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# ANALYSIS OF TRANSFUSION PREDICTORS IN SHOULDER ARTHROPLASTY

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**Background:** We are not aware of any previous study that has examined predictive factors for blood transfusion after shoulder arthroplasty. We analyzed the association between clinical factors and the need for postoperative blood transfusion and documented the use and waste of predonated blood in a group of patients managed with shoulder arthroplasty.

**Methods:** A retrospective study of 119 patients who underwent 124 shoulder arthroplasties (including eighty-seven primary uncomplicated total shoulder arthroplasties, twenty-seven revision or complicated primary total shoulder arthroplasties, and ten hemiarthroplasties) from 2001 to 2004 was performed. Logistic regression analysis was conducted to determine which clinical variables were predictive of transfusion.

**Results:** A postoperative transfusion was received after thirty-one arthroplasties (25%). The strongest predictor of blood transfusion after shoulder arthroplasty was the preoperative hemoglobin level (likelihood ratio test = 37.8,  $p < 0.0001$ ). Patients with a preoperative hemoglobin level of between 110 and 130 g/L had a five times greater estimated risk of transfusion than those with a level of  $>130$  g/L ( $p < 0.001$ ). Gender, body mass index, preoperative diagnosis, comorbid conditions, use of anticoagulants or aspirin, autologous predonation status, type of anesthesia, operative time, and decrease in hemoglobin or hematocrit were not predictors of blood transfusion. One hundred and two (78%) of the 131 predonated autologous units were discarded. Patients with a preoperative hemoglobin level of  $>130$  g/L had the highest percentage of wasted units (90%; fifty-five of sixty-one). Preoperative autologous blood donation did not eliminate the risk of allogeneic blood transfusion in autologous donors.

**Conclusions:** The preoperative hemoglobin level is the strongest predictor of blood transfusion after shoulder surgery, and individuals with a preoperative hemoglobin level of  $<110$  g/L have the highest risk of transfusion. On the basis of these findings, we do not recommend autologous predonation for individuals with a preoperative hemoglobin level of  $>130$  g/L, to avoid unnecessary expense and waste.

**Level of Evidence:** Prognostic Level II. See Instructions to Authors for a complete description of levels of evidence.

Shoulder arthroplasty may be accompanied by considerable blood loss<sup>1</sup>. As a consequence, some patients require perioperative blood transfusions. Blood transfusion, however, is not benign as it has been associated with several risks and complications, including allergic reactions; immune-mediated transfusion effects such as fever, urticaria, and hemodynamic overload<sup>2,3</sup>; and the risk of transmission of human immunodeficiency virus<sup>4</sup>, hepatitis B, hepatitis C, and human T-cell lymphotropic virus<sup>5</sup>. Posttransfusion febrile reactions and immune-mediated hemolytic reactions can occur, sometimes as a result of clerical error<sup>6</sup>.

For elective surgery such as shoulder arthroplasty, preoperative autologous blood donation represents an alternative to

allogeneic blood transfusion. Autologous transfusion is a relatively safe and effective option for these patients, although vasovagal episodes, anginal attacks, tetany, compartment syndrome, bacterial contamination, febrile nonhemolytic and septic reactions, phlebitis, vessel damage, donation-induced anemia, and clerical error sometimes occur<sup>7,8</sup>. Also, the cost-effectiveness of preoperative autologous donation may be poor because of the high percentage of units that are not used and are discarded<sup>9</sup>.

Several studies have established a relationship between various clinical risk factors and the need for postoperative blood transfusion in patients undergoing hip or knee arthroplasty<sup>2,9-18</sup>. However, we are not aware of any study that has determined the transfusion risk in patients undergoing

shoulder arthroplasty or that has established which patients are likely to benefit from predonation of autologous blood.

The purpose of the current study was to identify which preoperative variables are independently associated with blood transfusion after shoulder arthroplasty. We also analyzed the preoperative autologous blood donation and transfusion practice related to shoulder arthroplasty surgery at two tertiary medical centers.

