Systematic Criteria for Type and Screen Based on Procedure's Probability of Erythrocyte Transfusion

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ABSTRACT

Background: At many hospitals, the type and screen decision is guided by the hospital's maximum surgical blood order schedule, a document that includes for each scheduled (elective) surgical procedure a recommendation of whether a preoperative type and screen be performed. There is substantial heterogeneity in the scientific literature for how that decision should be made.

Methods: Anesthesia information management system data were retrieved from the 160,207 scheduled noncardiac cases in adults of 1,253 procedures at a hospital.

Results: Neither assuming a Poisson distribution of mean erythrocyte units transfused, nor grouping rare procedures into larger groups based on their anesthesia Current Procedural Terminology code, was reliable. In contrast, procedures could be defined to have minimal estimated blood loss (less than 50 ml) based on low incidence of transfusion and low incidence of the hemoglobin being checked preoperatively. Among these procedures, when the lower 95% confidence limit for erythrocyte transfusion was less than 5%, type and screen was shown to be unnecessary. The method was useful based on including multiple differences from the hospital's maximum surgical blood order schedule and clinicians' test ordering (greater than or equal to 29% fewer type and screen). Results were the same with a Bayesian random effects model.

Conclusions: We validated a method to determine procedures on the maximum surgical blood order schedule for which type and screen was not indicated using the estimated blood losses and incidences of transfusion.

What We Already Know about This Topic

- Maximum Surgical Blood Order Schedule (MSBOS) defines in many institutions whether a type and screen should be performed before surgery, but the basis for this schedule is incompletely validated

What This Article Tells Us That Is New

- In a review of more than 160,000 noncardiac surgical cases from more than 1,250 procedures, the authors validated an approach to define an appropriate MSBOS to avoid unnecessary type and screen orders before surgery

UNNECESSARY preoperative testing can be reduced with anesthesiologist involvement.[1] Nevertheless, the principal factor limiting reduction in testing is insufficient evidence regarding indications.[1] In this paper, we consider the decision to perform ABO and Rh(D) blood typing and identification of clinically important red cell antibodies ("type and screen") before elective procedures.

The project's principal objective was to develop a systematic process to use the estimated blood loss (EBL) recorded in an anesthesia information management system to choose

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procedures with sufficiently small intraoperative EBL that a type and screen is unnecessary. We hypothesized that statistical methods relating the incidence of transfusion to median EBL are inadequately developed for procedures with minimal EBL.

At many hospitals, the decision for type and screen is guided by the Maximum Surgical Blood Order Schedule (MSBOS), a document listing for each scheduled procedure the recommended maximum number of units of erythrocytes to be cross-matched for the patient, whether instead only a preoperative type and screen is recommended, or whether neither is required. Another study objective was to evaluate guidelines for type and screen in the MSBOS to reduce discrepancies between low incidences of transfusion (*e.g.*, 0.8%) and relatively high incidences of type and screen (*e.g.*, 49%).

The decision to perform type and screen preoperatively relates to the scheduled procedure's typical (*e.g.*, median) EBL. Friedman created the MSBOS using many hospitals' data, suggesting type and screen for procedures with "minimal blood loss."[2] Richardson *et al.* recommended type and screen, not cross match, for patients undergoing cholecystectomy because "the expectation of blood loss was low."[3] Another study objective was to determine how to apply prior knowledge from the median EBL of the procedure when making type and screen recommendations for a procedure. We hypothesized that among procedures with minimal EBL, the *a priori* probability of transfusion is low, and additional information on the observed incidence of transfusion for the procedure can be used to revise the probability.

An increase in the mean units transfused increases the appropriateness of ordering a preoperative type and screen.[4–6] Jayaranee *et al.* recommended type and screen for procedures with a mean more than 0.3 units per case.[4] Mahadevan suggested type and screen for a mean of more than 0.5 units per case.[6] Cheng *et al.* recommended that the MSBOS be updated using data from the anesthesia information management system, with type and screen performed for procedures having a mean of more than 0.5 units per case.[6] Using data from the anesthesia information management system, the facility's MSBOS can be revised automatically for all procedures, not just updated manually for common procedures. In this study, we used our anesthesia information management systems data for this purpose, and hypothesized that thresholds of mean of 0.3–0.5 units per case would be valid statistically for some procedures.

Quantification of the probability of transfusion as a criterion for type and screen has been validated.[7–9] van Klei *et al.* showed that not using type and screen preoperatively for procedures with the rate of transfusion less than 5% was suitable for cholecystectomy at multiple facilities.[8,9] We therefore examined the relationship between this standard of "5% probability of transfusion" and the median EBL of procedures. We hypothesized that for most procedures with relatively small sample sizes (*e.g.*, fewer than 163 cases)**,[10–16] the historical estimated median EBL could be used to forecast whether the risk of transfusion is less than the 5% criterion. Finally, we compared the incidence of type and screen in our study with that using current practice.

Materials and Methods

The study was approved by the Thomas Jefferson University Institutional Review Board (Philadelphia, Pennsylvania) without requirement for written patient consent. *All* use of the term "procedure" in the paper refers to the scheduled procedure, since the decision to type and screen is made in reference to scheduled procedures, not actual (performed) procedures.[15,17] No statistical power analysis was performed *a priori* because the objective initially was to describe the functional relationships described in the Introduction (*i.e.*, there was insufficient knowledge to perform the calculations).

