ORGANIZATION AND QUALITY SYSTEMS IN TRANSFUSION MEDICINE

Original article

Transfusion risk assessment for cesarean delivery: a preoperative tool to guide blood utilization

Rosa F. Drummond[1], Jane Quackenbush[2], Lauren Bernard[2], Yasmin Hasbini[1], Katharine Zhu[2], Michael Plazak[3], Allison Lankford[1]

[1]*Department of Obstetrics, Gynecology, and Reproductive Sciences, University of Maryland School of Medicine and Medical Center, Baltimore, MD, United States of America;*
[2]*University of Maryland School of Medicine and Medical Center, Baltimore, MD, United States of America;*
[3]*Department of Pharmacy, University of Maryland Medical Center, Baltimore, MD, United States of America*

Background - Cesarean delivery is performed in approximately one-third of pregnancies in the United States and is associated with an increased risk of intrapartum and postpartum hemorrhage. Routine crossmatching of blood for all cesarean deliveries requires substantial resources and may not be necessary for every patient. We aimed to identify preoperative and intrapartum predictors of intraoperative blood transfusion and develop a practical risk stratification tool to support perioperative blood preparation.

Materials and methods - We conducted a retrospective cohort study including 3,033 cesarean deliveries performed at a university medical center between 2018 and 2022. Multivariable logistic regression with bootstrap internal validation (10,000 replicates) was used to derive a weighted transfusion risk score. Model performance was assessed by discrimination and calibration across predefined risk groups.

Results - Intraoperative transfusion occurred in 114 cases (3.8%). Independent predictors were placenta previa (aOR 5.14), prior blood transfusion (aOR 4.18), preoperative hemoglobin <11 g/dL (aOR 3.06), suspected intraamniotic infection (aOR 2.43), cervical dilation ≥6 cm (aOR 2.33), uterine fibroids (aOR 2.23), vaginal bleeding (aOR 2.04), and multifetal gestation (aOR 1.83) (all p<0.05). The model demonstrated good discrimination (AUC 0.75). The risk score stratified patients into low-, medium-, and high-risk groups with observed transfusion rates of 2.1%, 5.4%, and 15.1%, closely matching predicted probabilities of 2.1%, 5.8%, and 15.0%, respectively. Using a cut-off score of 4, specificity (91.7%) and negative predictive value (97.4%) were high, whereas sensitivity (37.7%) and positive predictive value (15.4%) were low.

Discussion - This simple risk score, based on routinely available preoperative and intrapartum factors, may help identify patients at low risk for intraoperative transfusion, allowing more selective blood preparation, improved resource allocation, and more efficient utilization of blood products during cesarean delivery while supporting individualized clinical decision-making.

Keywords: *blood utilization, cesarean delivery, crossmatch, postpartum hemorrhage, transfusion.*

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Correspondence: Rosa Drummond
e-mail: rdrummond@som.umaryland.edu

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INTRODUCTION

Postpartum hemorrhage (PPH) remains one of the leading causes of severe maternal morbidity and mortality (SMM) worldwide and is a major driver of blood product utilization in obstetrics[1,2]. Cesarean delivery, which accounted for nearly one-third of births in the United States in 2023, carries an increased risk of intraoperative blood loss compared with vaginal delivery[3,4]. While transfusion can be lifesaving, inappropriate or unanticipated utilization contributes to increased maternal morbidity, blood bank strain, and hospital costs. The decision to transfuse blood during cesarean delivery (CD) is nuanced, and identifying patients who require packed red blood cells (pRBCs) to be immediately available in the operating room remains challenging.

There are three strategies for pRBC transfusion preparation. Teams can send a type and screen, perform an electronic crossmatch, or request crossmatched blood be brought to the operating room. Local practices may require different levels of preparedness, and standardized protocols generally involve a PPH prediction tool. However, these tools can under or overestimate a patient's risk, resulting in unpreparedness or desensitization to high risk scores[5]. At some hospitals, if a patient is deemed at high risk of postpartum hemorrhage, the patient may be recommended to deliver at a center with access to a large blood bank. Alternatively, if a patient is flagged as low risk of PPH, the actual risk of morbidity from acute blood loss anemia and need for pRBC transfusion may be different.