### Materials and Methods

A retrospective study involving all total shoulder arthroplasties or hemiarthroplasties that had been performed at two tertiary medical centers between September 30, 2001 and March 31, 2004 was conducted. A governing institutional review board reviewed and approved the study. Patients were excluded from the study if they had undergone surgery for the initial treatment of a shoulder fracture, had primary impairment of platelet or coagulation function, or had chronic liver impairment.

One hundred and twenty-four operations in 119 patients met the study criteria and were included in the study. All operations were performed by two attending surgeons (J.J.P.W. and P.J.M.) with use of the same surgical exposure and the same hemostasis techniques. All arthroplasties were performed through a deltopectoral approach. The cephalic vein was mobilized either laterally or medially, and perforating branches were electrocauterized. The anterior circumflex humeral vessels also were electrocauterized.

The operations included 114 total shoulder arthroplasties (eighty-seven primary uncomplicated total shoulder arthroplasties and twenty-seven revision or complicated primary total shoulder arthroplasties) and ten hemiarthroplasties (six primary and four revision or complicated primary hemiarthroplasties). The indications for an uncomplicated primary total shoulder arthroplasty included primary osteoarthritis, rheumatoid arthritis, posttraumatic arthritis, and osteonecrosis. The indications for revision or complicated total shoulder arthroplasty included mechanical failure or loosening and primary or secondary arthritis associated with a rotator cuff tear. Any primary total shoulder arthroplasty that was performed with rotator cuff reconstruction or glenoid reconstruction was categorized as a complicated arthroplasty. The indications for hemiarthroplasty included early-stage osteoarthritis, osteonecrosis, malunion, and chronic instability. The indications for revision hemiarthroplasty included a previous arthroplasty that had been complicated by mechanical failure or loosening.

Documents that were analyzed included the preoperative history and physical examination records, the operative report, the anesthesia record, the nursing notes, the transfusion records, the blood bank records, the physician's progress notes, and the electronic medical record. Preoperative, intraoperative, and postoperative variables were evaluated with regard to their suitability as criteria for requiring a postoperative transfusion. Preoperative variables included the hemoglobin and hematocrit values; gender; age; diagnosis; weight; body mass index; the presence of comorbid conditions such as hy-

pertension, coronary artery disease, chronic obstructive pulmonary disease, rheumatoid arthritis, and diabetes mellitus; medications (with special attention to oral anticoagulants, aspirin, and corticosteroids); and the autologous predonation status. Intraoperative and postoperative variables included the type of operative procedure, the type of anesthesia (general, regional, or combination), the operative time, the estimated blood loss, the lowest postoperative hemoglobin and hematocrit values, the number of units transfused, and whether or not autologous or allogeneic blood was transfused. Preoperative hemoglobin and hematocrit values were obtained prior to autologous blood donation.

At our two hospitals, preoperative autologous donation is performed at the patient's request after a discussion with the surgeon. The surgeon requests a number of units to be predonated on the basis of this discussion, the patient's medical history, and the type of operation to be performed. The typical amount to be predonated is one to two units, although, if the patient is able to tolerate it, a third unit can be predonated. Patients are evaluated prior to donation. Contraindications to predonation are a heart rate of >100 or <50 beats per minute, a systolic blood pressure of >180 or <100 mm Hg, and a capillary fingerstick hemoglobin of <110 g/L. Capillary fingersticks are performed with use of the HemoCue device (HemoCue, Angelholm, Sweden). If the patient fails to meet any of these criteria, predonation is not allowed. In addition, these criteria are checked after the donation of each unit to determine whether a patient continues to meet these criteria and whether additional donation can proceed.

None of the patients in the present study received preoperative erythropoietin. Intraoperative blood loss was measured by the anesthesiologist according to the contents of the suction bottles and the increase in weight of surgical sponges. Intraoperative or postoperative vacuum drainage was not routinely filtered and reinfused. No patient received antithrombotic prophylaxis other than compressive stockings or boots unless they had an associated comorbidity that required anticoagulation. The decrease in the hemoglobin and hematocrit levels was defined as the difference between the preoperative value and the lowest postoperative value.