We retrieved the anesthesia information management system data from all anesthetics performed at the studied hospital from November 2005, two weeks after implementation of the information system, through January 2011. Cases with American Society of Anesthesiologists' physical status "E" code were excluded, as were cases performed on weekends, and cases starting before 6:00 AM or after 6:00 PM. The latter criterion was applied because, at the studied hospital, elective cases are rarely scheduled to start after 5:00 PM. Cases involving liver transplantation and cardiac surgical procedures were excluded, since cross-matched blood was prepared for all such patients. These excluded cases were identified based on their having Current Procedural Terminology (CPT®) anesthesia codes of 0560, 0562, 0563, 0566, 0567, 0580, or 0796. Because relatively few pediatric cases are performed at the hospital, the 4,032 cases of patients with age less than 18 yr were excluded. Finally, 21 cases were excluded for which the anesthesia care provider had entered 50 units or more of erythrocytes transfused. These cases, 0.01% of records, were clinically implausible based on chart review (*e.g.*, more than 100 units administered for EBL less than 20 ml). Of the 21 cases, five had procedures of median EBL less than 50 ml, 0.004% of such records. The final data set contained 160,207 cases in adults of 1,253 elective procedures (table 1).[15,18,19]

Statistics

The transfusion index is used frequently for the type and screen decision and is based on the assumption that the probability distribution of numbers of erythrocytes units transfused for each procedure follows a Poisson distribution.[4–6] The sample mean is the maximum likelihood estimator for the Poisson distribution's single parameter, the mean. Equality of the mean and variance is a mathematical property of the Poisson distribution. This is in contrast, for example, to a binomial distribution, where the mean and the variance are different parameters. Equality of the mean and variance of

** To have a 90% statistical power to differentiate between 5.0% and 10.0% with Type I error rate of 0.05, sample size needed would be N = 163.

Table 1. Elective (Scheduled) Surgical Cases in Adults at the Studied Hospital

Discrete Characteristics of the n = 160,207 Cases of 1,253 Procedures

Case Characteristic	Cases
Transfusion	2.7%
Type and screen decision could be assessed*	73.2%
Type and screen performed (denominator cases of preceding row)*	43.7%
Estimated blood loss recorded in anesthesia information management system	38.4%
Hemoglobin checked preoperatively	59.5%
MSBOS-recommended type and screen, including patients with recommended cross matched erythrocytes in next row	36.8%
MSBOS-recommended cross match erythrocytes	9.1%
Cases of most common of the 14 specialties (out of operating room)	37.8%
Cases of second most common specialty (general surgery)†	17.8%
Cases of third-most-common specialty (orthopedics)	14.2%
Laparoscopic procedure scheduled	2.1%
Thoracoscopic procedure scheduled	0.6%
Maximum percentage of cases performed by any one of the 363 surgeons	3.5%
American Society of Anesthesiologists physical status 3 or 4	41.8%
Male	44.9%
Estimated blood loss of 500 ml or more, or if unlisted the median blood loss for the scheduled procedure was 500 ml or more	3.2%

Continuous Characteristics and Count Data of the Cases

Case Characteristic	Percentiles					
	10th	25th	50th	75th	90th	N
Units of erythrocytes transfused among patients receiving transfusion	1	1	1	2	4	4,391
Preoperative hemoglobin (g/dl) among cases with hemoglobin checked preoperatively	10	12	13	14	15	95,325
Estimated blood loss (ml) among cases with listed value	10	25	50	200	400	61,472
Age in years among cases with listed value	33	45	56	67	76	160,128
Weight in kilograms among cases with listed value	57	66	79	93	109	137,214

* Type and screen was known for every case. However, the decision to type and screen for each case could be assessed for the 117,322 cases for which the patient had no other surgery for at least 30 previous days. Because the type and screen was good for 30 days, its presence for a subsequent procedure within 30 days could have been either that it was considered necessary or the blood bank already had the specimen. To prevent bias, the 42,885 cases with previous surgery were excluded from the two calculations in the paper involving the incidence of Type and Screen, regardless of whether the patient had a type and screen. These two calculations are identified in the text by "(see table 1 footnote *)." One calculation is in the second-to-last paragraph of the Results section and the other in the third-to-last paragraph of the appendix. † Many hospitals have ophthalmology as the second-most-common specialty by numbers of cases after nonoperating room (*e.g.*, endoscopy), since cataract surgery cases are so brief.[15,18,19] However, no ophthalmology cases were included because cataract and retinal surgery was not performed at the hospital. There was a separate facility for ophthalmology and those cases are done by a different anesthesia group without an anesthesia information management system.

MSBOS = maximum surgical blood order schedule.

erythrocyte units transfused was tested for each procedure by comparing (n − 1) × (sample variance)/(sample mean) to a chi-square distribution with (n − 1) degrees of freedom.[20]

CIs for binomial proportions (*e.g.*, incidence of type and screen) and percentiles (*e.g.*, EBL) were calculated using the Clopper-Pearson method.[21,22] The computational accuracy of the relevant equation (table 2) in Office Excel 2010 (Microsoft, Redmond, WA) was better than within 0.001%.††

†† "Excel statistical functions: BETAINV" at http://support.microsoft.com/kb/828299.

‡‡ www.OpenBUGS.info. Accessed June 26, 2011.

Pairs of binomial proportions were compared inferentially using the Fisher exact test (SYSTAT 13; Systat Software Inc., Chicago, IL).

Logistic regressions ignoring procedure or treating procedure as a fixed effect were performed using SYSTAT.

Logistic regression with procedure treated as a random effect was performed using OpenBUGS‡‡. The dependent variable was the logit of the proportion of cases of the procedure for which there was erythrocyte transfusion with at least 1 unit of blood. One random intercept was estimated for each of the procedures. These random effects were treated as being random samples from a normal distribution.

Statistical consideration for absent values of EBL is described at the end of the section Classification of Scheduled Procedure and Missing Values for EBL.

Results

Criteria for the Type and Screen Decision

We needed to determine which probability of erythrocyte transfusion represents a suitable criterion for type and screen. van Klei *et al.* previously suggested that type and screen be performed for procedures with 5% or more incidence of transfusion with one or more units.[8,9] They showed that the criterion was suitable for multiple facilities, but studied only a few procedures, all with large numbers of cases.[8,9]

Consider the decision whether to type and screen for "unilateral total hip replacement." The procedure had a transfusion rate of 7.8% (n = 393/5,064). Consequently, if the threshold for type and screen were 10% or more probability of transfusion, type and screen would not be performed for total hip replacement. In contrast, if the threshold for type and screen were 5% or more probability of transfusion, patients would undergo type and screen preoperatively. The procedure had an incidence of type and screen of 98.9% (n = 4,985/5,039). This example shows that a threshold of 10.0% would not match clinician decision-making, whereas a threshold of 5.0% would match decisions. The choice of 5.0% matches the criterion from van Klei *et al.*[8,9]

