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Accurate Measurement of Intraoperative Blood Loss Improves Prediction of Postoperative Hemoglobin Levels

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Abstract

Background: Restrictive red cell transfusion is preferable to liberal transfusion in most clinical situations. However, intraoperative transfusion decisions are challenging due to uncertainty about the amount and rate of bleeding, the poor correlation of hemoglobin levels with blood loss and the effects of anesthetics on blood volume and physiologic responses. Clinicians frequently use hemoglobin levels to guide transfusion. While these "triggers" assume that the patient is normovolemic, they are often applied in situations confounded by hemodilution or hemoconcentration. We postulated that accurate measurement of surgical blood loss would facilitate prediction of postoperative hemoglobin levels, potentially leading to more accurate intraoperative transfusion decisions.

Methods: Using image-processing algorithms, a novel system accurately measures blood loss by photographing surgical sponges and canisters and calculating their hemoglobin content. A formula to predict postoperative hemoglobin levels was devised and used to calculate postoperative hemoglobin levels in a study group of 167 burn and other wound excision procedures performed on 103 patients using the system. In an historical group (100 similar procedures, 60 patients) clinician estimates of blood loss were used. These predictions were compared with actual values.

Results: The formula using measured blood loss in the study group was a better predictor of the actual postoperative day one hemoglobin value (R^2=0.822) than was the same formula using visually estimated blood loss used in the historical group (R^2=0.615). The mean absolute bias of postoperative day one hemoglobin levels in the study group was significantly lower than the mean bias in the historical group (study=group, mean 0.4, 95% CI 0.2 to 0.5 g/dL; historical group, mean 0.9, 95% CI 0.7 to 1.2 g/dL, p<0.001).

Conclusion: Blood loss measurements using the novel system are a significantly better predictor of hemoglobin values obtained after surgery than traditional blood loss estimates.

Keywords: Hemodilution; Blood loss; Surgical blood transfusion

Introduction

Restrictive red cell transfusion is preferable to liberal transfusion in most clinical situations [1-3]. Published guidelines support the use of predefined restrictive hemoglobin levels to determine the need for transfusion [4,5]. While these guidelines can be useful in normovolemic non-bleeding patients where the hemoglobin level may closely reflect the red cell mass, intraoperative transfusion decisions are more challenging. Changes in blood volume due to anesthetic agents, fluid administration, insensible losses, positioning, temperature and other factors leads to poor correlation between the measured hemoglobin and decreased red cell mass from surgical blood loss [6-8]. Moreover, both the amount and rate of bleeding are difficult to estimate leaving surgeons and anesthesiologists with little meaningful data to help decide whether a red cell transfusion is appropriate [9-11].

Ideally, red cell transfusions would be given only when there is the need to improve oxygen delivery to vital organs and other tissues. When the patient is normovolemic, the hemoglobin level and arterial oxygen saturation, combined with clinical evaluation, can be used to estimate oxygen delivery and guide transfusion. However, since intraoperative hemoglobin values can be confounded by hemodilution, hemoconcentration or volume redistribution, accurate contemporaneous measurement of surgical blood loss could provide the surgical team with the information they need not only to control bleeding but could also lead to more informed transfusion decisions than those based primarily on the hemoglobin concentration [7].

A recently introduced, FDA-cleared device that measures blood loss on surgical sponges and in suction canisters may provide useful, real-time information to guide surgical and anesthetic care. The performance of the device has been validated in bench-top and clinical settings [12-14]. To demonstrate the utility of this device, we postulated that accurate measurement of operative blood loss would facilitate prediction of postoperative hemoglobin levels following restoration of normovolemia. If this were the case, these contemporaneous measurements could be used in conjunction with knowledge of the patient's clinical condition and preoperative

hemoglobin level to guide transfusion decisions during and immediately following surgical procedures.

Materials and Methods

The 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 for this study was waived by the IRB. Procedures in adult patients with a baseline weight ≥ 50 kg having burn and other wound excisions before (January 2014 to November 2014; n=100 procedures, 60 patients; historical group) and after (November, 2014 to January, 2016; n=167 procedures, 103 patients; study group) the introduction of the blood loss measurement system were analyzed retrospectively. Since the hemoglobin levels related to a procedure could affect levels during subsequent procedures on the same patient, subsequent surgeries taking place 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. It is likely that the five day period coupled with hemodynamic stability prior to each procedure would minimize the effect one procedure might have on a subsequent one.

The novel FDA-cleared mobile application (Triton System™, Gauss Surgical, Inc., Los Altos, CA) on a tablet computer (iPad) was used to measure surgical blood loss. Using the enabled tablet camera, the application captures images of surgical sponges and employs image analysis algorithms (Feature Extraction Technology™) and cloud-based machine learning to accurately estimate hemoglobin mass on the surgical laparotomy sponges in real time (Figure 1). The technology can also measure the hemoglobin content of fluid collected in surgical suction canisters. The accuracy of the method is not affected by the admixture of irrigation or other fluids or the ambient lighting condition [13].

Figure 1: Demonstration of the mobile application on a tablet computer (iPad) to capturing an image of a surgical sponge. Image analysis algorithms and cloud-based machine learning accurately estimate hemoglobin mass on the sponge in real time.