The indications for transfusion included symptomatic anemia and asymptomatic anemia in high-risk patients, such as those with cardiac or pulmonary disease. A combination of a hemoglobin level of <90 g/L and symptoms of anemia (sinus tachycardia with a heart rate of >100 beats per minute, a systolic blood pressure of <100 mm Hg, urine output of <30 mL/hr), or the presence of a clinically relevant cardiac history were considered to be indications for transfusion. However, as there are many variables that must be considered in clinical practice, these were relative and not absolute indications for transfusion.

Statistical analysis consisted of both univariate and multivariate analyses with the goal of determining risk factors for blood transfusion. Variables were tested for normality with use of the Kolmogorov-Smirnov statistic, and no significant departures from a Gaussian (bell-shaped) distribution were detected<sup>19</sup>. Therefore, continuous variables were described with use of the

mean and the standard deviation, with groups being compared with use of the Student *t* test. The Pearson chi-square and Fisher exact tests were used to assess differences in categorical data and proportions. Patients who received a blood transfusion and those who did not were compared with regard to preoperative variables, including age, gender, weight, diagnosis, hemoglobin level, hematocrit, comorbid conditions, preoperative medications, and type of procedure. Variables that demonstrated a significant relationship on univariate analysis were included in a multiple stepwise logistic regression analysis with use of backward selection to identify the significant independent predictors of transfusion. Significance was evaluated with use of the likelihood ratio test and the odds ratio, and 95% confidence intervals were calculated for the multivariate predictors on the basis of the final regression coefficients and their standard errors<sup>20</sup>. The level of significance was set at  $p < 0.05$ . Analysis of the data was conducted with the SPSS statistical package (version 12.0; SPSS, Chicago, Illinois). A power analysis indicated that a minimum sample size of thirty cases in which a transfusion was received and ninety cases in which a transfusion was not received would provide 80% statistical power ( $\beta = 0.2$ ) for the detection of a mean preoperative difference of 20 g/L, assuming a standard deviation of 20 g/L (effect size, 1.0) (nQuery Advisor, version 6.0; Statistical Solutions, Saugus, Massachusetts).

## Results

A total of 124 operations (119 patients) were evaluated. The mean age was 63.8 years (range, thirty-two to eighty-six years), and the mean weight was 86.2 kg (range, 42.3 to 136.4 kg). The preoperative diagnosis was primary osteoarthritis in seventy-nine cases, secondary osteoarthritis in thirty-six, and mechanical failure or loosening in nine. The causes of secondary arthritis were trauma in eighteen cases, osteonecrosis in seven, malunion in four, inflammatory arthritis in three, rotator cuff arthropathy in two, chronic locked posterior dislocation in one, and glenoid dysplasia in one.

Hypertension was a comorbid condition in fifty-nine cases (48%). Other comorbidities included coronary artery disease in thirty cases (24%), pulmonary disease in twenty-eight cases (23%), and diabetes mellitus in six cases (5%). Aspirin or another anticoagulant was used in twenty-eight cases (23%). Preoperative hemoglobin levels were available in 121 cases (98%). The mean preoperative hemoglobin recorded during presurgical testing was 132 g/L (range, 93 to 169 g/L). No blood was donated before fifty-one arthroplasties, one unit was donated before seventeen arthroplasties, two units were donated before fifty-four arthroplasties, and three units were donated before two arthroplasties. The overall mean operative time was 194 minutes (range, eighty to 426 minutes). The mean operative time for uncomplicated primary total shoulder arthroplasty was 189 minutes (range, 103 to 281 minutes). The mean operative time for revision or complicated primary total shoulder arthroplasty was 224 minutes (range, 137 to 308 minutes). The mean operative time for uncomplicated primary hemiarthroplasty was 146 minutes (range, eighty to 285 minutes). The mean operative time for revision or complicated hemiarthro-

plasty was 196 minutes (range, 129 to 239 minutes).