A criterion based on an incidence of transfusion (*e.g.*, 5.0% or more) differs from one based on the mean units transfused for each procedure (*i.e.*, the "transfusion index").[4–6,23,24] One of our objectives was to interpret use of the mean units transfused. We start by considering the procedure of unilateral total knee replacement. The procedure had an incidence of type and screen of 98.3%. There was transfusion of 0 units for n = 2,417 cases, 1 unit for 262 cases, 2 units for 4 cases, and 3 units for 1 case. The mean equals 0.102 units, where $0.102 = (0 \times 2{,}417 + 1 \times 262 + 2 \times 4 + 3 \times 1)/(2{,}417 + 262 + 4 + 1)$. This mean would be related to the incidence of transfusion provided the number of units transfused per case follows a Poisson distribution§§.[25] Setting the probability equal to 5.0% and solving for the unknown mean gives 0.051. Thus, if the mean number of units transfused exceeds 0.051 units, each patient would have a probability of transfusion exceeding 5.0%. The mean is slightly larger than the corresponding probabilities (*e.g.*, 0.051 more than 5.0%) because occasionally more than one unit is transfused. Still, the issue of 0.051 *versus* 5.0% (*i.e.*, 0.050) is minor considering that Mahadevan and Cheng *et al.* recommended 0.5 units as the threshold to perform a type and screen (*i.e.*, a value effectively 10 times larger than the 5.0% threshold).[5,6] We address this discrepancy below in the section Scheduled Procedures with Minimal Median EBL (Less Than 50 ml) and in the appendix.

To evaluate whether the decisions based on the two common criteria (incidence of transfusion and on the mean erythrocyte units transfused, *i.e.*, the "transfusion index") were equivalent, we evaluated fits to Poisson distributions.##

Table 2. Method that We Used to Determine Procedures on the MSBOS for which Type and Screen Was Not Indicated

1. For each scheduled procedure, calculate the median estimated blood loss (EBL) while treating the cases with absent EBL as having EBL that were not larger than the median EBL of the procedure. This is accomplished by setting the EBL equal to 0 ml for each case with absent EBL.
2. Select a threshold for "minimal EBL" (*e.g.*, 50 ml) by using the smallest median EBL with many scheduled procedures and cases for which the lower 95% confidence limit for the incidence of erythrocyte transfusion was more than 5.0%. The following equation can be used:*
   1 − BETAINV(1 − 0.05, n − m + 1, m),
   where n = sample size and m = number of cases with transfusion of at least 1 unit of erythrocytes. An example of its use is given in section Scheduled Procedures with Minimal Median EBL (Less Than 50 ml).
3. For each of the scheduled procedures with median EBL from step #1 less than threshold from step #2, calculate the lower 95% confidence limit for the incidence of transfusion. The above equation can be used with the appropriate sample size inserted.
4. For each of the scheduled procedures for which the calculated value from step #3 is less than 5.0% and for which there are 19 or more cases, set the MSBOS to indicate no type and screen.

For an analogy to BETAINV, NORMSINV(1 − 0.05/2) gives the commonly used value of 1.96. The accuracy is described at http://support.microsoft.com/kb/828299. The BETAINV function is equivalent (http://office.microsoft.com/en-us/excel-help/β-inv-function-HP010335670.aspx). Both accessed August 28, 2011. For implementation using SQL or other database language lacking these functions, create and store a table with two columns, one column being n and the other column with the maximum value of m for which type and screen could be deferred.

* For no observed transfusion, m = 0, do not apply the equation; type and screen would not be recommended in the Maximum Surgical Blood Ordering Schedule. BETAINV is the Excel function that calculates the inverse of the cumulative β probability density function, as used by the Clopper-Pearson method to calculate confidence intervals for proportions.[21,22]

MSBOS = maximum surgical blood order schedule.

§§ *P* (transfusion 1 unit or more) = 1 − *P* (transfusion with 0 units) = 1 − exp (−1 × mean) = cumulative chi-square distribution with 2 degrees of freedom and parameter 2 × mean.[25]

An alternative is to benchmark the geometric mean. See U.S. patent application 2010/0106516, from Timothy Hannon, "Method for optimizing blood utilization," www.google.com/patents?id=RO3OAAAAEBAJ. Accessed April 22, 2011. The geometric mean is the unbiased estimator for the median of log-normal distributions. This does not help for the type and screen decision, for two reasons. First, the median transfused would always be 0 units among procedures for which the type and screen decision would be under consideration. Second, the log-normal distribution cannot apply because by definition all units per case would have to be more than 0 units (*i.e.*, 1 unit or more).

For some procedures, the Poisson distribution appeared reasonable. For example, above we reported data from the study hospital for total knee replacement. The sample mean transfusion was 0.102 units, very close to the sample variance of 0.097 units, confirming a Poisson distribution ($P = 0.97$). In contrast, for some other procedures, the sample means and variances were markedly different (*i.e.*, poor fit to a Poisson distribution). For example, consider erythrocyte transfusions for the procedure of combined anterior and posterior cervical fusion. The procedure had an incidence of type and screen of 97.3%. Among the 541 cases, there were 500 with 0 units, 24 with 1 unit, eight with 2 units, four with 3 units, three with 4 units, one with 7 units, and one with 12 units. The sample mean equaled 0.153 units whereas the sample variance equaled 0.593 units, $P < 0.0001$. Overall, there were 317 procedures with sample mean of more than 0 units, excluding procedures with just n = 1. For 61% of these 317 procedures, the data were inconsistent with Poisson at $P < 0.05$. This incidence was considerably greater than the 5% incidence expected at random if a Poisson distribution were a reasonable fit for many procedures. Similarly, for 56% of the procedures, the data were inconsistent with Poisson at $P < 0.01$, rather than the 1% incidence expected at random. Thus, recommendations based on the mean transfusion and assuming a Poisson distribution would be unreliable. Instead, we rely on a 5.0% incidence of transfusion as the threshold for type and screen, not on a specific probability distribution and its parameters.

