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Accurate Measurement of Intraoperative Blood Loss during Wound Excision Leads to More Appropriate Transfusion and Reduced Blood Utilization

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Abstract

Objective: To determine if accurate measurement of surgical blood loss using a novel device that photographs surgical sponges and calculates their hemoglobin content affects transfusion practice.

Methods: We retrospectively compared transfusion events for patients having wound excisions using visual estimation of blood loss (traditional group; n=178) to similar events following device implementation (study group; n=221).

Results: The study group (age 43 ± 22 years, body surface area burn 11.2 ± 18.0%, excision area 624, IQR 757 cm^2, preoperative hemoglobin 10.7 ± 2.4 g/dl) did not differ significantly from the traditional group (age 42 ± 23 years (p=0.527), body surface area burn 12.2 ± 22.6% (p=0.661), excision area 753, IQR 505 cm^2 (p=0.485), and preoperative hemoglobin 10.7 ± 2.2 g/dl (p=0.833).

Postoperative transfusion rates were significantly lower in the study group (6.3% *vs.* 12.9%; p=0.024), as was the proportion of transfused patients undergoing multiple transfusion events (13.0% *vs.* 34.9%; p=0.01). Red cell dose (units/transfused patient) was less in the study group compared to the traditional group (1.83 ± 1.09 *vs.* 2.51 ± 1.61 units; p=0.021).

In a subgroup of patients requiring excision of burned areas ≥ 1,000 cm^2 (traditional group n=36, study group n=43), these differences were more significant. The postoperative transfusion rate fell from 44.4% to 14.0% (p=0.003), as did the percent of transfused patients experiencing multiple transfusion events (50.0% *vs.* 14.3%; p=0.004).

Conclusions: Accurate measurement of surgical blood loss was associated with a decrease in transfusions suggesting more timely decision making. Informed transfusion decisions may result in fewer transfusions by avoiding over-transfusion related to both excessive hemodilution and inaccurate visual estimates.

Keywords: Surgical blood loss; Blood transfusion; Burns

Introduction

In most clinical situations patients managed with restrictive transfusion of allogeneic red cells (lower "transfusion triggers") experience similar or better outcomes than those patients transfused more liberally [1-3]. However, while treating patients with acute surgical bleeding it can be difficult to avoid inappropriate transfusion. Anesthesiologists and surgeons typically guide transfusion decisions by assessing the amount of blood loss, the patient's hemodynamic stability and cardiac status, and also by selecting a minimally acceptable hemoglobin level based on their patient's clinical condition.

While this pre-determined value assumes that the patient is normovolemic, it is often applied in situations confounded by hemodilution or hemoconcentration due to the infusion of crystalloid and/or colloid solutions, blood product transfusion, the effects of anesthetic agents and patient temperature and position as well as blood loss. This can lead to inappropriate transfusion [4].

Visual estimates of surgical blood loss, regardless of the experience level or specialty of the clinician, are consistently inaccurate and are therefore a poor guide to proper transfusion [5-7]. Frequently, clinicians underestimate at high blood loss volumes and overestimate at low volumes [8,9]. Although simulations and training may improve providers' accuracy in blood loss estimation, the long-term retention of these skills has been shown to decay [10].

Gravimetric determination of blood loss by weighing soiled laparotomy sponges and subtracting their known dry weight has been explored (particularly in patients having cesarean deliveries) but this method is impractical for real-time intraoperative use and is easily confounded by the presence of non-sanguineous fluids [11]. Similarly, procedures for rinsing and assaying hemoglobin content from blood-absorbing media to assess intraoperative blood loss have been

described in research studies but are not feasible for routine intraoperative use [12].

A novel FDA-cleared mobile application (Triton System™, Gauss Surgical, Inc., Los Altos, CA) on a tablet computer (iPad) offers an alternative method of blood loss estimation. The enabled tablet camera captures images of surgical sponges, then uses image analysis algorithms and cloud-based machine learning to accurately estimate hemoglobin mass on the surgical laparotomy sponges in real time. The technology can also measure the hemoglobin content of fluid collected in surgical suction canisters. The performance of the device has been validated previously in bench-top and clinical settings and the results are accurate despite contamination with asanguinous fluids [13-15].

