Blood Conservation in Coronary Artery Bypass Surgery: Prediction with Assistance of a Computer Model

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Summary
A computer assisted model was created with the data from 514 consecutive coronary bypass patients in order to predict the potential need of a blood transfusion. During this time period strict management protocols were used. In this series 261 (55.9%) patients were never and 46 (9.9%) were only intraoperatively transfused. Intra- and postoperative transfusions were necessary for 160 (34.2%) patients. Preoperative hematocrit, age, sex, and weight were the statistically significant parameters in the development of the model.

Bluteinsparung in der Koronarchirurgie: Vorhersage mit Hilfe eines Computermodelles
Anhand von 514 konsekutiven Bypassoperationen wurde unter strikter Anwendung von Behandlungsprotokollen ein Computermodell zur Vorhersage der Notwendigkeit einer Bluttransfusion entwickelt. In dieser Serie wurden 261 (55.9%) Patienten nie, 46 (9.9%) nur intraoperativ und 160 (34.2%) intra- und postoperativ transfundiert. Präoperative Hamatokrit, Geschlecht, Gewicht und Alter waren die statistisch signifikanten Parameter, welche für das Modell ausschlaggebend waren.

Key words
Coronary artery bypass – Blood transfusion – Transfusion predictors – Computer assisted model

Blood Usage

Introduction
Over the last decade, blood conservation techniques have significantly reduced homologous blood transfusion requirements in patients undergoing cardiac surgical procedures. This had led from an average transfusion requirement of nine units per operation in 1970 (1), to less than one unit per operation in 1982 (10). Little information is available regarding factors that influence the need and dictate the amount of transfusion. This study describes the development of a mathematical model for prediction of transfusion in patients undergoing coronary artery bypass grafting (CABG).

Methods
All patients who underwent CABG between July 1, 1985, and June 30, 1988, at the University of Texas Medical Branch were included. Surgical and perfusion techniques were constant throughout the study period. The surgical technique with few minor modifications is that described by Kirklin and Burrat-Boyce (8). Blood conservation techniques used during extracorporeal perfusion included the use of nonhemolytic prime (21 ratio, Plasma-Lyte A® and 5% Dextrose/0.45 sodium chloride) for all patients with a preoperative hematocrit (Hct) greater than 32%, salvage of blood from the operative field with a pump sucker, usage of ultrafiltration during bypass (Amicon 36 ultrafilter in bypass circuit), transfusion of oxygenated blood at the end of the pump run after hemoconcentration, and autotransfusion of chest tube drainage. During bypass packed red blood cells were only transfused for Hct less than 18%. Postoperative management was standardized by a protocol which included criteria for transfusion. Patients with a preoperative Hct > 32% who received no intraoperative transfusions, received no postoperative transfusion unless Hct was < 25%, then they were transfused to a Hct of 30%. If patients were transfused intraoperatively, they received blood transfusion postoperatively to raise any Hct < 28% to a level of 30%. For antiplatelet therapy a modified Mayo Clinic regimen was used consisting of Dipyridamole 75mg the evening before surgery and postoperatively Q. I. D. (= every six hours), as well as 324mg of Aspirin orally Q. A. M. (= every morning) beginning the day after surgery. Elective operations were delayed if the patient was found to be on Aspirin preoperatively. Twelve preoperatively available variables were analyzed for use in the computer model: recent myocardial infarction (within two weeks), unstable angina, use of internal mammary artery, number of distal grafts, age, sex, weight, body surface area, preoperative platelet count, preoperative Hct, renal dysfunction (creatinine > 2.0 mg/dl), as well as use of autotransfusion. A multivariate logistic analysis was used to estimate the probability of bank blood usage and to assess the predictive significance of the variables on bank blood usage. Computer assisted models were then generated which use the maximum-likelihood method of Walker and Duncan (see Appendix 1). Using the patient data from July 1982 to December 1986, models were generated to find which explanatory variables could predict the probability of bank blood usage. The second half of the patient population (January 1987 to June 1988) were used to test and confirm the model.