Classification of Scheduled Procedure and Missing Values for EBL

In order to forecast whether an individual case has a probability of erythrocyte transfusion with more than 0 units of 5.0% or more (*i.e.*, to make the decision whether to type and screen), the procedure needs to be specified. The hospital had 1,253 procedures using its internal classification system, many of which were performed rarely. For procedures that have less than 19 cases, the fifth percentile of the observed data cannot be calculated. There were 2.5% of cases for which there were less than 19 cases per procedure (95% confidence limit less than 2.6% of cases).‖‖[26] The larger problem is that to judge reliably when incidences differ from 5.0% based solely on observed numbers of cases with and without transfusion, sample sizes less than 163 are small.** For 18.1% of cases (95% confidence limit less than 18.2%) there were less than 163 cases per procedure.

One potential approach to addressing the procedures with less than 19 cases and/or less than 163 cases is to merge procedures into broader categories, resulting in a larger group. The anesthesia CPT coding system is a rational, systematic, and broader classification schema than the hospital's internal procedure classification system.

CPT codes were assigned to the primary procedure for each case *via* a crosswalk process, facilitated by use of the anesthesia CPT code for the performed (not scheduled) procedure from the department's billing office. The use of anesthesia CPT did result in fewer cases unable to be analyzed because of sample size considerations. For example, the anesthesia CPT 0750 encompassed six of the studied hospital's surgical procedures, including umbilical hernia repair (n = 426, median EBL less than 10 ml) and Spigelian hernia repair (n = 7, median EBL less than 10 ml). None of the 488 cases with anesthesia CPT 0750 included transfusion (*i.e.*, the anesthesia CPT predicted no transfusion).

However, concordance of transfusion rates among procedures with the same anesthesia CPT was poor for some anesthesia CPT codes. For example, among the hospital's 58 procedures that mapped to anesthesia CPT 0790 were both: gastrostomy or jejunostomy tube placement with a 0% transfusion rate (n = 0/38) and minimal blood loss (median EBL less than 10 ml), and right colectomy/hemicolectomy with a 7% transfusion rate (n = 10/138) and more substantial blood loss (median EBL 100 ml). Similarly, the anesthesia CPT 0670 included both: the procedure cervical laminectomy for tumor with a 12% transfusion rate (n = 6/52) and median EBL of 200 ml, and the procedure posterior thoracic lumbar fusion with a 50% transfusion rate (n = 235/468) and median of EBL 700 ml. Thus, pooling of procedures into larger categories was unsuccessful because the categories were too inhomogeneous with respect to transfusion, likely because of heterogeneity in blood loss.

Among the six listed examples of procedures in the preceding two paragraphs, the rank sequence of median EBL (less than 10 ml, less than 10 ml, less than 10 ml, 100 ml, 200 ml, and 700 ml) matched the rank sequence of transfusion rates (0%, 0%, 0%, 7%, 11%, and 50%). Therefore, we explored further whether to use the median EBL of historical cases as additional data about each procedure beyond simply the binary descriptor of "transfused" or "not transfused" from each case.

Experimental studies show median recorded EBL are biased.[27,28] For example, among EBL near the 50 ml threshold used in the section Scheduled Procedures with Minimal Median EBL (Less Than 50 ml), there were 7% overestimation for EBL 25 ml, 23% overestimation for EBL 30 ml, 10% underestimation for EBL 60 ml, and 11% underestimation for EBL 70 ml.[27,28] Multiplying, each of these biases was less than 10 ml, negligible relative to the 500 ml range of median EBL in figure 1. The experimentally measured bias could substantively influence the created MSBOS for EBL near the threshold of 50 ml. However, actual reported EBL have digit bias. Among recorded EBL of 40–60 ml, 99.3% are 40 ml, 50 ml, or 60 ml (n = 12,201/12,292).

‖‖ For case duration prediction (*i.e.,* managerial decision making), rare types of procedures are of much larger importance.[10,13–16] First, for most decisions what matters is whether an operating room there contains at least one case of a rare type of procedure, which can be much larger probability than the incidence of any one case being of a rare type of procedure.[15,16] Second, for case duration prediction, what matters is whether a combination of procedure, surgeon, and type of anesthetic is rare, not just the procedure.[26] This markedly increases in the incidence of cases that are of rare combinations.

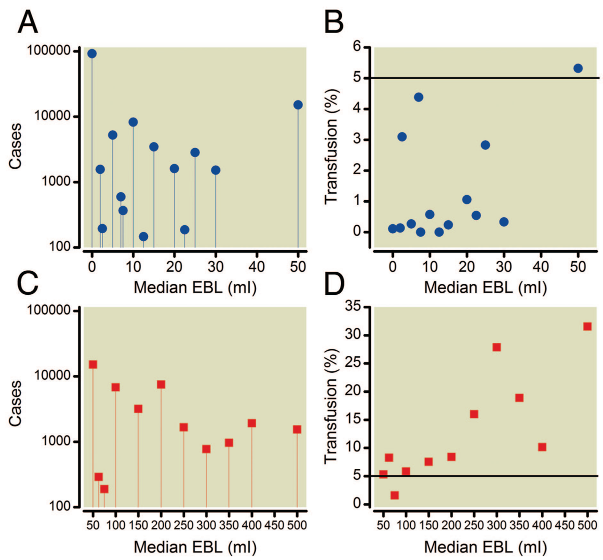

Fig. 1. Relationship for scheduled procedures between median estimated blood loss (EBL) and the incidences of transfusion. The median EBL was calculated for each procedure. The graph applies to the 133,320 cases for which there were at least 100 cases with the same median EBL. The threshold of 100 cases was applied because otherwise the vertical axes were too compressed. Observe that for median EBL 50 ml or less, anesthesia providers typically report blood loss in increments of 10 ml except for 25 ml (*A*). In contrast, for median EBL larger than 50 ml, the blood loss choices are most commonly multiples of 50 ml (*C*). For median EBL less than 50 ml, there is no functional relationship between median EBL and incidence of transfusion (*B*). We refer to this range as minimal blood loss. In contrast, starting somewhere between 50 ml and 100 ml, procedures with larger median EBL are associated with larger incidences of transfusion (*D*).

The important potential sources of bias in using EBL to predict transfusion are different.

First, performed procedures have predictable relationships between cases' EBL and transfusion rates, but performed procedures and cases' EBL are known only *post hoc*. We rely only on scheduled procedures, which frequently[15] differ from actual procedures.