The overall estimated blood loss was 362 mL (range, minimal to 2000 mL). The mean estimated blood loss for uncomplicated primary total shoulder arthroplasty was 374 mL (range, minimal to 1000 mL). The mean estimated blood loss for complicated primary total shoulder arthroplasty was 450 mL (range, minimal to 2000 mL). The mean estimated blood loss for uncomplicated primary hemiarthroplasty was 200 mL (range, minimal to 500 mL). The mean estimated blood loss for revision or complicated hemiarthroplasty was 325 mL (range, minimal to 600 mL). The mean postoperative hemoglobin level was 107 g/L (range, 76 to 142 g/L). The mean hemoglobin decrease was 26 g/L (range, 0 to 57 g/L).

## Transfusion

A total of 131 units of blood were donated before seventy-three arthroplasties (59%) (average, 1.8 units per arthroplasty) for possible autologous transfusion. A transfusion of autologous or allogeneic blood, or both, was received after thirty-one arthroplasties (25%). Forty-six transfusions (thirty autologous and sixteen allogeneic) were performed (average, 1.5 units per transfusion). A transfusion of autologous blood only was received after twenty-one arthroplasties (17%), a transfusion of allogeneic blood only was received after eight arthroplasties (6%), and a transfusion of both forms of blood was received after two arthroplasties (2%). In ninety-three cases overall (75%) and in fifty-one cases in which blood had been predonated (70%), no transfusion of autologous or allogeneic blood occurred.

## Effect of Age, Weight, Initial Hemoglobin Level, and Blood Loss on Transfusion Requirements

The results of univariate analysis comparing demographic and clinical data between patients who underwent transfusion and those who did not are summarized in Table I.

The mean preoperative hemoglobin level was significantly higher in the group of patients who did not receive a transfusion than in the group of patients who did receive a transfusion ( $136 \pm 14$  g/L compared with  $118 \pm 13$  g/L;  $p < 0.0001$ , *t* test). The mean blood loss was significantly lower in the group of patients who did not receive a transfusion than in the group of patients who did receive a transfusion ( $320 \pm 210$  mL compared with  $495 \pm 374$  mL;  $p < 0.01$ ).

On the average, patients who did not receive a transfusion weighed more than those who did receive a transfusion (mean,  $88.5 \pm 18.4$  kg compared with  $79.2 \pm 18.9$  kg;  $p = 0.02$ ). Also, a higher percentage of patients who received a transfusion were of advancing age (more than seventy-five years old) ( $p = 0.03$ ).

The rate of blood transfusion associated with uncomplicated primary total shoulder arthroplasty (22%, nineteen of eighty-seven) was lower than that associated with revision or complicated total shoulder arthroplasty (41%, eleven of twenty-seven). However, this difference was only marginally significant ( $p = 0.05$ ). Gender, body mass index, preoperative diagnosis, comorbid conditions, use of anticoagulants or aspi-

**TABLE I Comparison of Demographic and Clinical Data According to the Need for Transfusion**

Variable	Transfusion (N = 31)	No Transfusion (N = 93)	P Value*
Age† (yr)	65.8 ± 14.8	63.1 ± 11.5	0.28
Advancing age (>75 yr)‡	8 (26%)	9 (10%)	0.03§
Gender‡			0.29
Male	17 (55%)	61 (66%)	–
Female	14 (45%)	32 (34%)	–
Preop. diagnosis‡			0.98
Primary osteoarthritis	20 (65%)	59 (63%)	–
Secondary osteoarthritis	9 (29%)	27 (29%)	–
Mechanical failure/loosening	2 (6%)	7 (8%)	–
Comorbidities‡			
Hypertension	15 (52%) of 29	44 (49%) of 90	0.83
Heart disease	10 (35%) of 29	20 (22%) of 90	0.22
Pulmonary disease	9 (30%) of 30	19 (21%) of 90	0.33
Anticoagulant or platelet therapy	8 (27%) of 30	19 (21%) of 90	0.53
Weight† (kg)	79.2 ± 18.9	88.5 ± 18.4	0.02§
Body mass index† (kg/m <sup>2</sup> )	28.4 ± 5.5	27.1 ± 5.8	0.24
Preop. hemoglobin level† (g/L)	118 ± 13	136 ± 14	<0.0001§
Preop. hematocrit† (%)	35.3 ± 3.2	39.1 ± 3.7	<0.0001§
Type of anesthesia‡			0.29
General	9 (29%)	19 (20%)	–
Regional	0 (0%)	5 (5%)	–
Combined general and regional	22 (71%)	69 (74%)	–
Type of operation‡			0.11
Primary total shoulder arthroplasty	19 (61%)	68 (73%)	–
Revision or complex total shoulder arthroplasty	11 (35%)	16 (17%)	–
Primary hemiarthroplasty	0 (0%)	6 (6%)	–
Revision or complex hemiarthroplasty	1 (3%)	3 (3%)	–
Operative time† (min)	190 ± 57	206 ± 76	0.22
Preop. donation status‡			0.14
No	9 (29%)	42 (45%)	–
Yes	22 (71%)	51 (55%)	–
One unit	5	12	–
Two units	17	37	–
Three units	0	2	–
Total blood loss† (mL)	495 ± 374	320 ± 210	<0.01§
Decrease in hemoglobin† (g/dL)	2.5 ± 1.1	2.6 ± 1.4	0.68
Decrease in hematocrit† (%)	6.8 ± 3.2	8.1 ± 3.6	0.08