Patients with burn injuries present a unique blood management challenge [16]. Multiple excision and grafting procedures are common and may lead to several extensive blood loss events during a single hospitalization. Moreover, severe burn injuries are characterized by significant hemolysis, rapid fluid shifts and activation of inflammation and coagulation pathways potentially leading to coagulation system dysfunction and continued bleeding [17]. Because of these considerations burn patients were selected as an ideal population to study the impact of the novel system on red cell transfusion practice [18,19].

The objective of this study was to determine how accurate, real-time measurement of blood loss would affect transfusion practice in patients requiring burn or other extensive wound excisions. A cohort of patients in whom the system was employed was compared to a similar group treated prior to its implementation.

Methods

Study population

The investigational protocol was approved by the IRB (HS#: 2015-2418) at the University of California Irvine School of Medicine. As a retrospective chart review, the requirement for written informed consent was waived by the IRB. Burn and other wound excision procedures before (January, 2014 to November, 2014) and after (November, 2014 to January, 2016) the introduction of the Triton System were analyzed retrospectively.

Since the transfusion practice related to a procedure could potentially affect practice during subsequent procedures on the same patient, cases less than five days from the previous intervention were excluded. The five day period was chosen since the investigator's typical policy was to wait until a patient had hemodynamically and physiologically recovered from one surgical intervention before proceeding with a subsequent excision. A five day period coupled with hemodynamic stability prior to each procedure minimizes the effect one procedure might have on a subsequent one. This resulted in 178 procedures (103 patients) in the traditional group and 221 procedures (140 patients) in the study group. There were no patients who were included in both groups.

Information in the patient's medical record that was recorded included date of surgery, patient age (years), total body surface area (BSA) (m^2), total size of burn or wound (% BSA), size of wound excised (cm^2), visually estimated blood loss (ml) and hemoglobin concentrations (g/dl) preoperatively, on the day of surgery and on postoperative days one, two and three. All packed red cell (PRBC) and component transfusions (units) given from the day of surgery through

postoperative day two were documented. Triton measurement of intraoperative blood loss (ml) on surgical sponges was recorded for patients in the study group.

Blood loss measurements

Investigators followed their standard of care for use and management of surgical sponges. In these patients almost all of the blood loss was able to be captured on the sponges with only a small amounts amassing on surgical drapes since attempts were made to use sponges to absorb that blood. Also, only minimal amounts of blood were collected in suction canisters. Surgical technique was similar in both groups. Sponges were soaked in epinephrine (1 mg/ml) at a concentration of 30 ml per liter of saline and QuickClot® Trauma pads were used to assist in hemostasis once an adequate wound bed was achieved. No additional hemostatic agents were implemented during the study period and surgical suction was minimal in both groups. Excisions were typically full thickness and tourniquets were not used.

In the traditional group (system not used) estimated blood loss was determined by consensus between the attending surgeon and anesthesiologist. Estimates were typically based on the size of the excised area and observed bleeding. In the study group all laparotomy sponges were collected during the procedure and scanned using the Triton System with Feature Extraction Technology™ (Version 2.0.9) to capture scanned images of the sponges.

This resulted in a measured amount of Hgb loss per sponge that was converted to a volumetric measure using the patient's pre-procedure Hgb value. Continuous measurement of blood loss on surgical sponges was achieved by scanning sponges as they were discarded from the surgical field and the results were provided to the surgeon and anesthesiologist and used in conjunction with other clinical information to guide transfusion decisions.

Device measurement of blood loss is illustrated in Figure 1. The blood collected in suction canisters was not measured since the surgeons attempted to capture all of the blood loss with sponges and the amount of blood in the canisters was minimal.
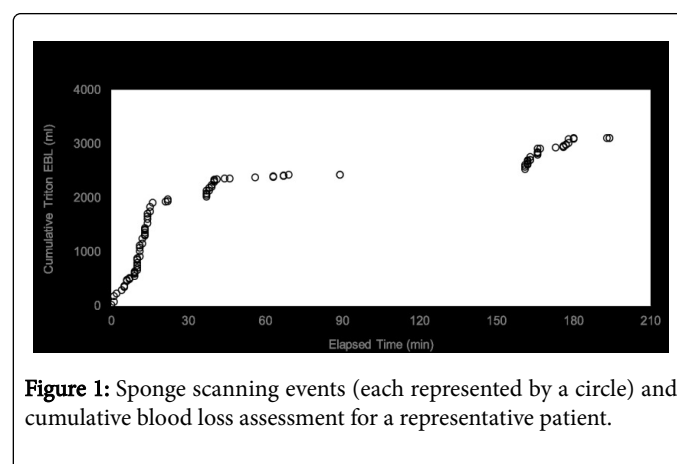