Second, for 62% of cases, the actual EBL was not listed (table 1). From electronic qualitative chart review, absences often reflected anesthesia providers' communication of clinical information.*** Three procedures accounted for 50% of all such cases without a listed EBL, and each had an incidence of erythrocyte transfusion less than 0.1%. Ten procedures each accounted for at least 1,000 such cases, and each had an incidence of transfusion less than 0.3%. The one of these 10 procedures, upper endoscopic ultrasound, with no EBL specified for 100% of cases had a 0.0% incidence of transfusion (n = 0/1326). Instead of entering a small number (*e.g.*, 10 ml) that could not possibly have been measured, the anesthesia provider made no entry. In contrast, for total hip revision with a 36% incidence of transfusion (n = 298/822), the EBL was missing for only 1.6% of cases. This explanation was tested quantitatively, among procedures with 19 or more cases, by treating procedure as a fixed effect in logistic regression. The presence (Y) or absence (N) of a listed EBL significantly increased the incidence (Y *vs.* N) of transfusion ($P <$ 0.0001, odds ratio 1.45, 95% CI 1.30–1.67). When the analysis was repeated using a larger threshold, specifically 59 or more cases, the results were effectively the same ($P <$ 0.0001, odds ratio 1.45, 95% CI 1.27–1.63). Thus, the anesthesia providers were more likely to enter an EBL when there was transfusion. Imputing the EBL for cases for which the EBL was unstated by using EBL for those cases of the procedure with an EBL listed would result in bias in estimates of the relationship between EBL and transfusion.

Procedures with EBL sufficient for transfusion had few absent EBL (*e.g.*, 1.6% of total hip revision cases in the preceding paragraph). Figure 1 shows transfusion plotted against EBL without stratification by procedure. The corresponding odds ratio between presence (Y) or absence (N) of a listed EBL and transfusion (Y) was 17.2 (95% CI 15.5–19.1). The median EBL was used, as compared with other statistics such as the mean or mode, so that substitution of any value for the few absent EBL causes no change in the summary EBL for such procedures. For example, for total hip revision, from results of the preceding paragraph, absent EBL likely were less than the median EBL of 500 ml. Nevertheless, the calculated median EBL would be the same whether all absent values were treated as equaling 10 l, 10 ml, or the median EBL itself of 500 ml.

Absent values of EBL were treated as equaling any value not larger than the median EBL of the procedure. For example, consider patients scheduled to undergo orbital or maxillary resection with reconstruction. Among the seven cases, one received transfusion, a patient with an EBL of 150 ml. Among the seven cases, the EBL were the following: absent, absent, 25 ml, 25 ml, 150 ml, 250 ml, and 500 ml. Substituting any EBL for the absent values of 0–25 ml gives the same median EBL of 25 ml. The substitution was achieved mathematically, for all procedures regardless of median EBL, by setting absent values equal to 0 ml. Because the median was used, substituting values of 0 ml *does not imply* that there was no blood loss, just the EBL of the cases with absent EBL were not larger than the median EBL of the procedure (see Discussion).

*** We did not correct for these omissions and inaccuracies by using the EBL from the operating room information system because the incidence of "no value" in the operating room nurses' system was higher (77%, n = 160,207). When the nurse asks the surgeon(s) what value that she or he should enter, often the value stated is "minimal," which functionally the nurses interpret either by not entering a value or by choosing a small amount (*e.g.*, 20 ml). Our use of 0 ml for missing values matches this decision. Consistent with this model for behavior, among procedures with median EBL less than 50 ml *versus* 50 ml or more from the anesthesia data, the operating room information system was missing the EBL for 88% *versus* 21% of cases, respectively. Classification of the 1,253 procedures as having median EBL less than 50 ml *versus* 50 ml or more was identical to that obtained using the anesthesia data. This was despite the operating room entry differing from the anesthesia entry for 54% of the cases with an EBL entered by the anesthesia provider.

We used the 32 common secondary procedures to examine further calculation of median EBL.††† For the 14 combinations for which at least one component procedure had a median EBL of 50 ml or more, all combinations' median EBL were 50 ml or more. For the 10 combinations for which both component procedures had a median EBL less than 10 ml, all combinations' median EBL were less than 10 ml. For the 18 combinations for which both component procedures had median EBL less than 50 ml, all combinations' median EBL were less than 50 ml. For example, the procedures functional endoscopic sinus surgery, septoplasty, and turbinectomy had a median EBL = 15 ml (n = 2,511 cases). The procedures septorhinoplasty and nasal reconstruction had a median EBL = 10 ml (n = 593 cases). The cases with the combination had median EBL = 23 ml (n = 54 cases).

Scheduled Procedures with Minimal Median EBL (Less Than 50 ml)

Some procedures had a median EBL that was sufficiently small for the EBL to be considered minimal, from a physiologic perspective. Again, it was not that each case had minimal EBL, but that the cases were scheduled as a procedure whose median EBL was minimal. We realize that this may seem pedantic, but it is a key distinction.

The median EBLs of procedures were not uniformly distributed, either 0–50 ml or 50–500 ml (fig. 1). Among the many points in figure 1, the value at a median EBL of 50 ml shows that the pooled incidence of transfusion was more than 5.0% among all cases of procedures with that median EBL. The observed incidence of transfusion was 5.3% (n = 810/15,223), with 95% lower confidence limit equaling 5.02%, which is larger than our threshold transfusion value of 5.00% (see Introduction and Criteria for the Type and Screen Decision). The next smallest median EBL that was common and thus shown in figure 1 was 30 ml, with an observed rate of erythrocyte transfusion of 0.3% (n = 5/1,520). Cases of scheduled procedures with median EBL of less than 10 ml had transfusion rates of 0.1% (n = 148/100,066). Consequently, at the studied hospital, cases of procedures with median EBL less than 50 ml could be considered procedures expected to have minimal EBL. Other hospitals can create their own figure 1 to choose their threshold.