\*As determined with the two-sample Student t test for continuous variables and with the Fisher exact test or chi-square analysis for the percentages and the categorical data, respectively. †The data are given as the mean and the standard deviation. ‡The data are given as the number of arthroplasties, with the percentage in parentheses. Percentages are based on the available data. §Significant.

rin, autologous predonation status, type of anesthesia, operative time, and decrease in hemoglobin or hematocrit did not differ significantly between the patients who had a transfusion and those who did not (Table I).

In addition, we categorized the patients into three groups on the basis of the preoperative hemoglobin level: <110 g/L

(fourteen arthroplasties), 110 to 130 g/L (forty-four arthroplasties), and >130 g/L (sixty-six arthroplasties). Transfusion was performed in nine cases (64%) in which the preoperative hemoglobin level was <110 g/L, in sixteen cases (36%) in which the preoperative hemoglobin level was 110 to 130 g/L, and in six cases (9%) in which the preoperative hemoglobin

**TABLE II Univariate and Multivariate Predictors of Postoperative Transfusion**

Variable	Univariate P Value	Multivariate Results (Logistic Regression)		
		Odds Ratio	95% Confidence Interval	P Value
Weight	0.02	–	–	0.09
Advancing age (>75 yr)	0.03	–	–	0.41
Preop. hemoglobin decrease* (g/L)	<0.0001	1.11	1.06-1.16	<0.0001†
Preop. hematocrit*	<0.0001	–	–	–

\*Preoperative hemoglobin and hematocrit were highly correlated. Therefore, we chose to include hemoglobin in the multivariate analysis.  
†Significant.

level was >130 g/L. There was a highly significant difference in the distribution of preoperative hemoglobin levels between these groups, with the patients who required transfusion having higher hemoglobin levels (chi-square = 24.3, degrees of freedom = 2,  $p < 0.0001$ ).

Logistic regression analysis demonstrated that, of the three significant predictors that were identified with univariate analysis (an age of more than seventy-five years, weight, and preoperative hemoglobin level), preoperative hemoglobin level was the only significant independent predictor of blood transfusion (likelihood ratio test = 37.8,  $p < 0.0001$ , odds ratio = 1.1, 95% confidence interval = 1.06 to 1.16). In other words, for each reduction of preoperative hemoglobin by 1 g/L, the

odds of transfusion increased by 10% (95% confidence interval = 6% to 14%). Multivariate analysis indicated that weight ( $p = 0.09$ ) and advancing age ( $p = 0.41$ ) provided no additional information regarding the need for transfusion beyond the information predicted by the hemoglobin level (Table II). Although the estimated blood loss was significantly associated with the need for transfusion in the univariate analysis, it was not included in the multivariate regression analysis because it is a postoperative variable and therefore is limited in terms of predictive utility.