Figure 1: Sponge scanning events (each represented by a circle) and cumulative blood loss assessment for a representative patient.

Transfusion practice

In both groups an attempt was made to limit red cell transfusions and use a restrictive transfusion "trigger." In the traditional group, transfusions were given for evidence of hemodynamic instability in the presence of ongoing blood loss or when a rapidly measured

hemoglobin level was <7 g/dl. In the study group, a transfusion was considered when the measured blood loss suggested that the normovolemic hemoglobin level would be below 7 g/dl. In both groups transfusions after the day of surgery were guided by hemoglobin levels.

Statistical Analysis

Values are expressed in mean ± standard deviation (SD) or count (%0) as appropriate. Univariate analyses were performed using chi-square test, t-test, Man-Whitney U-test, and Pearson or Spearman's correlations as appropriate. Odds ratios are provided with 95% confidence interval (95% CI). To compare the transfusion rates among the study cohorts adjusted for other predictors of transfusion, logistic regression analysis was performed with transfusion as the dependent variable and study cohorts and other significant predictors of transfusion rate as the independent variables. Additionally, a subgroup analysis was performed on patients who had undergone excision of burned area ≥ 1000 cm^2.

The primary endpoint used for sample size calculation was the postoperative transfusion rate (based on the assumption that better transfusion management during the intraoperative period would results in fewer transfusions in the postoperative period).

Assuming a transfusion rate of 15% in the traditional cohort, to detect a transfusion rate of 6.5% in the study system cohort with alpha of 0.05 and power of 80% as statistically significant using uncorrected chi-square test, and assuming the availability of 6 study procedures for every 5 traditional procedures, 231 study and 192 traditional procedures are required. P values <0.05 were considered statistically significant. Statistical analyses were performed using SPSS (version 13.0, SPSS, Inc.).

Results

Demographics

The traditional group consisted of 178 procedures performed on 103 patients. In the study group (Triton) there were 140 patients who had 221 surgical interventions. The baseline characteristics of study group (age 43 ± 22 yrs., BSA burn area =11.2 ± 18.0%, excision area 624, IQR 757 cm^2, pre-op Hgb 10.7 ± 2.4 g/dl) did not differ significantly from the traditional group (age 42 ± 23 yrs (p=0.527), BSA burn area 12.2 ± 22.6% (p=0.661), excision area 753, IQR 505 cm^2 (p=0.485), and pre-op Hgb 10.7 ± 2.2 g/dl (p=0.833)).

A subgroup of procedures involving excision of burned areas ≥ 1,000 cm^2 was identified (traditional n=36, study n=43). In this subgroup the extent of burn injury was greater in the traditional group (39.9 ± 33.8% *vs.* 22.0 ± 23.6%; p=0.010), as was the area excised during each surgical procedure (traditional = 2811.7 ± 2032.6 cm^2 *vs.* study 2045.2 ± 889.6 cm^2; p=0.041).

Transfusion data

During the time period from the day of surgery through the second postoperative day, the transfusion rate (% of patients who received at least one unit of PRBC) was similar between the groups (24.2% traditional; 24.4% study; OR 0.985, 95%CI 0.622 to 1.561, p=0.949). Intraoperative transfusion rates were also similar (16.9% traditional; 19.0% study; OR 0.864, 95%CI 0.515 to 1.448, p=0.579).

Similarly, in a multivariate logistic regression analysis adjusting for other significant predictors of intraoperative transfusion, group assignment was not significantly associated with intraoperative transfusion rate (OR 1.074, 95% CI 0.402 to 2.868, p=0.888). Significant predictors of increased intraoperative transfusion rate were higher estimated or measured blood loss, larger excised area, and lower preoperative hemoglobin level.

