RC	36	145.1 $\pm$ 11.38	120	172	[141.2 ; 148.9]	
	All patients	230	148 $\pm$ 12.12	113	184	[146.4 ; 149.6]	
Preoperative [Hb]	No Allo RC	84	125.9 $\pm$ 11.94	93	153	[123.3 ; 128.5]	0.5424
	Allo RC	22	127.7 $\pm$ 14.64	106	166	[121.2 ; 134.2]	
	All patients	106	126.3 $\pm$ 12.49	93	166	[123.9 ; 128.7]	
Nadir [Hb] in ICU	No Allo RC	194	81.04 $\pm$ 10.09	60	110	[79.61 ; 82.47]	< 0.0001
	Allo RC	36	71.67 $\pm$ 15.04	44	124	[66.58 ; 76.75]	
	All patients	230	79.57 $\pm$ 11.49	44	124	[78.08 ; 81.06]	
Discharge [Hb]	No Allo RC	193	101.6 $\pm$ 11.36	74	135	[99.95 ; 103.2]	0.9545
	Allo RC	36	101.4 $\pm$ 9.533	83	127	[98.22 ; 104.7]	
	All patients	229	101.5 $\pm$ 11.07	74	135	[100.1 ; 103]	

Note: n: number of patients; [Hb]: hemoglobin concentration

"Baseline" refers to predonation [Hb], "preoperative" to [Hb] immediately prior to surgery, "nadir" to the minimal [Hb] during the first 24h in the intensive care unit and "discharge" to [Hb] at the time of discharge or seven days postoperatively.

* P values are based on Student's unpaired t test.

Results

Two hundred and two patients underwent simple revascularization or valve operations and 28 had reoperative or complex procedures (more than one valve and/or valve and coronary artery bypass surgery). Simple operations required allogeneic red cell transfusion less often than complex/reoperative surgery (12.4% *vs* 39.3% respectively; $P=0.001$) but, when initiated, the number of units transfused was the same (2 [1-9] *vs* 3 [1-9] respectively; median [min-max]; $P=0.38$). The number of autologous units collected was the same whether patients required allogeneic red cells or not (2.8 ± 0.4 *vs* 2.9 ± 0.5 units respectively; $P=NS$). Hemoglobin concentrations before predonation, prior to surgery and on discharge were not different between patients who required allogeneic red cells or not. Patients requiring allogeneic red cells had lower nadir hemoglobins during the first 24 hr in the intensive care unit compared to patients who did not receive allogeneic blood (Table I).

One hundred and seventy six patients received some autologous blood. In the 194 patients not transfused any allogeneic blood, 50 (25.8%) received all three units collected, 58 (29.9%) received two units, 32 (16.5%) received one autologous unit only and 54 (27.8%) were not transfused. In the 36 patients transfused additional allogeneic units, all patients received all the units collected (three units in 23 patients and two units in 13 patients). Mean nadir [Hb] in the ICU was lower in patients transfused allogeneic red cells (Table I). Eighty one percent of patients who received allogeneic blood had a nadir [Hb] below 80 g/L, compared to 51% in the group of patients who did not ($P=0.0011$).

FIGURE 1 Receiver Operating Characteristic (ROC) curve of red cell volume to predict allogeneic red cell transfusion in 202 patients undergoing simple cardiac operations with autologous blood.

The ROC curve suggested a cutpoint at 2070 ml below which patients were at increased risk for allogeneic red cell transfusion (sensitivity 69.4%, specificity 58.2%). The sensitivity and specificity were higher for patients undergoing simple operations (sensitivity 76%, specificity 59.3%) (Figure 1). For subsequent analyses, patients were classified as having a high or a low red cell volume, based on this figure of 2070 ml.

TABLE II Descriptive statistics of predictors and univariate logistic regression

Predictor	Autologous blood only (n = 194)	+ allogeneic red cells (n = 36)	P*	Unit	Odds Ratio	Odds ratio and 95% confidence intervals
Female sex: n (%)	49 (25.3)	13 (36.1)	0.181		1.67	
Complex surgery: n (%)	17 (8.8)	11 (30.6)	0		4.58	
Low level of RCV: n (%)	81 (41.8)	25 (69.4)	0		3.17	
ECC duration (min)	74.1 ± 28.8	97.8 ± 53.1	0	30†	1.68†	
RCV (ml)	2182 ± 967	1869 ± 432	0	-500†	1.67†	
Body mass (kg)	77.4 ± 14.6	71.5 ± 12.5	0.03	-10	1.34	
Predonation Hct (%)	43.72 ± 3.62	42.3 ± 3.9	0.04	-5	1.66	
Age (years)	52.4 ± 12.0	54.8 ± 14.3	0.299	10	1.17	
Collected red cells (units)	2.88 ± 0.47	2.83 ± 0.45	0.613	-1	1.2	
Height (cm)	168.5 ± 7.8	168.1 ± 8.2	0.765	10	0.93	

Note: n: number of patients; mean ± SD where applicable; RCV: red cell volume; ECC: extracorporeal circulation; Hct: hematocrit

* P values are based on univariate logistic regression

† Odds ratio were calculated for an increase of 30 units (units are shown in parentheses) of ECC duration, for a decrease of 500 units of RCV, etc.