The final exponential equation based on the modeling of the data for estimating the probability of transfusion on the basis of the preoperative hemoglobin level (Hb) is: probabil-

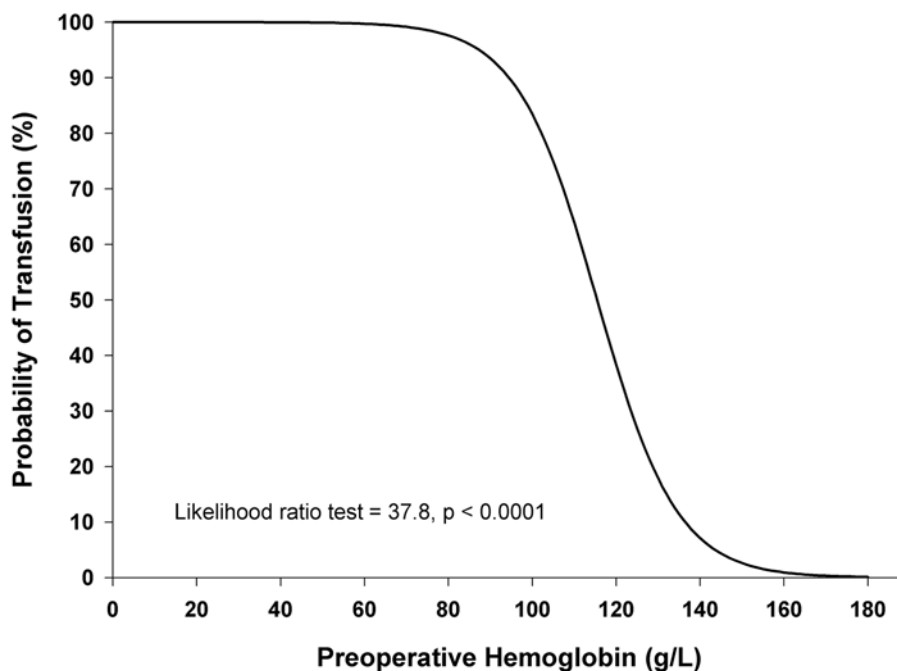


Fig. 1

Graph illustrating the relationship between the preoperative hemoglobin level and the probability of blood transfusion (expressed as a percentage) after shoulder surgery. The likelihood ratio test from regression analysis indicates a highly significant inverse relationship ( $p < 0.0001$ ), with lower hemoglobin levels being predictive of higher probabilities of transfusion. The theoretical curve was derived from the logistic regression model fitted to the actual data.

TABLE III Utilization of Predonated Autologous Blood

Preoperative Hemoglobin Level (g/L)	No. of Arthroplasties	No. of Arthroplasties with Transfusion	No. of Donated Units	No. of Units Wasted
<110	14	9	16	9 (56%)
110-130	44	16	54	38 (70%)
>130	66	6	61	55 (90%)
Overall	124	31	131	102 (78%)

ity =  $\exp(12.1 - 0.105 \times \text{Hb}) / (1 + [\exp(12.1 - 0.10546\text{Hb})])$ , where exp is the base of the natural logarithm, approximately 2.72. Figure 1 illustrates the inverse relationship between the preoperative hemoglobin level and the probability of blood transfusion (expressed as a percentage) after shoulder surgery. The curve depicts a probability of transfusion of 83% for patients with a preoperative hemoglobin level of 10 g/dL (100 g/L), 38% for patients with a preoperative hemoglobin level of 12 g/dL (120 g/L), and only 7% for patients with a preoperative hemoglobin level of 14 g/dL (140 g/L).

After categorizing patients into three groups on the basis of their preoperative hemoglobin levels and refitting the model with use of these categories as opposed to a continuous variable, regression analysis estimated that the odds of receiving a transfusion were approximately twenty times higher among patients with a preoperative hemoglobin level of <110 g/L as compared with those with a preoperative hemoglobin level of >130 g/L ( $p < 0.001$ , odds ratio = 20.3, 95% confidence interval = 4.9 to 83.2). The odds of receiving a transfusion were nearly five times higher for patients with a preoperative hemoglobin level ranging from 110 to 130 g/L as compared with patients with a value of >130 g/L ( $p < 0.001$ , odds ratio = 4.7, 95% confidence interval = 1.7 to 13.1). Finally, patients with a preoperative hemoglobin level of <110 g/L had a significantly greater risk of blood transfusion compared with patients with values ranging from 110 to 130 g/L ( $p = 0.03$ , odds ratio = 4.3, 95% confidence interval = 1.1 to 16.7).