There were other data suggesting the validity of "minimal EBL" being median EBL less than 50 ml. For larger median EBL, the hemoglobin was generally (more than 90%) checked preoperatively. Knowledge of the hemoglobin is critical for the transfusion decision, because the decision to transfuse 1 unit of erythrocytes is necessarily based on the preoperative hemoglobin among cases with EBL less than 500 ml.[29] Among cases of procedures with most EBL absent or equaling 0 ml, the hemoglobin was checked preoperatively for 37% of cases (n = 34,217/92,100). Among cases for which the procedure had median EBL larger than 0 ml but less than 50 ml, the hemoglobin was checked preoperatively for 84% of cases (n = 22,318/26,492). Each further increase in the median EBL was associated with an increase in the percentage of cases with the hemoglobin checked preoperatively. For example, there were 180 procedures with at least 19 or more cases per procedure and median EBL larger than or equal to 50 ml and less than or equal to 500 ml. Applying linear logistic regression to these 39,259 cases, procedures with a median EBL of 50 ml and 500 ml had overall estimated incidences of hemoglobin checked preoperatively of 93% and 96%, respectively ($P < 0.0001$).

To assess the validity and usefulness of assessing the incidence of transfusion among procedures with minimal median EBL, we limited consideration to the 382 procedures and 115,855 cases with 19 or more cases per procedure and median EBL less than 50 ml. The procedure was treated as a random effect in a Bayesian logistic regression analysis.

The overall rate of transfusion among the 115,855 cases was 0.3%. Therefore, for procedures with few data (*e.g.*, n = 20), unless the observed proportion transfused was significantly different from 0.3%, the Bayesian estimated incidence of transfusion was close to 0.3%. For example, among the 20 patients who underwent endometrial ablation with balloon, none was transfused. The Bayesian estimate was not 0.0% but closer to 0.3%. The Bayesian random effect effects analysis implied shrinkage of the procedure's observed incidence of transfusion toward the underlying incidence of 0.3% among all procedures.

An alternative approach to using the Bayesian method is to calculate the lower 95% confidence limit for the incidence of transfusion *via* the Clopper-Pearson method,[21,22] using the observed number of cases with and without transfusion for the procedure. Type and screen would be performed for those procedures for which the lower limit exceeds 5.0%. The lower limit applied because, *a priori*, the probability of transfusion was low based on choosing only procedures with minimal median EBL. A large incidence of transfusion would need to be observed for a procedure to warrant type and screen.

For example, consider the procedure gastrostomy or jejunostomy tube placement with 38 cases, none of who was transfused. The lower 95% confidence limit for the incidence of transfusion equaled 0%. The recommendation would be not to type and screen.

For another example, consider the procedure jejunostomy. There were 56 cases without transfusion and three cases with transfusion: 1 unit, 2 units, and 2 units. The lower 95% confidence limit for the incidence of transfusion equaled 1.4%, obtained using the Excel formula in table 2[21,22]:

††† The hospital's procedure codes include typical combinations of procedures. Facilities scheduling using systematic vocabularies such as CPT would use combinations of CPT codes.[10–13] We classified each case by its primary procedure code, since only 3.7% of records had another procedure and just 1.3% of such procedures had 19 or more cases (n = 32/2,443). Still, we could study these n = 32 combinations since each had n sufficiently large for median EBL to be insensitive to outliers.

$$= 1 - \text{BETAINV}(1 - 0.05, 56 + 1, 3)$$

Because 1.4% is less than 5.0%, the recommendation would be not to perform type and screen preoperatively for this procedure. The scenario is typical among procedures with minimal median EBL, in that 99.97% of such cases had transfusion with 0, 1, or 2 units (n = 115,821/115,855).

We compared decisions made using the two methods. Applying the random effects logistic regression to the 382 procedures with at least 19 cases and minimal median EBL, there were 2 of 382 procedures with Bayesian estimated incidence of transfusion more than 5.0%. For both of the two procedures, the lower 95% confidence limits were 5.0% or more. For the other 380 procedures, the Bayesian estimated incidences were less than 5.0%, as was the lower 95% confidence limit. There was perfect concordance.‡‡‡ Although the random effects logistic regression and the lower 95% confidence limit calculated using the Excel formula produced identical results, for the remainder of the paper we refer to using the lower 95% confidence limit because it is a simpler method.

The lower 95% confidence limit was less than 5.0% for 380 of the 382 procedures. Validity of the recommendation not to perform type and screen preoperatively for these procedures was that they had a pooled incidence of transfusion of 0.2% (n = 247/115,684, 95% upper confidence limit 0.24%). More than 2 units of erythrocytes were administered for 0.02% of patients (n = 26/115,684).

The lower 95% confidence limit was 5.0% or more for two of the procedures with minimal median EBL. One procedure was sternal debridement/rewiring, with median EBL of 25 ml.§§§ The other procedure was bronchoscopy and mediastinotomy, with median EBL less than 10 ml. These two procedures had low median EBL but a significant incidence of transfusion, 23% (n = 39/171, lower 95% confidence limit 18%). The decision to recommend type and screen for these two procedures was supported by current practice, which was to type and screen for most of these cases (91%, n = 79/87, lower 95% confidence limit 84%, $P <$ 0.0001). The sample size was smaller (n = 87) for assessing incidences of type and screen than transfusion (n = 171) because patients who had undergone surgery during the prior 30 days could not be studied, as their type and screen may have been for the previous procedure(s).

In the section Criteria for the Type and Screen Decision, we described a discrepancy among authors suggesting type and screen for procedures with mean erythrocyte units transfused (*i.e.*, the "transfusion index") of more than 0.50 units,[5,6] even though by Poisson distribution this would correspond to a prediction that 50% of patients would have been transfused. Both of the procedures with a lower 95% confidence limit for incidence of transfusion more than 0.05 had means of more than 0.50 units. Thus, recommendations matched, because the Poisson distribution assumption did not hold. The recommendations are, in contrast, strikingly inconsistent for larger median EBL (see appendix).