Tools such as the California Maternal Quality Care Collaborative (CMQCC) hemorrhage risk score have demonstrated value in predicting hemorrhage, though they are not specific to transfusion risk at the time of CD[6]. Identifying reliable predictors of intraoperative transfusion may improve preoperative planning, guide crossmatch and blood bank allocation, and allow for targeted interventions such as antenatal anemia treatment.

We sought to identify preoperative and intrapartum risk factors that are associated with patients undergoing intraoperative pRBC transfusion and develop a risk stratification tool to guide perioperative blood allocation during cesarean delivery.

MATERIALS AND METHODS

We conducted a retrospective cohort study of all cesarean deliveries performed at a single tertiary-care university medical center between January 1, 2018, and December 31, 2022. Cases were excluded if there was preoperative concern for placenta accreta spectrum disorder, cesarean delivery occurred outside the labor and delivery operating room (labor room, intensive care unit, or main operating room), or if the fetus was nonviable (defined as intrauterine fetal demise or anomalies precluding neonatal resuscitation). Cases were identified using Current Procedural Terminology (CPT) codes, and each chart was individually reviewed by study staff to ensure eligibility and accuracy of data abstraction. There was no missing data pertinent to our results.

During the study period, there was not a standardized transfusion protocol for patients undergoing cesarean delivery. Preoperative and intrapartum risk factors were reviewed, including starting hemoglobin. Two units of crossmatched packed red blood cells were available in the operating room for every patient. Standard postpartum intravenous oxytocin was administered to each patient. Additional uterotonics (methylergonovine, carboprost, and misoprostol) were available as needed, as well as uterine balloon tamponade/vacuum devices. Intraoperative viscoelastic testing was not used during the study period, and cell salvage techniques were rarely used. The anesthesiology team administered transfusion of packed red blood cells according to clinical status, incorporating quantitative blood loss, hemodynamic stability, and starting hemoglobin values.

We collected demographic characteristics, medical and surgical history, obstetric history, antepartum and intrapartum courses, perioperative and postoperative courses, and operative findings through manual chart review. The primary outcome was intraoperative transfusion of packed red blood cells. The decision to transfuse was made at the discretion of the operative surgical and anesthesiology teams. Transfusion of additional blood products and components (plasma, platelets, cryoprecipitate, fibrinogen concentrate) were not assessed.

Patients who received intraoperative pRBC transfusion were compared with those who did not. Continuous variables were analyzed using independent *t*-tests, and

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categorical variables using chi-square or Fisher's exact tests, as appropriate. Variables significant in univariate analysis (p<0.05) were entered into a multivariable logistic regression model. Clinically important variables (placenta previa, vaginal bleeding concerning for placental abruption, and history of intraoperative transfusion) were planned to be included regardless, however each was significant in the univariate analysis. Collinearity among predictor variables was assessed using the Variance Inflation Factor (VIF), and a value >5 was considered to indicate collinearity. Continuous predictors were categorized based on statistically significant thresholds for inclusion in the regression model. Internal validation was performed using bootstrap resampling with 10,000 replicates drawn with replacement. Regression coefficients, adjusted odds ratios (aORs), and corresponding 95% confidence intervals (CIs) were calculated. Model discrimination was evaluated using a receiver operating characteristic (ROC) curve.

A transfusion risk score was derived from weighted regression coefficients, with points assigned according to coefficient magnitude. Observed transfusion rates were then compared with predicted probabilities across the score spectrum. For clinical applicability, patients were stratified into low risk (<5%, 0-2 points), medium risk (5-9.9%, 3 points), and high risk (≥10%, ≥4 points) groups. ROC curve analysis was also used to evaluate the performance of the risk score.

Quantitative blood loss was compared between groups using the Mann-Whitney U test given its non-normal distribution.

Analyses were performed using R statistical software (version 4.6.0; R Core Team, 2026)[7]. Institutional Review Board (IRB) approval was obtained from University of Maryland Medical Center (HP-00107599).

Study data were collected and managed using REDCap electronic data capture tools at University of Maryland[8,9].