Results
Between July 1, 1985, and June 30, 1988, 514 consecutive myocardial revascularizations including emergencies were performed. Of these, 35 were reoperations and 12 were patients with chronic renal failure. These 47 patients were excluded from further analysis. Of the 467 patients studied

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304 were male (65%) and 163 were female (35%). Mean age was 56.1 ± 6.0 years, with a range from 31 to 83 years. Mean number of grafts was 4.0 ± 1.6, and 340 (73%) received an internal mammary artery graft. During the study period 36 patients (7.7%) suffered an identifiable major complication postoperatively which led to death in 12 cases (2.5%). Two hundred and sixty-one (55.9%) received no blood during their hospitalization [2 deaths (0.8%)]. The rest received a mean per patient 2.55 ± 1.58 units blood during hospitalization. Forty-six (9.9%) were transfused only in the operating room [2 deaths (4.1%)]; 73 (15.6%) during their postoperative course [1 death (1.4%)], and 87 (18.6%) received blood both intra- and postoperatively [7 deaths (8.0%)] (Table 1).

From the 12 preoperatively determinable parameters, seven had a univariate likelihood ratio statistic (LRS) significance less than 0.05. This eliminated as nonsignificant the number of distal anastomosis, recent myocardial infarction, preoperative platelet count, and autotransfusion. In addition, body surface area was eliminated since it represents a derived value calculated from weight and sex. In order of significance the seven remaining variables were: preoperative Hct, weight, sex, age, renal dysfunction, use of internal mammary graft, unstable angina, with LRS’s (and associated probability levels) ranging from 92.85 (p < 0.000001) to 5.71 (p < 0.016869). The first four of these predictors, preoperative Hct, weight, sex, and age, were the most important, with a multivariate LRS of 148.14 (p < 0.000001). For each patient the individual probability in the four variable models was calculated using the coefficients and LRS’s depicted in Appendix 2. The resulting predictive values are shown in two dimensions in Figs. 1 and 2. In Fig. 1 variables of weight, preoperative Hct, and sex are shown. In Fig. 2 the variables of age, preoperative Hct and sex are shown. Values to the left of the dotted or uninterrupted line signify a greater than 90% probability that these patients will require banked blood during their hospitalization. On the contrary, values to the right of the oblique lines have a 90% or better probability of not requiring blood. Fig. 3 and 4 show a three dimensional depiction of the four important variables of bank blood usage, stratified by sex. While preoperative Hct was by far the most important variable in both sexes, weight was more important in females and age was more important in males. In the three-dimensional graphs, values to the left of the dotted plane represent patients with a greater than 90% chance of requiring a blood transfusion. Univariate or multivariate logistic regression analysis or analysis of frequencies did not yield a trend for the amount of blood transfused.

![Fig. 1](image1.png) Depiction of the 10% error rate for blood transfusions separated by sex. Weight and preoperative hematocrit (PREHCT) are used as parameters. Comparison with Fig. 2 distinguishes the different importance of weight and age in the two sexes.

![Fig. 2](image2.png) The 10% error rate separated by sex is depicted by using preoperative hematocrit (PREHCT) versus age as variables. Values to the right of the oblique lines signify a ≥ 90% chance of not requiring a blood transfusion.