Duration of extracorporeal circulation, complex/reoperative surgery, body mass, predonation hematocrit and low red blood cell volume, but not age and sex, were associated with the need for allogeneic red cells by univariate logistic regression analyses (Table II). Only complex/reoperative surgery and low level of red cell volume were selected as explanatory variables in the ensuing multivariate stepwise logistic regression model (Figure 2). From the fitted multivariate stepwise regression model, a predicted event probability (that of being transfused allogeneic red cells) was computed for each patient. When this predicted probability exceeded 0.20 (the value that maximized sensitivity), the patient was predicted to receive allogeneic red cells; otherwise, he was predicted not to. A 2 × 2 table was obtained by cross-classifying the observed and predicted responses and then, the performance of the model was evaluated using the c-index (0.721), the sensitivity (83.3%) and the specificity (54.1%). Finally, the classification error rate was calculated (41.3%), i.e. 95/230 patients were entered into the wrong category.

Results of the multivariate stepwise logistic regression model were improved by application of the RECPAM analysis which led to classification of the patients into four homogeneous classes (Figure 3) characterized by different prognoses. Patients were classified as follows:

- Class I (complex/reoperative surgery),
- Class II (concomitance of simple surgery, low red cell volume and age > 64yr),
- Class III (concomitance of simple surgery, low red cell volume and age ≤ 64yr) and
- Class IV (concomitance of simple surgery and high

FIGURE 2 Odds ratio and 95% confidence limits describing the need for allogeneic red cell transfusion by multivariate logistic regression analyses.

red cell volume).

Class IV was associated with the best prognosis (a 5.4% rate of allogeneic red cell transfusion) and was then used as the reference level for computing odds ratios. Classes I and II were associated with the worst prognoses with odds ratios of 11.3 (95% CI = [3.7, 34.7]) and 13.6 (95% CI = [3.8, 49.2]) respectively, compared with class IV. Class III was associated with an intermediate prognosis with an odds ratio of 3.3 (95% CI = [1.2, 9.3]).

Thus, from the fitted RECPAM model, patients in classes I and II may be predicted to require allogeneic red cells whereas patients in other classes should be predicted not to require allogeneic transfusions. Classification error rate may then be calculated. For this model, the classification error rate was 19.1% (i.e. patients were entered into the wrong class of patients).

FIGURE 3 Logistic regression tree-structure, as obtained by REcursive Partitioning and Amalgamation (RECPAM) tree-growing analysis.

Discussion

Our results suggest that predonation red blood cell volume is a good predictor of the requirements for allogeneic blood in patients undergoing simple cardiac surgery with autologous blood. Predonation red blood cell volume integrates three of the important determinants of transfusion (sex, weight and predonation hematocrit), thus predicting the need (or absence thereof) for allogeneic red cells more effectively than each variable taken in isolation. Despite the availability of autologous blood, our results show that patients undergoing complex/reoperative surgical procedures and older patients with a low red cell volume undergoing simple procedures are more likely to require allogeneic red cells. Younger patients with a low red cell volume undergoing simple procedures carry an intermediate risk. Patients with a high red blood cell volume undergoing simple procedures (either myocardial revascularization or valve surgery) carry the lowest risk of being transfused allogeneic blood (approximately 5%).

In our institution, a cutpoint of 2070 ml was chosen since it corresponds to the decision threshold that yields the optimal mix of false-positive and false-negative results.¹⁸ Rejection of the hypothesis that the theoretical area under the curve is 50% provides evidence that RCV has the ability to distinguish between the two groups.¹⁸ Nevertheless, transfusion practice is institution dependent^{19,20} and, therefore, the figure of 2070 ml may not be a valid cutpoint for red cell vol-

ume in all cardiac surgery centres. Thus each institution should determine, in the light of their transfusion practice, the cutpoint under which allogeneic transfusion becomes more likely in ABD patients.

In addition, since the number of ABD patients was limited, we were unable to test our prediction model either in a new cohort of patients or in one construed from the one presented herein. Consequently, performance of the model as a whole should be established prospectively in each institution.