#### Utilization of Autologous Blood

Blood was donated before seventy-three arthroplasties (59%). The median donation of autologous blood was two units (range, one to three units) (Table III). Overall, 102 (78%) of the 131 predonated autologous units were not used, and only thirty-nine units were reinfused. Patients who had a preoperative hemoglobin level of >130 g/L had the highest percentage of wasted units (90%; fifty-five of sixty-one). The percentage of predonated autologous units that were wasted was 56% (nine of sixteen) among the patients who had a preoperative hemoglobin level of <110 g/L and 70% (thirty-eight of fifty-four) among patients who had a preoperative hemoglobin level of 110 to 130 g/L.

Seventy-seven (76%) of 101 predonated units were wasted in the group of patients who had a primary uncomplicated total shoulder arthroplasty and sixteen (62%) of twenty-six units were wasted in the group of patients who had had a

revision arthroplasty or a complicated primary arthroplasty.

#### Discussion

Previous studies have examined specific risk factors for transfusion after elective total knee arthroplasty and total hip arthroplasty<sup>2,3,10-18</sup>. Most studies have demonstrated an association between a low preoperative hemoglobin level and the need for transfusion. Advancing age, weight, female gender, a higher American Society of Anesthesiologists physical status rating, arthroplasty with cement, revision surgery, and the use of low molecular weight heparin postoperatively also have been identified as predictors of transfusion after knee or hip arthroplasty<sup>10,12</sup>. To our knowledge, the present report describes the first study of preoperative clinical predictors of transfusion after total shoulder arthroplasty and hemiarthroplasty.

The clinical parameters used to determine the need for postoperative blood transfusion in patients undergoing shoulder arthroplasty are different from those in patients undergoing knee and hip arthroplasty. The estimated blood loss associated with shoulder arthroplasty is less than that associated with hip arthroplasty and equal to or greater than that associated with unilateral total knee arthroplasty. The estimated blood loss following total hip arthroplasty and total knee arthroplasty ranges from 450 to 1500 mL<sup>2,12,21,22</sup> and from 180 to 330 mL<sup>10,21</sup>, respectively. The estimated blood loss in the current study was 362 mL. The average decrease in the hemoglobin level in the present study was 26 g/L. This value was lower than those associated with total hip arthroplasty and total knee arthroplasty as reported in previous studies (40 and 38 g/L, respectively)<sup>16,21</sup>. It should be noted that postoperative anti-thromboembolic prophylaxis was not routinely used after shoulder arthroplasty.

Our multivariate analysis revealed a very significant relationship between postoperative transfusion and the preoperative hemoglobin level. Patients who had a preoperative hemoglobin level of <110 g/L were twenty times more likely to receive a transfusion compared with those who had a preoperative hemoglobin level of >130 g/L, and those who had a hemoglobin level of 110 to 130 g/L were five times more likely to receive a transfusion compared with those who had a preoperative hemoglobin level of >130 g/L. This finding supported the various studies that have demonstrated a relationship between the preoperative hemoglobin level and the need for blood transfusion<sup>2,10,12,14,16,18</sup>.

The current study demonstrated no relationship be-

tween the need for transfusion and gender, age, diagnosis, body mass index, the presence of comorbid conditions, the use of oral anticoagulants or aspirin, the autologous predonation status, the type of operative procedure, the type of anesthesia, or operative time. Despite these findings, it should be noted that a larger study population could clarify some of the trends seen in our univariate analysis that approached but did not reach significance. Hypertension, cardiac disease, weight, type of operation, predonation status, and decrease in hematocrit are potentially important variables that could be identified as significant in a larger study population.