**Table 1** Summary of patient data

<table>
<thead>
<tr>
<th>n</th>
<th>Total 467*</th>
<th>Hct ≥ 30% 231</th>
<th>Hct &lt; 30% 228</th>
<th>Hct &lt; 25% 70</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean Hct (%)</td>
<td>30.2 ± 3.7</td>
<td>33.0 ± 2.4</td>
<td>27.3 ± 2.2</td>
<td>24.6 ± 1.6</td>
</tr>
<tr>
<td>Age (years)</td>
<td>56.0 (16.4)</td>
<td>56.4 (10.2)</td>
<td>55.5 (10.6)</td>
<td>54.3 (10.5)</td>
</tr>
<tr>
<td>Male</td>
<td>304 (64.9)</td>
<td>155 (67.1)</td>
<td>146 (64.0)</td>
<td>45 (64.3)</td>
</tr>
<tr>
<td>Female</td>
<td>163 (35.1)</td>
<td>76 (42.9)</td>
<td>82 (36.0)</td>
<td>25 (35.8)</td>
</tr>
<tr>
<td>Complications absolute (%)</td>
<td>36 (7.7)</td>
<td>18 (7.8)</td>
<td>19 (8.0)</td>
<td>3 (4.5)</td>
</tr>
<tr>
<td>Never transfused</td>
<td>261 (55.8)</td>
<td>118 (51.3)</td>
<td>143 (62.8)</td>
<td>48 (68.2)</td>
</tr>
</tbody>
</table>

![Units of blood transfused per patient:](image3.png)

| All patients (n = 467) | 1.1 ± 1.0 | 1.3 ± 1.7 | 0.9 ± 1.6 | 1.0 ± 1.7 |
| Transfused patients (n = 206) | 2.5 ± 1.6 | 2.5 ± 1.6 | 2.4 ± 1.6 | 2.8 ± 1.7 |
| Post-op stay (days) | 8.9 ± 1.6 | 8.9 ± 1.6 | 8.9 ± 1.6 | 8.8 ± 1.6 |

**Discussion**

Without blood transfusions, modern cardiac surgery would not be possible. Early in the history of transfusion medicine, it was recognized that transfusions are associated with significant morbidity. The world-wide AIDS epidemic has sen-
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The prediction for transfusion. The required quantity could not be determined. The variance was too great and the fact that once the decision was made to transfuse, at least two units were given, contributes to the failure of a quantitative prediction. Not even a trend could be determined. Therefore, a larger case number will not help in resolving this issue. With modern myocardial preservation, time-saving technical aspects of modern cardiac surgery are of less importance than in the past. The number of distal anastomoses, the use of the technically demanding internal mammary artery and the cross-clamp time are not significant parameters. These findings can not be generalized and are specific for the transfusion criteria used in this patient population. It is interesting to note that under the given circumstances a patient group could be identified which could tolerate a low Hct without prolonged hospitalization or increased complications (Table 1). Although conceivable, we are not aware of any patients receiving blood transfusions after discharge outside of the hospital, also we did not readmit any patients within the first 30 days for transfusing blood. A recent consensus conference pointed out the lack of knowledge regarding the tolerance of normovolemic anemia in the surgical patient (3). Serious doubts were raised about the number 30 as least acceptable Hct in postoperative patients. Although not in a randomized fashion, the doubts were confirmed in the present study. Another finding recently confirmed was the beneficial use of ultrafiltration and cell separation techniques for hemocoencentration (2). No deleterious effects from these techniques alone were observed. With the aid of this computer model it should become possible to change the transfusion protocol to even lower acceptable Hcts before transfusion and still be able to perform safe CABG.

Acknowledgement

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References


sitized the general population to the subject of blood transfusion. The incidence of non-A non-B hepatitis is still not precisely known, but the best estimates are 1 : 100 transfusions (4). Although the inoculation with the AIDS virus represents only a minimal risk and is estimated to be 1 : 40 000 to 1 : 1 000 000, it is responsible for the current public debate over blood transfusions (11). Transfusion reactions include fever, shaking chills, and urticaria in 1 : 100, hemolytic reactions in 1 : 6 000, and deadly reactions in 1 : 100 000 cases (9). Knowing these facts, it is not astonishing that early in the history of cardiac surgery attempts were made to avoid blood transfusions. Reports about the decrease in blood usage can be found at periodic intervals in the literature (1, 3, 7, 9). Except for the report by Cosgrove et al. (4), all other reports describe technical advances in blood salvage. Methods which contain criteria deciding for or against transfusions are largely unknown. Cosgrove et al. (5) found the preoperative blood volume the strongest predictive parameter. Blood volume is defined by height, age, sex and Hct. Tables for blood volume do not take into consideration obesity, hypertension, and therapy with diuretics (6). Our model using components was amazingly exact in

Fig. 3

Three dimensional depiction of 10% error rate taking into account weight, age and preoperative hematocrit (PREHCT) stratified by sex. Patients with values to the right of the dotted plane had a ≤ 10% chance of requiring a transfusion.