	All Patients			**Excision ≥ 1,000 cm^2**		
	Traditional N=178	Triton N=221	p	Traditional N=36	Triton N=43	p
Total PRBC transfusion rate N (%)	43 (24.2%)	54 (24.4%)	0.949	30 (83.3%)	28 (65.1%)	0.068
Intraoperative PRBC transfusion rate (%)	30 (16.9%)	42 (19.0%)	0.579	25 (69.4%)	23 (53.5%)	0.148
Postoperative PRBC transfusion rate (%)	23 (12.9%)	14 (6.3%)	0.024	16 (44.4%)	6 (14.0%)	0.003
Total PRBC transfusion dose (units)	2.51 ± 1.61	1.83 ± 1.09	0.021	3.07 ± 1.62	2.14 ± 1.27	0.019
Postoperative Day 1 Hgb (g/dL)						
Transfused	8.30 ± 1.53	8.39 ± 1.04	0.713	8.49 ± 1.43	8.55 ± 1.11	0.859
Not Transfused	10.29 ± 1.95	10.58 ± 2.16	0.332	9.05 ± 1.47	9.800 ± 1.43	0.368

Transfusion Rate = % of patients who received at least one PRBC transfusion. Transfusion Dose = PRBC units transfused per transfused patient.

Table 1: Transfusion data.

The postoperative transfusion rate decreased during the treatment period in the traditional group but fell to 0% in the first quartile of the study group. By the final two quartiles of the study group the postoperative transfusion rate was ≤ 10%.The incidence of multiple transfusion events was relatively stable during the first three quartiles in the traditional period but fell during the fourth quartile. This rate fell to 0% during the last two quartiles in the study group. Likewise, the transfusion dose did not reach its nadir until the final quartile of the study period (Table 2 and Figure 2).

Postoperative transfusion rates were significantly lower in the study group (14 of 221 procedures (6.3%) *vs.* 23 of 178 procedures (12.9%); OR 2.194, 95% CI 1.094 to 4.402; p=0.024). In a multivariate regression analysis adjusting for age, burn wound as opposed to non-burn wound excision, patient weight, EBL, preoperative hemoglobin level and excised area, OR of postoperative transfusion for patients in traditional *vs.* study group was 3.301 (95% CI 1.367 to 7.974, p=0.008).

The proportion of transfused patients receiving RBC transfusion on multiple occasions was also significantly lower in the study group (7 of 54 or 13.0% *vs.* 15 of 43 or 34.9%; OR 3.597, 95%CI 1.308 to 9.894; p=0.010). When adjusted for the same variables as above, OR of

multiple transfusion events for patients in traditional *vs.* study group was 4.850 (95% CI 1.269 to 18.535, p=0.021).

In transfused patients, PRBC dose (units/transfused patient) was significantly less in the study group compared to the traditional group (1.83 ± 1.08 *vs.* 2.51 ± 1.61 units; p=0.021). The observed decrease in transfusions was not associated with significant change in the postoperative day 1 Hgb values in either transfused (8.30 ± 1.53 g/dl, traditional *vs.* 8.39 ± 1.04 g/dl, study; p=0.713) or non-transfused patients (10.29 ± 1.95 g/dl traditional *vs.* 10.58 ± 2.16 g/dl study; p=0.332) (Table 1).

In the subgroup of procedures involving excision of burned areas ≥ 1,000 cm^2, the rate of PRBC transfusions was 83.3% in the traditional group *vs.* 65.1% in the study group (OR 2.679, 95%CI 0.912 to 7.870; p=0.068).

The postoperative transfusion rate fell from 44.4% in the traditional group to 14.0% in the study group (OR 4.933, 95% CI 1.668 to 14.593; p=0.003). When adjusted for the same variables as above, OR of postoperative transfusion for patients in traditional *vs.* study group was 6.681 (95% CI 1.700 to 26.252, p=0.007).