RESULTS

During the study period, 3,268 cesarean deliveries were performed. After applying exclusion criteria, 3,033 cases were included in the final cohort (**Figure 1**). Excluded cases were placenta accreta spectrum disorders (No.=146), deliveries performed outside the labor and delivery operating room (No.=46), and deliveries of nonviable fetuses (No.=43).

Overall, 3.8% of patients (114/3,033) required intraoperative packed red blood cell transfusion. Patients who received transfusion were older than those who did not (mean 32.5 years *vs* 30.8 years, p=0.003). No significant differences were observed in race, body mass index, parity, history of hypertensive disorders of pregnancy, diabetes mellitus, coagulopathy, or number of prior cesarean deliveries. The incidence of transfusion was not significantly different between scheduled and intrapartum cesarean deliveries (3.2% *vs* 4.3%, p=0.12). Gestational age at delivery was similar between groups (mean 36 weeks), and transfusion rates did not differ when stratified by gestational age (**Table I**).

Several preoperative characteristics were associated with increased rates of intraoperative pRBC transfusion. Placenta previa was strongly associated with increased transfusion (8% *vs* 1.4%, p<0.0001). Preoperative hemoglobin level was significantly lower among transfused patients (9.8 g/dL *vs* 11.1 g/dL, p<0.001). Anemia in pregnancy is defined as hemoglobin <11 g/dL, and was present in 74% of transfused patients compared with 45% of non-transfused patients (p<0.001). A history of prior blood transfusion (27% *vs* 8%, p<0.001), multifetal gestation (6.3% *vs* 3.5%, p=0.01), and the presence of uterine fibroids (18% vs 10%, p=0.005), particularly large fibroids ≥5 centimeters (70% *vs* 29%, p=0.0001) were all associated with increased rates. A history of abdominal surgery other than cesarean delivery was also more common among transfused patients (27% *vs* 18%, p=0.01).

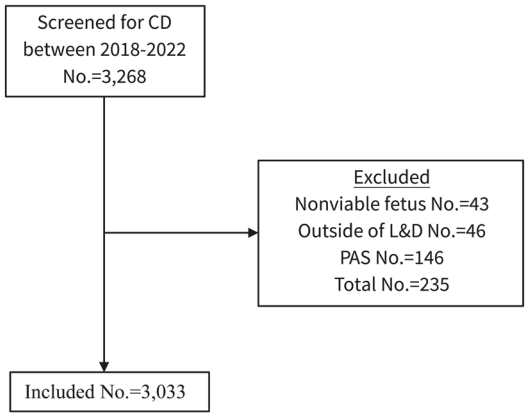


Figure 1 - Flowchart of final cohort
CD: cesarean delivery; PAS: placenta accreta spectrum.

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Table I - *Baseline and operative characteristics of patients who underwent CD*

Characteristic	Blood transfusion (No.=114)	No blood transfusion (No.=2919)	p-value
Age (years)	32.5 (6)	30.8 (6)	0.003[a]
≥35	39 (34)	846 (29)	0.22[b]
Race			
Black	67 (58)	1,711 (59)	0.71[b]
White	28 (25)	815 (28)	
Asian	4 (4)	94 (3)	
Other	15 (13)	299 (10)	
BMI	35.8 (10)	35.9 (9.3)	0.91[a]
<30	38 (33)	786 (27)	0.29[b]
30-39.9	47(41)	1,371 (47)	
≥40	29 (26)	762 (26)	
Parity	1.4 (1.5)	1.3 (1.4)	0.46[a]
0	41 (36)	1,023 (35)	0.55[b]
1	32 (28)	865 (30)	
2	21 (18)	527 (18)	
3	8 (7)	298 (10)	
≥4	12 (11)	206 (7)	
Number of fetuses			
Singleton	98 (86)	2,683 (92)	0.01[b]
Twins/triplets	16 (14)	236 (8)	
Preoperative Hb	9.8 (1.6)	11.1 (1.4)	<0.0001[a]
<11 g/dL	84 (74)	1,308 (45)	<0.0001[b]
Prior CD	0.75 (1)	0.73 (1)	0.83[a]
0	63 (55)	1,612 (55)	0.82[b]
1	31 (27)	760 (26)	
2	10 (9)	345 (12)	
3	7 (6)	147 (5)	
≥4	3 (3)	55 (2)	
Other abdominal surgery (≥1)	31/114 (27)	525 (18)	0.01[b]
Laparoscopy only	11/31 (35)	305/525 (58)	0.01[b]
Laparotomy	16/31 (52)	119/525 (23)	0.001[b]
Hypertensive disorder of pregnancy	39 (34)	1,182 (40)	0.18[b]
Diabetes mellitus	20 (18)	581 (20)	0.54[b]
Coagulopathy	5 (4)	63 (2)	0.11[b]
Vaginal bleeding	17 (15)	145 (5)	<0.00001[b]
Fibroids	20 (18)	280 (10)	0.005[b]
Large (≥5 cm)	14/20 (70)	82/280 (29)	0.0001[b]
Large and n≥3	6/20 (30)	26/280 (9)	0.004[b]
Small and n≥3	3/20 (15)	46/280 (16)	0.87[b]
Placenta previa	11 (10)	41 (1.4)	<0.0001[b]
Intraamniotic infection suspected	9 (8)	102 (3.5)	0.014[b]
History of transfusion	31 (27)	225 (8)	<0.0001[b]