Fig. 4

Fig. 3, 4 Three dimensional depiction of 10% error rate taking into account weight, age and preoperative hematocrit (PREHCT) stratified by sex. Patients with values to the right of the dotted plane had a ≤ 10% chance of requiring a transfusion.
APPENDIX 1

A logistic model was developed using the maximum-likelihood method of Walker & Duncan. The approach is to find appropriate estimates of the unknown parameters of the model

\[ P = \frac{1}{1 + e^{-\beta x}} \]

where

- \( P \) = probability of success (bank blood usage)
- \( \beta \) = exponential constant
- \( x \) = vector of explanatory or independent variables
- \( B \) = constant

After parameters were estimated, the accuracy of the resulting model was tested by the likelihood ratio statistic (LRS) which is a chi-squared distribution with degrees of freedom equal to the number of explanatory variables. Various logistic models were tested to determine which explanatory variables could predict the probability of bank blood usage with the least number of misclassifications. A misclassification was initially defined to occur if the predictive model indicated a probability of bank blood usage to be 0.5, but the patient did not need blood or if the model gives the probability of bank blood usage as 0.5, but the patient did not need blood.

The overall multivariate likelihood ratio statistic (LRS) of the model fitting all twelve variables was 157.55 (\( P < 0.0001 \)) using patients from July 1985 to December 1986. Explanatory variables were then dropped in order of least significance and the model was retested each time. A final model containing weight, sex, preoperative HCT and age, resulted.

\[ \Phi = 7.304 - 0.178 * \text{PREHCT} - 0.043 * \text{WEIGHT} + 0.066 * \text{AGE} - 0.888 * \text{SEX} \]

This value would then be used to predict the probability of blank blood usage. The above introduced general formula was changed in the final model to:

\[ \text{Probability} = \frac{e^\Phi}{1 + e^\Phi} \]

**Improvement of the Model**

Individual probabilities were calculated for each patient from January 1987 to July 1988 using the above formula. An arbitrary cut-off of 0.5 was used initially to determine a yes or no prediction of blank usage.

The major concern when using predicted probabilities at a given cut-off level of 0.5 was when bank blood transfusion was not predicted but the patient did need blood. By using appropriate “cut-off levels” on probability values, this type of error can be set so that it will occur at a fixed percent. For this report 10% error rates were chosen.

**APPENDIX 2**

Coefficients and the likelihood Ratio Statistics (LRS) for males and females in the linear logistic model for estimating the probability of bank usage.

<table>
<thead>
<tr>
<th></th>
<th>Males</th>
<th>Females</th>
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</thead>
<tbody>
<tr>
<td>CONSTANT</td>
<td>5.6259</td>
<td>7.9408</td>
</tr>
<tr>
<td>PREHCT</td>
<td>-0.1778</td>
<td>-0.2067</td>
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<tr>
<td>WEIGHT</td>
<td>-0.0326</td>
<td>-0.0602</td>
</tr>
<tr>
<td>AGE</td>
<td>0.0590</td>
<td>0.0922</td>
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<tr>
<td>LRS</td>
<td>54.1808</td>
<td>44.9235</td>
</tr>
<tr>
<td>P</td>
<td>&lt;.000001</td>
<td>&lt;.000001</td>
</tr>
<tr>
<td>PREHCT</td>
<td>preoperative Hematocrit</td>
<td></td>
</tr>
<tr>
<td>LRS</td>
<td>likelihood ratio statistic</td>
<td></td>
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</tbody>
</table>