Three observations suggest the usefulness of our suggested method, consisting of: identifying procedures with minimal EBL and then applying lower 95% confidence limits to estimate incidences of transfusion. First, among the 380 procedures for which type and screen would not be recommended by our approach, the hospital's MSBOS included type and screen for 23% of procedures (n = 88/380 procedures, lower 95% confidence limit 20%). Second, among these cases, 20.2% had type and screen performed and were not transfused (n = 15,185/75,182 cases, lower 95% confidence limit 20.0%). Third, during the study period, there were 51,322 cases for which type and screen was performed, among cases without recent surgery (see table 1 footnote *). By definition, this count included all such patients transfused. If the 15,185 type and screens had not been performed, there would have been a 30% reduction in the incidence of type and screen at the hospital for elective surgery among patients typically seen in a preanesthesia evaluation clinic (n = 15,185/51,322, lower 95% confidence limit 29%).###

In the appendix, we apply the approach to cases with larger median EBL (50–500 ml). The approach achieved a statistically significant additional reduction in the incidence

‡‡‡ Cohen's kappa is undefined when there is perfect concordance. We can instead calculate the 95% lower confidence limit for the concordance *per se*, which equals 99.2%. This value of 99.2% seems high. However, in the appendix (50 ml or more median EBL less than 500 ml) where only 37 procedures are studied, the lower 95% confidence limit for the concordance equals 92.2%, which seems low. Cohen's kappa would take into account the random probability of agreement. However, neither confidence limit is Bayesian, taking into account our understanding of the reason for the concordance. Our local conclusion was that for median EBL less than 50 ml, the sample size was sufficiently large for clinical implementation. In contrast, for median EBL of at least 50 ml, we consider the value of the work to be its scientific consistency with that for median EBL less than 50 ml. The latter results are shown in the Appendix only.

§§§ The procedure's 149 cases had EBL 75th percentile = 100 ml (95% confidence interval 100–200 ml) and 90th percentile = 230 ml (95% confidence interval 200–300 ml). In comparison, the most common procedure with median EBL equal to 25 ml was laparoscopic nissen fundoplication for hiatal hernia repair. The procedure's 371 cases had 75th percentile = 50 ml (95% confidence interval 50–50 ml) and 90th percentile = 100 ml (95% confidence interval 100–150 ml). Results for this procedure highlight why we have not included preoperative hemoglobin in the MSBOS calculations. When the 16% of patients (n = 18,027/115,855, table 1) with a known preoperative hemoglobin less than 12 g/dl were excluded, all procedures with median EBL less than 50 ml had a lower 95% confidence limit less than 5.0%, including sternal debridement/rewiring.

Potentially the reduction could be more, because we limited consideration to procedures with 19 or more cases. The remaining 2,737 cases of 461 scheduled procedures have less than 19 cases per procedure. For 459 of these 461 procedures, the lower 95% confidence limit less than 5.0% because all cases of the procedure had no transfusion. Adding the 459 procedures would reduce type and screen by another 639 cases, resulting in an estimated reduction of 31%, rather than 30%. However, whereas the median EBL is highly insensitive to individual cases and the time series nature of the data for 19 or more cases, this would not necessarily apply for 19 or less. Throughout our Results, we have neglected the time series nature of the data (*e.g.*, training and testing dataset) because our results cannot be affected since we use the median EBL. That would not hold, though, for small n.

of type and screen ($P < 0.0001$), but the reduction was substantively minor (1.6%). The statistical significance among procedures with larger EBL further suggests validity of the preceding results.

Discussion

In the Introduction, we summarized heterogeneity in the scientific literature for the type and screen decision before elective surgery. In retrospect, it has been challenging for clinicians to make evidence-based decisions, since prior evidence has suggested both type and screen for procedures with mean more than 0.50 erythrocyte units[5,6] and for procedures with $P > 5.0\%$[8,9] for erythrocyte transfusion. From sections Criteria for the Type and Screen Decision and Scheduled Procedures with Minimal Median EBL (Less Than 50 ml) and appendix, these two previously developed and applied criteria differ 10-fold and result in divergent recommendations. For example, if the 0.50 unit (transfusion index) criterion was used, then patients scheduled to undergo total knee replacement or anterior and posterior cervical fusion would not undergo type and screen, even though the current incidence exceeds 97%.

Our suggested approach for choosing elective cases not routinely to type and screen preoperatively is given in table 2. The benefit was for the many procedures with minimal EBL and low rates of transfusion, but for which routine type and screen is performed nonetheless (*e.g.*, because sample sizes were too low for accurate quantification of the incidence of transfusion*[10–16]). Our approach relies on the median EBL for the procedure only to the extent that this identifies procedures with minimal EBL. Then, the observed incidences of transfusion are used for the MSBOS recommendation.

The economic value of choosing type and screen systematically likely exceeds the published $30 cost per test.[30] Recently, Katz *et al.* evaluated preoperative testing, recommended that hospitals screen for unnecessary tests, and recommended further investigation whether the benchmarked value to compare providers can be the percentage of patients with at least one unnecessary test.[1] Tsai's and Polk's subsequent Letter to the Editor emphasized the need to reduce variability in preoperative testing among providers.[31] However, the cost of implementing lean six sigma management processes to reduce unnecessary tests is mostly, if not entirely, a fixed cost (*i.e.*, same whether one targets one or many preoperative tests). Thus, the economic value of implementing processes to reduce the incidence of unnecessary preoperative tests is increased by scientific understanding of when use of each test is appropriate.[31]

The EBL was not entered for many of the cases and a limitation is that this incidence may vary among hospitals. In most anesthesia information management systems, "minimal" is not an entry option, as the field requires a number. Providers enter some very small number (*e.g.*, 10 ml) that could not possibly have been measured (at least in adults), or skip the entry. The MSBOS should be used as a recommendation, with treatment of each patient based on clinical information (*e.g.*, the patient's preoperative hemoglobin and/or recent administration of anticoagulants).

Our results are not meant to suggest that type and screen is appropriate for all procedures with nonminimal median EBL. Among the 160,207 cases studied, only 2.7% received transfusion with 1 unit or more. Since the current type and screen rate was 43.7% (table 1), likely this incidence could be reduced far more than we calculated for procedures with minimal median EBL. There is a balance between type and screen for many cases *versus* having a patient undergoing a procedure with a very low incidence of transfusion who has large blood loss and O-negative blood is used.

There have recently been multiple studies indicating that for many procedures with nonminimal median EBL (*e.g.*, major thoracic surgery), erythrocyte transfusion of patients with 1 or 2 units provides no clinical benefit or causes harm.[32–37] These findings may substantially reduce the percentage of patients receiving transfusion, because, in most circumstances, only 1 or 2 units are administered. A consequence of such a change would be that the transfusion threshold for the median EBL of 50 ml would progressively be larger and more cases and procedures would no longer be included in the MSBOS for type and screen. We think that the benefit of our study is the creation of a framework for taking advantage of such gains in the future. Fortuitously, our framework (table 2) turns out to be simple statistically and should be easy for other hospitals to apply.