Characteristic	Blood transfusion (No.=114)	No blood transfusion (No.=2919)	p-value
Timing of CD			
Scheduled	50 (44)	1,497 (51)	0.12[b]
Laboring	64 (56)	1,422 (49)	
Cervical dilation in labor	4.9 (3)	4.3 (3)	0.12[a]
≥6 cm	44/64 (69)	415/1,422 (29)	<0.00001[b]
Hours in labor	20 (18)	17 (17)	0.17[a]
≥24	26/64 (41)	418/1,422 (29)	0.054[b]
GA (weeks)	36 (29)	36 (25)	0.90[a]
<28	9 (8)	124 (4)	0.11
28-33	20 (18)	391 (13)	
34-36	21 (18)	514 (18)	
≥37	64 (56)	1,890 (65)	
Indication for CD			
Scheduled primary	22	598	0.76[b]
Scheduled repeat	30	921	0.24[b]
Failed IOL	8	142	0.30[b]
Arrest of dilation	4	86	0.58[c]
Arrest of descent	4	68	0.34[c]
Arrest disorder	8	154	0.42[b]
Failed operative delivery	0	7	1.0[c]
NRFHT remote from delivery in labor	21	441	0.33[b]
NRFHT as antepartum, no labor	1	72	0.52[c]
Presented in labor in setting of 1 CD, declined TOLAC	1	65	0.52[c]
Presented in labor in setting of 2 CD, declined TOLAC	2	47	0.71[c]
Presented with labor in setting of >2 CD	4 (3.5)	32 (1.1)	0.04[c]
Labor, fetal malpresentation	7	185	0.93[b]
Placental abruption	5 (4.4)	42 (0.8)	0.03[c]
Maternal request during labor/IOL	3	113	0.80[c]
QBL (mL)	2,208 (1,489-2,880)	800 (545-1,000)	<0.001[a]

Mean (SD) independent *t* test ([a]); No. (%) chi square ([b]) or Fisher's exact test ([c]). BMI: body mass index in kg/m2, CD: cesarean delivery, GA: gestational age, IOL: induction of labor, NRFHT: non reassuring fetal heart tracing, TOLAC: trial of labor after cesarean, QBL: quantitative blood loss.

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Intrapartum characteristics associated with increased transfusion risk included suspected intraamniotic infection (8% *vs* 3.5%, p=0.01) and cervical dilation ≥6 centimeters (the definition of the active stage of labor) (69% *vs* 29%, p<0.0001). However, the mean cervical dilation at delivery was not significantly different between groups (4.9 cm *vs* 4.3 cm, p=0.12).

Regarding indication for cesarean delivery, clinical concern for placental abruption (4.4% *vs* 0.8%, p=0.03) and presentation in labor with history of two or more prior CDs (3.5% *vs* 1.1%, p=0.04) were significantly associated factors. Vaginal bleeding in the setting of placenta previa or concerning for placental abruption was associated with increased transfusion rates (15% *vs* 5%, p<0.001).