Should they choose to offer ABD to their patients, knowledge of the factors that limit effectiveness of predonation with respect to allogeneic blood exposure ought to help clinicians decide which patients should be included in the program. Despite the arguments in favour of autologous blood, not only do the benefits of predonation on long term mortality remain unproven, but case reports suggest that morbidity, and mortality, from predonation *per se* may be significant, specially when donors do not meet the criteria for blood donation because of their cardiac condition.²¹ Results of the present study should discourage clinicians from accepting patients with marginal indications for autologous blood predonation, specially those in classes I and II identified by RECPAM analysis (Figure 3).

Tree-growing analysis is a powerful prediction tool with several useful features not easily accessible by other analytical methods such as multivariate stepwise logistic regression. One of its main advantages is its ability to detect interactions, i.e. non-homogeneity in the relationship between predictors and object of prediction, across different subpopulations. In the context of this study, RECPAM improved the predictive model by allowing the detection of the influence of age in patients who had a simple cardiac operation with low levels of red cell volume. The improvement of the classification error rates of the models is quite impressive: 51 additional patients are predicted correctly by tree-regression compared to the better known multivariate stepwise regression, a gain of 22.2% (51/230 patients). From the clinical standpoint, prediction of the need for allogeneic transfusions is correct in less than 60% (100% – 41.3%) of cases by multivariate stepwise regression compared to a correct prediction in more than 80% (100% – 19.1%) of cases by RECPAM analysis.

Few randomized clinical trials have demonstrated the benefits of erythrocyte transfusions. Consequently, the indications for the transfusion of red cells remain imprecise. It is impossible to determine from our review if patients were transfused because they truly required blood (e.g. a physiological trigger was reached) or because of the attending practitioner's

choice. The effect of age on transfusion requirements is difficult to interpret but, since clinicians often consider that older patients require higher [Hb]s in the perioperative period,²² we suspect the latter indication is likely. Nevertheless, on the whole, the evolution of [Hb]s supports the concept that patients who received allogeneic red cells were transfused according to protocol, given their nadir [Hb] in the first 24 hr after operation was lower than their counterparts who did not receive allogeneic blood. Also, discharge [Hb] was not different between patients who received allogeneic red cells and those who did not.

Autologous donation decreases the need for allogeneic transfusions in part because physicians tolerate lower hemoglobin levels in patients who are autologous donors.²³ Yet, unfortunately, because autologous blood is considered safe, it is transfused more liberally and total exposure to any blood product is increased.² This attitude towards autologous blood is inappropriate because errors do occur in a considerable proportion of cases. A recent Canadian study documented an error rate of 1/149 autologous units collected. By chance, the majority of these errors were of minor clinical consequence but, nonetheless, one unit of fresh frozen plasma was transfused to the wrong recipient in the 16 873 units studied.²⁴

The issue of the optimal quantity of blood to be harvested has not been resolved. Unused, wasted blood is expensive.²⁵ Thus, sufficient blood must be collected to eliminate the use of allogeneic red cells in a high percentage of donors while avoiding collection of units that will be wasted. For example, Axelrod *et al.* determined that five autologous units would be necessary to avoid any allogeneic blood in 90% of their patients undergoing myocardial revascularization,²⁶ while Pinkerton concluded that two units of autologous blood would suffice to avoid allogeneic red cell transfusion in 77% of patients, the collection of an additional unit resulting in substantial wastage with little additional benefit.²⁷ In this institution, collection of three units appears appropriate since it avoids exposure to allogeneic red cells in close to 88% of patients undergoing simple procedures.

In summary, the results of this retrospective analysis of the impact of ABD on allogeneic transfusion in 230 patients undergoing various cardiac operations show that complex/reoperative surgery, low red cell volume and increased age are the main factors associated with the need for allogeneic red cell transfusion despite ABD. Given the limitations of a retrospective study and the variability of transfusion practice, we suggest our model should be validated prior to use in other institutions. Should clinicians choose to offer

ABD to their patients, knowledge of the factors that limit effectiveness of predonation with respect to allogeneic blood exposure ought to help them decide which patients should be included in the program.

Acknowledgments

The authors would like to thank Dr. Raymond Martineau for his meticulous upkeep of the database of the Department of Anesthesiology of the Montreal Heart Institute and Ms. Micheline Roy, Lynda Dufresne and Raymonde Garant for collecting the data with such attention to detail.