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Appendix: Scheduled Procedures with Median EBL of at Least 50 ml but Less Than 500 ml

The lower 95% confidence limit for the incidence of erythrocyte transfusion was more than 5.0% among cases of procedures with median EBL equal to 50 ml. In addition, the incidence of transfusion increased with larger median EBL (fig. 1). Therefore, among patients undergoing procedures with median EBL of 50 ml or larger, the only way to identify patients who have an individual risk less than 5.0% of transfusion was to use another predictor besides EBL. The first such variable we examined was whether the hemoglobin was checked preoperatively (see section Scheduled Procedures with Minimal Median EBL [Less Than 50 ml]). Among procedures with 19 or more cases per procedure and median EBL less than 50 ml, cases with the hemoglobin checked preoperatively had an incidence of transfusion of 0.49%, much larger than the 0.03% incidence among cases without preoperative hemoglobin checked ($P < 0.0001$). Controlling for procedure as a fixed effect in logistic regression, checking the hemoglobin preoperatively increased the odds of transfusion by 43% ($P < 0.0001$, 95% CI 1.21–1.70). We thus relied on the hemoglobin being checked as a marker for the median EBL equaling at least 50 ml but less than 500 ml.

There was a clinically relevant association between the procedure's incidence of transfusion and median EBL, among procedures with 50 ml or less median EBL less than 500 ml (fig. 1). Among the 100 procedures with median EBL equal to 50 ml, totaling 15,223 cases, there was transfusion for 5.3% of cases, with lower 95% confidence limit = 5.02%. In contrast, among the seven procedures and 1,547 cases with median EBL equal to 500 ml (*e.g.*, total hip revision code 1176), the observed incidence of transfusion was 32%, with lower 95% confidence limit of 29%.

Our objective was to identify cases with a probability of transfusion less than 5.0%. Therefore, we limited consideration to procedures with median EBL of at least 50 ml but less than 500 ml and at least 19 or more cases without the hemoglobin checked preoperatively. There were 1,815 such cases spanning 37 procedures. We created a random intercept (Bayesian) logistic regression model, the same as above in section Scheduled Procedures with Minimal Median EBL (Less Than 50 ml), but also including a linear function|||||| of the median EBL. The procedure's median EBL was obtained using all cases for the procedure, not just the cases without hemoglobin checked, based on the results of the preceding paragraph.

Among the 37 procedures studied, there was perfect concordance between the Bayesian estimate more than 5.0% and the observed (sample) incidence more than 5.0%, and *vice versa*. Specifically, for the 10 procedures with Bayesian estimate more than 5%, the observed (sample) incidences were more than 5%. The opposite held for all of the other 27 procedures. There was perfect concordance§§ for the observed (simple) incidence, as compared with the 95% lower confidence limit for the incidence in section Scheduled Procedures with Minimal Median EBL (Less Than 50 ml), because, by definition, the *a priori* probability of transfusion was larger than for the preceding category of median EBL less than 50 ml.

|||||| logit(transfuse) = procedure + β (median EBL). To determine the best functional model of the median EBL, the sample size of 1,815 values was small. All the data were used to determine the median EBL for each procedure. We then studied the 36,263 cases with a preoperative hemoglobin measured and median EBL at least equal to 50 ml but less than 500 ml. Five categories were produced with different hemoglobin: 5.8–9.9 g/dl, 10.0–10.9 g/dl, 11.0–11.9 g/dl, 12.0–12.9 g/dl, 13.0–13.9 g/dl, and 14.0 g/dl or greater. For each hemoglobin range, the deviance was calculated using transformations of the median EBL: X^{-2}, X^{-1}, $X^{-0.5}$, ln(X), $X^{0.5}$, X^1, and X^2. Averaging among hemoglobin categories, the deviance was least for a linear function of the median EBL. Generally, hemoglobin would not be checked for patients when expected to be normal. Among patients with preoperative hemoglobin 12.0 g/dl or larger, the deviance was least for a linear function of the median EBL for all but the hemoglobin category of 13.0 to 13.9 g/dl for which quadratic was significantly less $P = 0.0081$, but not with correction for the 18 comparisons. Based on these results, we used a linear function of median EBL.

Two observations suggest the novelty of our findings. First, among the 27 procedures for which type and screen would not be recommended, the hospital's MSBOS included type and screen for 85% (n = 23/27 procedures, 95% lower CL more than 69%). Second, among cases without prior surgery within 30 days (see table 1, footnote *), 64% had type and screen performed and were not transfused (n = 843/1,316 cases, lower 95% confidence limit 62%).

However, the usefulness of the observation for clinical practice was limited,§§ because for only 6.9% of cases of a procedure with median EBL of at least 50 ml but less than 500 ml was the hemoglobin not checked preoperatively (n = 2,686/38,949). During the study period, there were a total of 51,322 cases for which type and screen was performed, among cases without prior surgery. By definition, this count included all patients transfused. If the 843 type and screen had not been performed, there would have been a 1.6% reduction in type and screen at the hospital for elective surgery (n = 843/51,322, lower 95% confidence limit 1.6%). This is in addition to, but much smaller than, the 30% reduction among procedures with minimal median EBL described in section Scheduled Procedures with Minimal Median EBL (Less Than 50 ml).

Finally, also in section Scheduled Procedures with Minimal Median EBL (Less Than 50 ml), we showed that the two procedures with minimal median EBL and lower 95% confidence limit for the incidence of transfusion more than 5.0% both had mean erythrocyte units transfused (*i.e.*, the "transfusion index") of more than 0.50 units. In contrast, among cases without preoperative hemoglobin checked and median EBL at least equal to 50 ml but less than 500 ml, only one of 10 procedures with Bayesian incidence of transfusion more than 5% (*i.e.*, observed incidence more than 5%) had mean (transfusion index) of more than 0.50. Among the other nine procedures, the mean ranged from 0.09 units to 0.19 units. Thus, the criterion of type and screen based on the mean (transfusion index) fails for moderate to large median EBL.