Similarly, the percentage of transfused patients undergoing multiple transfusion events was 50.0% in traditional *vs.* 14.3% in the study group; OR 6.000, 95%CI 1.672 to 21.531; p=0.004). When adjusted for the same variables as above, OR of multiple transfusion events for patients in traditional vs. study group was 8.504 (95% CI 1.719 to 42.062, p=0.009). In these more complex patients, the transfusion dose was 3.07 ± 1.62 units in the traditional group *vs.* 2.14 ± 1.27 units in the study group (p=0.019) (Table 1).

A trend analysis was performed for the subgroup of procedures involving excision of burned areas ≥ 1,000 cm^2. The procedures in each group were divided into sequential quartiles based on the date of surgery. The subgroup analysis was chosen to avoid the heterogeneity found in subgroups of the entire population. For example, in the traditional group the rate of procedures involving excision of burned areas ≥ 1,000 cm^2 in consecutive quartiles fell from between 24.4% and 25.6% in the first three quartiles to 6.7 % in the final quartile potentially confounding a trend analysis of the entire group.
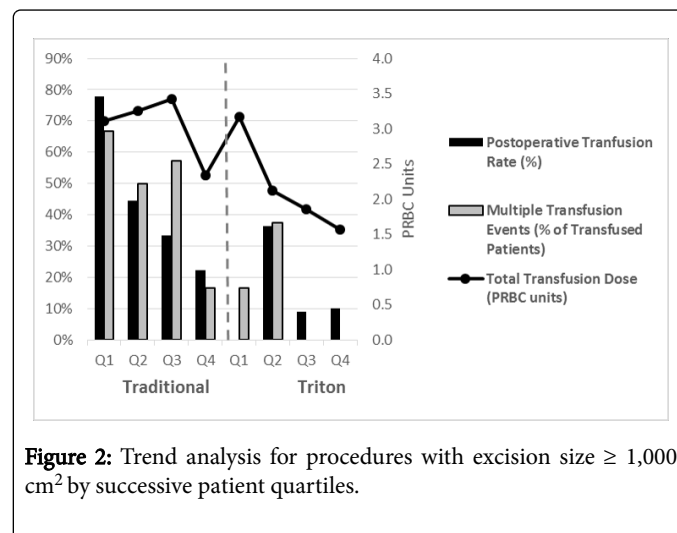

Figure 2: Trend analysis for procedures with excision size ≥ 1,000 cm^2 by successive patient quartiles.

Transfusion of blood components was similar in both groups. Fresh frozen plasma was given to 5 patients in the traditional group and 3 patients in the study group. Two patients in each group received a platelet transfusion and cryoprecipitate was not administered in either group. An average of 877 ml of crystalloid was given in the study group. For the traditional group the average amount of crystalloid given was 913 ml.

	Postoperative Transfusion Rate	Multiple Transfusion Events	Transfusion Dose (units)
Traditional (N=36)			
Quartile 1	77.8%	66.7%	3.1
Quartile 2	44.4%	50.0%	3.3
Quartile 3	33.3%	57.1%	3.4
Quartile 4	22.2%	16.7%	2.3
Triton (N=43)			
Quartile 1	0.0%	16.7%	3.2
Quartile 2	36.4%	37.5%	2.1
Quartile 3	9.1%	0.0%	1.9
Quartile 4	10.0%	0.0%	1.6
Multiple Transfusion Events = % of transfused patients transfused on multiple occasions.			
Transfusion Dose = PRBC units transfused per transfused patient.			

Table 2: Trend analysis for excisions ≥ 1,000 cm^2.

Discussion

Appropriate transfusion of packed red blood cells is difficult to define and perhaps even more difficult to achieve. In 1942 an arbitrary minimally acceptable hemoglobin level of 10 g/dl was proposed for patients requiring general anesthesia and that level became a standard for all hospitalized patients [20]. During the 1970s this "transfusion

trigger" was questioned as the rapid growth of cardiac and orthopedic surgery put increasing demands on limited transfusion resources [21].

When the public became aware of the risks of transfusion transmitted disease during the AIDS crisis, increased efforts were made to avoid unneeded transfusion and in the following years many randomized, prospective studies demonstrated that restrictive transfusion practice produced either similar or better outcomes than more liberal transfusion [1,2,22]. In addition, the cost savings associated with fewer transfusions are of increasing concern in the current era of value oriented care [23].