A high percentage of the autologous units were discarded, and many patients never received any of their predonated autologous units. Overcollection of autologous units has been noted to be a common problem, with reported wastage rates of 38%<sup>23</sup> to 49%<sup>23</sup>. The results of a 1989 survey of blood collection in the United States showed that only 356,000 (54%) of 655,000 units of predonated blood were transfused back to the patients<sup>23</sup>. Etchason et al.<sup>9</sup> reported that substituting autologous for allogeneic blood resulted in little expected health benefit (0.0002 to 0.00044 quality-adjusted year of life saved) at considerable additional cost (\$68 to \$4783 per unit of blood). In 1992 dollars, the direct cost of collecting, testing, and processing predonated autologous blood was \$198.04 per unit whereas the direct cost of allogeneic blood was \$149.80 per unit. The additional cost of autologous blood was primarily a function of the discarding of units that were donated but not transfused and the more labor-intensive donation process. Bierbaum et al.<sup>2</sup> reported that 41% (1532) of 3736 autologous units that had been donated by patients undergoing primary unilateral hip replacement were wasted. Billote et al.<sup>13</sup>, in a prospective, randomized study of patients managed with hip replacement surgery, demonstrated that 69% of donors received an autologous transfusion and that 41% of autologous units were wasted.

The results of the present study demonstrate that, with the practices employed in our hospitals, shoulder arthroplasty was associated with a much higher rate of autologous unit waste (70%) in comparison with knee or hip arthroplasty. Revision or complicated primary total shoulder arthroplasty was associated with a higher prevalence of postoperative blood transfusion (41%) in comparison with other shoulder arthroplasty procedures, although this difference was not significant. Finally, it should be noted that allogeneic blood was transfused in two of the seventy-three cases in which autologous blood had been predonated. Thus, predonation did not completely eliminate the risk of allogeneic blood transfusion.

One notable discrepancy in our study was that while the criterion for predonation was a hemoglobin level of >110 g/L, it appears that some patients with a hemoglobin level of <110 g/L were allowed to predonate. The screening method used by the blood bank in our hospitals involves capillary hemoglobin measurement. The capillary fingerstick hemoglobin levels determined with the HemoCue device are known to be higher than the values determined with venous laboratory tests. This has been disclosed by the device manufacturer, and experiments

have demonstrated that capillary fingerstick hemoglobin levels vary by >10 g/L in comparison with venous laboratory measurements<sup>24</sup>. Patients who were screened with the HemoCue device subsequently met the criteria for predonation, although their venous measurement would seem to exclude them from predonation according to blood bank guidelines.

A notable shortcoming of the present study was the lack of strict guidelines for transfusion. While a prospective study involving strict guidelines for transfusion would be ideal, the data from retrospective studies have value, and the present study was performed with a logical basis. We believe that our blood-management protocol meets reasonable standards and that we were not particularly aggressive or conservative in our postoperative blood management. Our indications for transfusion fall within the scope of standard practice nationally, and consequently our findings have generalized utility for other practices.

The current recommendation of the National Heart, Lung, and Blood Institute is that patients should predonate autologous blood if they have a >10% chance of requiring a postoperative transfusion. On the basis of these recommendations and the results of the current study, a patient with a preoperative hemoglobin level of >130 g/L should be advised not to predonate autologous blood for shoulder arthroplasty. On the basis of the present study and existing predonation guidelines, autologous blood donation before shoulder arthroplasty should be reserved for patients with a preoperative hemoglobin level of 110 to 130 g/L.

In summary, the results of the present study demonstrate that the preoperative hemoglobin level was the strongest predictor of blood transfusion after shoulder surgery and that patients with a preoperative hemoglobin level of <110 g/L have the highest risk of requiring a transfusion. Given that the use of predonated autologous blood was inefficient, the present study supports the strategy of limiting predonation to patients with a preoperative hemoglobin level of between 110 and 130 g/L. Focusing autologous donations in such a way affords the opportunity to improve the overall efficiency of autologous collection programs for shoulder arthroplasty procedures. ■

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