In multivariable logistic regression analysis with bootstrap internal validation, independent predictors of intraoperative transfusion included placenta previa (aOR 5.14, 95% CI 2.21-10.41, p<0.001), prior blood transfusion (aOR 4.18, 95% CI 2.56-6.66, p<0.001), preoperative hemoglobin <11 g/dL (aOR 3.06, 95% CI 1.98-5.10, p<0.001), suspected intraamniotic infection (aOR 2.43, 95% CI 1.15-5.12, p=0.02), cervical dilation ≥6 cm (aOR 2.33, 95% CI 1.35-3.74, p<0.001), uterine fibroids (aOR 2.23, 95% CI 1.22-3.64, p=0.002), vaginal bleeding (aOR 2.04, 95% CI 1.05-3.53, p=0.02), and multifetal gestation (aOR 1.83, 95% CI 1.02-3.92, p=0.04) (**Table II**). Collinearity diagnostics indicated no concern in the final regression model, as VIF values ranged from 1.01-1.21. Bootstrap resampling demonstrated stable coefficient estimates with consistent directionality across predictors. The model demonstrated an apparent area under the ROC curve (AUC) of 0.74 (95% CI 0.70-0.79) (p<0.0001) (**Figure 2**), while the optimism-corrected AUC was 0.73. The calibration slope was 0.9912, calibration intercept was 0.0032, and Brier score was 0.0331 (*Online Supplementary* **Figure S1**).

A transfusion risk score was generated from weighted regression coefficients and categorized into three groups: <5% risk of transfusion (0-2 points), <10% risk of transfusion (3 points), and ≥10% risk of transfusion (≥4 points) (**Table III**). The transfusion risk score demonstrated an equivalent discrimination to the full

Table II - *Multiple logistic regression of significant preoperative and intrapartum factors associated with a need for transfusion*

Characteristic	Regression coefficients	Adjusted odds ratio (95% CI)	p-value	Points
Placenta previa	1.64	5.14 (2.21-10.41)	<0.001	3
History of blood transfusion	1.43	4.18 (2.56-6.66)	<0.001	2
Preoperative Hb <11 g/dL	1.11	3.06 (1.98-5.10)	<0.001	2
Intraamniotic infection suspected	0.89	2.43 (1.15-5.12)	0.02	1
Dilation ≥6 cm	0.87	2.33 (1.35-3.74)	<0.001	1
Fibroids	0.77	2.23 (1.22-3.64)	0.002	1
Vaginal bleeding	0.70	2.04 (1.05-3.53)	0.02	1
Multifetal gestation	0.60	1.83 (1.02-3.92)	0.04	1

Estimates are based on bias-corrected and accelerated bootstrap resampling with 10,000 replicates. Points weighted based on regression coefficients.

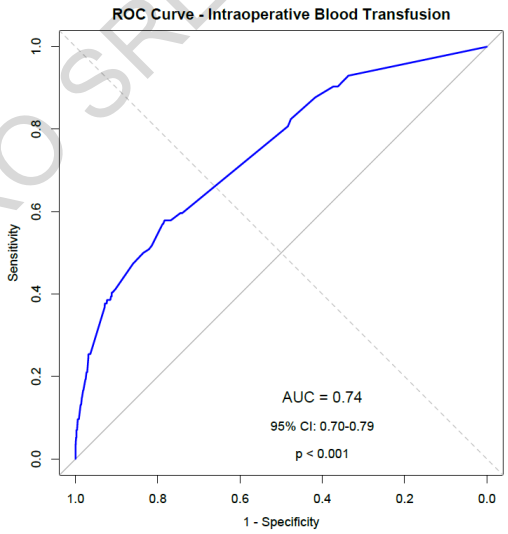


Figure 2 - ROC curve for the risk of blood transfusion - preoperative and intrapartum risk factors

Table III - *Transfusion rates in three risk groups*

Category of risk	Transfusions	Transfusion rate	Mean predicted probability of transfusion (%)
0-2 points <5% (No.=2,361)	50	2.1%	2.1%
3 points <10% (No.=388)	21	5.4%	5.8%
≥4 points ≥10% (No.=284)	43	15.1%	15.0%

The rate of transfusion in three different groups (<5%, <10%, and ≥10% rate of transfusion) was similar to the mean predicted probability of transfusion of the model.