References

- 1 Report of the Expert Working Group. Guidelines for red blood cell and plasma transfusion for adults and children. *Can Med Assoc J* 1997; 156: S1–23.
- 2 *Forgie MA, Wells PS, Laupacis A, Fergusson D* Preoperative autologous donation decreases allogeneic transfusion but increases exposure to all red blood cell transfusion. Results of a meta-analysis. International Study of Perioperative Transfusion (ISPOT) Investigators. *Arch Intern Med* 1998; 158: 610–6.
- 3 *Owings DV, Kruskall MS, Thurer RL, Donovan LM* Autologous blood donations prior to elective cardiac surgery. Safety and effect on subsequent blood use. *JAMA* 1989; 262: 1963–8.
- 4 *Dzik WH, Fleisher AG, Ciavarella D, Karlson KJ, Reed GE, Berger RL* Safety and efficacy of autologous blood donation before elective aortic valve operation. *Ann Thorac Surg* 1992; 54: 1177–81.
- 5 *Britton LW, Eastlund DT, Dziuban SW, et al.* Predonated autologous blood use in elective cardiac surgery. *Ann Thorac Surg* 1989; 47: 529–32.
- 6 *Love TR, Hendren WG, O'Keefe DD, Daggett WM* Transfusion of predonated autologous blood in elective cardiac surgery. *Ann Thorac Surg* 1987; 43: 508–12.
- 7 *Goodnough LT, Monk TG, Andriole GL* Erythropoietin therapy. *N Engl J Med* 1997; 336: 933–8.
- 8 *Paone G, Spencer T, Silverman NA* Blood conservation in coronary artery surgery. *Surgery* 1994; 116: 672–8.
- 9 *Scott WJ, Rode R, Castlemain B, et al.* Efficacy, complications, and cost of a comprehensive blood conservation program for cardiac operations. *J Thorac Cardiovasc Surg* 1992; 103: 1001–7.
- 10 *Goodnough LT* Stratifying patients preoperatively for transfusion outcomes. *Ann Thorac Surg* 1996; 61: 8–9.
- 11 *Magovern JA, Sakert T, Benckart DH, et al.* A model for predicting transfusion after coronary artery bypass grafting. *Ann Thorac Surg* 1996; 61: 27–32.
- 12 *Cosgrove DM, Loop FD, Lytle BW, et al.* Determinants of blood utilization during myocardial revascularization. *Ann Thorac Surg* 1985; 40: 380–4.

- 13 *Bilfinger TV, Conti VR* Blood conservation in coronary artery bypass surgery: prediction with assistance of a computer model. *Thorac Cardiovasc Surg* 1989; 37: 365–8.
- 14 *Walker RH* Mathematical calculations in transfusion medicine. *Clin Lab Med* 1996; 16: 895–906.
- 15 *Hosmer DW Jr, Lemeshow S*. Applied Logistic Regression. New York: Wiley & Sons, 1989.
- 16 *Ciampi A* Constructing prediction trees from data: the RECPAM approach. *In: Antoch J (Ed.)*. Computational Aspects of Model Choice. Heidelberg: Physica-Verlag, 1993: 105–51.
- 17 *Breiman L, Friedman JH, Olshen RA, Stone CJ*. Classification and Regression Trees. Belmont, CA: Wadsworth International Group, 1984.
- 18 *Zweig MH, Campbell G* Receiver-operating characteristic (ROC) plots: a fundamental evaluation tool in clinical medicine. *Clin Chem* 1993; 39: 561–77.
- 19 *Stover EP, Siegel LC, Parks R, et al*. Variability in transfusion practice for coronary artery bypass surgery persists despite national consensus guidelines. *Anesthesiology* 1998; 88: 327–33.
- 20 *Goodnough LT, Johnston MFM, Toy PTCY, and the Transfusion Medicine Academic Award Group*. The variability of transfusion practice in coronary artery bypass surgery. *JAMA* 1991; 265: 86–90.
- 21 *Goodnough LT, Monk TG* Evolving concepts in autologous blood procurement and transfusion: case reports of perisurgical anemia complicated by myocardial infarction. *Am J Med* 1996; 101: 33S–7.
- 22 *Carson JL, Duff A, Berlin JA, et al*. Perioperative blood transfusion and postoperative mortality. *JAMA* 1998; 279: 199–205.
- 23 *Wasman J, Goodnough LT*. Autologous blood donation for elective surgery. Effect on physician transfusion behavior. *JAMA* 1987; 258: 3135–7.
- 24 *Goldman M, Rémy-Prince S, Trépanier A, Décary F*. Autologous donation error rates in Canada. *Transfusion* 1997; 37: 523–7.
- 25 *Etchason J, Petz L, Keeler E, et al*. The cost effectiveness of preoperative autologous blood donations. *N Engl J Med* 1995; 332: 719–24.
- 26 *Axelrod FB, Pepkowitz SH, Goldfinger D* Establishment of a schedule of optimal preoperative collection of autologous blood. *Transfusion* 1989; 29: 677–80.
- 27 *Pinkerton PH*. Autologous blood donation in support of cardiac surgery: a preliminary report on a hospital-based autologous donor programme. *Can J Anaesth* 1994; 41: 1036–40.