Despite this emphasis on restrictive transfusion, studies in both medical and surgical patients have demonstrated that anemic patients are at increased risk for morbidity and mortality [24-26]. Therefore, finding the right balance between over and under transfusion is critical. Achieving this balance in surgical patients can be particularly challenging since accurate measurement of blood loss is difficult and clinicians are forced to resort to surrogate information to inform transfusion decisions.

This study demonstrates that accurate, contemporaneous measurement of surgical blood loss changes transfusion practice. Although the percentage of patients receiving a transfusion was similar among the groups, real-time monitoring of surgical blood loss in patients cared for using the novel system was associated with reductions in postoperative transfusions, transfusion dose and multiple transfusion events, all of which could be indicative of improved transfusion decision making. Notwithstanding limitations of this retrospective study namely limited available baseline characteristics, we believe that these changes are likely related to the timing of intraoperative transfusions.

In the study group, transfusions were given when the measured blood loss suggested that normovolemic level would be below 7 g/dl. However, in the traditional group, transfusions were deferred until there was evidence of hemodynamic instability with a rapidly measured hemoglobin level<7 g/dl. This change in practice with the implementation of measured blood loss led to transfusions being given earlier to patients in the study group, reducing hemodilution and hemodynamic instability and avoiding the need for "catch up" transfusions later in the hospitalization. Timelier transfusions can also lead to improved hemostasis by avoiding dilutional coagulopathy [27].

The trend analysis demonstrates that there were changes in transfusion outcomes during the traditional period. While these changes may have been due to the emerging clinical interest in reducing transfusion another explanation is that despite limiting the trend analysis to procedures with excision areas $\geq$ 1,000 cm^2, the average excision area in the final quartile (1,575 cm^2) was significantly smaller than the excision areas in the first three quartiles (3,224 cm^2) (p=0.017). In any event, the observed changes continued through the study period and the results in the final two quartiles in the study group demonstrate that once there was clinical familiarity and confidence in the novel device, the greatest change occurred.

Resuscitation without transfusion leads to excessive hemodilution and associated volume expansion increasing the number of transfusions needed to meet the hemoglobin target. Informed transfusion decision making not only avoids hemodilution, but also aids in avoiding over-transfusion based on inaccurate over estimation of ongoing bleeding.

Both the preoperative and postoperative hemoglobin concentrations in transfused and not transfused patients were similar among the groups including the subgroups requiring more extensive procedures. This suggests (although does not rule out other possibilities) that the decrease in the transfusion dose was not due to a change in either the preoperative preparation of the patients or the transfusion trigger or target hemoglobin levels but was more likely due to avoiding excessive hemodilution and over response to inaccurate estimates of blood loss.

In addition to decreasing the total number of PRBC transfusions given, improved decision making also is associated with fewer postoperative transfusions. This change in the location of transfusion decreases the professional and logistical costs of transfusion episodes in the recovery area or nursing unit.

A limitation of this study is that it was not randomized and retrospectively compared historical data to a novel intervention. This resulted in a limited number of accessible variables including baseline characteristics and potential risk factors for the outcomes. However, this approach helped to eliminate any confounding of the visual estimations that could have occurred if the device was introduced using a random study design ("learning curve"). As providers begin to use the device, the knowledge they gain can change the way they estimate blood loss. Therefore, the accuracy of visually estimated blood loss would change during the study creating a potential confounder if a randomized design was chosen. Furthermore, there were no patients treated between the end of the traditionally treated group and the introduction of the novel system and the participating clinicians made no other changes in their clinical care or transfusion practice as evidenced by the similarity in postoperative hemoglobin levels. Treatment algorithms remained unchanged except that the measured blood loss in the study group was used to help guide intraoperative transfusions.

Another limitation is the possibility that unrecognized changes in practice patterns independent of the device could have accounted for some of the differences noted. Furthermore, it is uncertain that this experience in patients having wound excisions is applicable to other surgical situations. While the device has been shown to be accurate in estimating surgical blood loss when compared to visual estimation and a quantitative method of weighing sponges and measuring the fluid in suction canisters [28], further studies are underway to answer these and other questions related to the clinical utility of the novel device.

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