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logistic regression model (AUC of 0.74, 95% CI 0.69-0.79) (p<0.0001). Predicted and observed transfusion rates were similar across all risk categories: low-risk group (2.1% *vs* 2.1%), medium-risk group (5.8% *vs* 5.4%), and high-risk group (15.1% *vs* 15%) (**Table III**).

Using a threshold of ≥4 points to identify patients at high risk for transfusion, the score demonstrated a sensitivity of 37.7%, specificity of 91.7%, positive predictive value of 15.3%, and negative predictive value of 97.4%. Given the low overall transfusion prevalence of 3.8%, the score showed high specificity and negative predictive value, indicating good ability to identify patients unlikely to require transfusion.

Median quantitative blood loss was significantly higher among patients who required intraoperative transfusion (2,208 mL [Q1-Q3 1,489-2,880]) compared with those who did not (800 mL [Q1-Q3 545-1,000], p<0.001).

DISCUSSION

We identified a set of preoperative and intrapartum risk factors significantly associated with the risk of intraoperative transfusion of packed red blood cells: placenta previa, history of any prior blood transfusion, anemia, suspected intraamniotic infection, cervical dilation ≥6 cm, uterine fibroids, vaginal bleeding at time of delivery, and multifetal gestation. We developed a weighted risk stratification tool, the Transfusion Risk Assessment (TRA), to help guide blood utilization practices. The actual transfusion rate in our cohort and predicted probabilities were similar.

In this study, 3.8% of patients received an intraoperative packed red blood cell transfusion. This is similar to a rate of 3.9% reported by Bruno *et al.* when analyzing 10,785 patients[10]. Our model demonstrated moderate discrimination (AUC 0.74) and was successfully converted into a clinically applicable transfusion risk score illustrated by low, medium, and high risk groups. The TRA demonstrated high specificity (91.7%) and a high negative predictive value (97.4%), indicating strong performance in identifying patients unlikely to require intraoperative pRBC transfusion using a cut-off value of 4. In contrast, sensitivity was low (37.7%), suggesting that a substantial proportion of patients who ultimately received transfusion would not have been identified as high risk. The positive predictive value was 15.3%, which is expected given the low overall transfusion prevalence of 3.8% in the study population. Importantly, predicted and observed transfusion rates were closely aligned across all risk categories, supporting good calibration of the model. These findings suggest that the TRA may be most useful as a tool for identifying patients at low risk for transfusion. These findings support the potential role of transfusion-focused risk assessment as a complement to existing hemorrhage risk stratification strategies.

Our findings regarding anemia are consistent with population-level obstetric transfusion data. In a nationwide analysis of over six million vaginal and cesarean deliveries in Germany, Kloka *et al.* reported a 1.2% rate of pRBC transfusion along with a 70% rate of anemia[11]. In our cohort, preoperative anemia was similarly one of the strongest independent predictors of intraoperative transfusion (aOR 3.06), occurring in 74% of transfused patients compared with 45% of non-transfused patients. The consistent association between maternal anemia and transfusion risk across diverse cohorts supports the importance of antenatal anemia identification and treatment.

Albright et al developed a tool that identified placenta previa and HELLP syndrome as strong predictors of transfusion (final model AUC of 0.82), while Ahmadzia et al also emphasized the importance of antepartum hemoglobin and abnormal placentation in their model (final model AUC of 0.77)[12,13]. However, the data analyzed are over 20 years old and the obstetric population has become increasingly medically and surgically complex. Our study adds to the literature by confirming these risk factors in an independent population and by identifying additional characteristics. Our transfusion risk assessment is easy to use as it provides a simple point system. The California Maternal Quality Care Collaborative (CMQCC) categorical risk tool is a well-known model used by many hospital systems to stratify risk of postpartum hemorrhage and guide blood typing and crossmatching strategies[14]. However, this toolkit primarily focuses on risk of hemorrhage, not specifically intraoperative transfusion. The TRA provides a more targeted approach by incorporating multiple risk factors that may otherwise be overlooked and concentrating on intraoperative transfusion at cesarean delivery, a clinical outcome with direct implications for blood bank utilization.

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Packed red blood cells are a finite hospital resource, and obstetric hemorrhage represents one of the most unpredictable and resource-intensive drivers of transfusion demand[15-17]. Hospitals must balance the immediate, often large volume requirements of massive obstetric hemorrhage against competing surgical and medical needs. At our hospital, we currently request crossmatched blood to be available in the operating room during every cesarean delivery. While this errs on the side of safety for the index patient and may save time in institutions where acquiring blood emergently is challenging, this is resource intensive, costly, and actually may create delays in surgery in other centers. While the TRA was not designed to be used as a strict algorithm across all centers, it is intended as a tool for preoperative risk communication and identification of patients who are unlikely to require intraoperative transfusion. Because blood bank resources, staffing, turnaround times, and transfusion practices vary substantially among institutions, the way this information is incorporated into clinical workflows will likely differ between centers[18,19]. Following external validation, the TRA may assist institutions in developing center-specific strategies for blood product preparedness and resource allocation. The transfusion risk score is intended to be reassessed during labor and re-evaluated prior to moving forward with cesarean delivery as risk factors may change during labor. In facilities without 24-hour on-site blood banks, the TRA may help identify patients who are unlikely to require transfusion and therefore may be appropriate for delivery at community hospitals[20].

While this model was derived from a large cohort at a high-volume tertiary care center, external and prospective validation is necessary before widespread implementation. The TRA should therefore be viewed as a risk stratification and communication tool rather than a fixed protocol. Future studies should evaluate how incorporation of the score into diverse clinical settings affects blood product utilization, patient outcomes, and healthcare costs. Although reducing unnecessary crossmatching and blood product waste may be cost saving, unanticipated transfusions and emergency acquisition of blood products may also increase resource utilization. Prospective cost-effectiveness analyses will be important to define the optimal role of the TRA in clinical practice.

Strengths of this study include a large tertiary-center cohort, examination of multiple variables, and a simple scoring system. However, as a single-center retrospective study, generalizability may be limited. The decision to transfuse intraoperatively was at the discretion of the anesthesiology teams, so this scoring system based on retrospective data may partly reflect clinician behavior rather than only bleeding physiology. Additionally, having crossmatched blood immediately available in the operating room may influence the probability and timing of transfusions, and this may be different depending on an individual center's practice. As such, our findings lack external validation and may not be generalizable to different centers with different populations, blood bank infrastructure, and transfusion practice. However, the QBL was significantly higher in the transfused group, objectively confirming the high risk nature of this group. Provider discretion in pRBC transfusion remains critical. Of note, patients with preoperative concern for placenta accreta spectrum disorder (PAS) were excluded from this analysis. Patients with suspected PAS are at the highest risk of obstetric hemorrhage, and should be managed at a tertiary facility with a robust blood bank regardless of any other risk factors[21].

CONCLUSIONS

We developed a simple Transfusion Risk Assessment (TRA) for preoperative risk stratification of intraoperative packed red blood cell transfusion during cesarean delivery. The model demonstrated moderate predictive performance and identified several clinically relevant risk factors associated with transfusion. A score of less than four may suggest a low likelihood of pRBC transfusion. Although external and prospective validation is required before clinical implementation, the TRA may provide a useful framework for risk communication and blood management planning. Following validation, transfusion-focused risk stratification may complement existing hemorrhage risk assessment tools and support efforts to optimize blood product preparedness and utilization. These findings emphasize the importance of evidence based transfusion practices and highlight opportunities for improved blood utilization management in obstetrics.

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Authors' contributions

RD performed data collection, performed data analysis, and wrote the manuscript. JQ, LB, YH, and KZ performed data collection and assisted with the manuscript writing. MP performed data analysis and assisted with manuscript writing. AL conceived of the project, assisted with the manuscript writing, and oversaw the project.

The Authors report no conflicts of interest.

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