In the historical group (system not used) a visual estimation of 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 surgical sponges were collected during the procedure and scanned with the system to capture images of the sponges. This resulted in a measured amount of hemoglobin loss per sponge that was converted to a volumetric measure using the patient's pre-procedure hemoglobin value. The operating team attempted to capture all blood loss using surgical sponges. Surgical suction was not used for these procedures so scanning of and estimation of the blood collected in surgical suction canisters was not performed.

Data extracted from the patient's medical records included date of surgery, patient age (years), total body surface area (BSA) (meters^2), total size of burn or wound (% BSA), size of wound excised (cm^2), visually estimated blood loss (in the historical group) (ml) and hemoglobin concentrations (g/dl) preoperatively, immediately following surgery and on postoperative days one, two and three when available. All packed red cell (PRBC) and component transfusions (units) given from the day of surgery through postoperative day two were documented. Measurements of blood loss (ml) on surgical sponges was recorded when the system was used.

A simplified formula to predict postoperative hemoglobin levels was devised and used to calculate hemoglobin levels on postoperative days one, two and three following each surgical procedure for which the patient's baseline weight, preoperative hemoglobin and transfusion data were obtained. These predictions were compared with the actual values when available.

The formula assumed a blood volume of 70 ml/kg body weight [15]. It was also assumed that each transfused unit raised the hemoglobin level by 1 g/dl [16]. Using these assumptions, the predicted postoperative hemoglobin (g/dl) (PPOHgb) is calculated as follows:

PPOHgb (g/dl)=Preop Hgb (g/dl)-((EBL (ml)/(70 × weight (kg))) × Preop Hgb (g/dl))+1 × transfused units

Preop Hgb is the preoperative hemoglobin (g/dl) and EBL is the estimated blood loss (ml), which was obtained from the visual estimate recorded in the chart in the historical group, and the system's measured blood loss in the study group. In this formula, the hemoglobin loss is calculated as a fraction of the blood volume lost multiplied by the preoperative hemoglobin. The number of transfused units given prior to the measurement of the particular postoperative hemoglobin value is included.

Statistical analysis

Data are provided as mean (95% confidence intervals) and frequency (%). Univariate comparisons were performed using chi square, Fisher's exact, Student t-test, or Mann-Whitney U-test as appropriate. The main study endpoint was the bias between the predicted and actual post-operative Day 1 hemoglobin level. Association between the actual and predicted postoperative hemoglobin values were evaluated using scatter plots and further analyzed using linear regression models to obtain the unstandardized and standardized correlation coefficients with corresponding confidence intervals. Further subgroup analyzes were performed depending on whether any red cell transfusions were received or not at any time during the day of surgery. Agreement between the predicted and actual postoperative hemoglobin values was also characterized using the Bland-Altman method by calculating the bias (predicted

minus actual values) and limits of agreement (bias ± 1.96 × standard deviation) with corresponding confidence intervals as previously described [17]. A p value of 0.05 or less was considered to be statistically significant. Based on the preliminary studies, it was expected that the absolute bias of postoperative day 1 hemoglobin would be half a standard deviation smaller than the historical group. To detect such a difference using t-test with alpha of 0.05 and power of 90%, 85 subjects were needed per group. This sample size was further adjusted to 99 per group by dividing it by 0.864 according to the Pitman Asymptomatic Relative Efficiency (ARE) method to make it independent of underlying distribution. This number was considered as the minimum sample size needed and additional eligible subject were added if records were available. All analyses were performed using SPSS (SPSS Inc., Chicago, IL).

Results

Characteristics of the historic and study cohorts are provided in Table 1.

	Historic Group (N=100)	**Study Group (N=167)**	**P Value**
Age at time of surgery (years)	50.2 (46.4 to 53.9)	46.8 (44.0 to 49.5)	0.148
Weight at admission (Kg)	82.2 (77.5 to 86.8)	85.8 (82.1 to 89.4)	0.231
Case type:			
Burn excision	57 (57.0%)	103 (61.7%)	0.449
Other wound excision	43 (43.0%)	64 (38.3%)	0.449
Total burn/wound surface area (% of total body surface area)	12.6 (8.6 to 16.6)	13.8 (10.1 to 17.4)	0.666
Total area excised:			
Area (cm^2)	923 (608 to 1238)	782 (643 to 921)	0.418
% of total body surface area	4.8 (3.1 to 6.4)	4.0 (3.2 to 4.7)	0.379
Estimated blood loss (mL)	215 (157 to 273)	351 (286 to 417)	0.002
Hemoglobin levels (g/dL):			
Preoperative	10.4 (9.9 to 10.8) N=100	10.5 (10.1 to 10.9) N=167	0.564
Postoperative same day	9.5 (8.7 to 10.2) N=26	9.8 (9.4 to 10.3) N=62	0.35
Postoperative Day 1 (N=100 & 167)	9.6 (9.2 to 10.0) N=100	10.0 (9.6 to 10.3) N=167	0.204
Postoperative Day 2	8.9 (8.4 to 9.3) N=48	9.1 (8.7 to 9.4) N=78	0.482
Postoperative Day 3	9.4 (8.9 to 9.9) N=61	9.2 (8.8 to 9.6) N=74	0.454
Patients transfused red blood cells			
Preoperative same day	4 (4.0%)	6 (3.6%)	1
Intraoperative	22 (22.0%)	39 (23.4%)	0.799
Postoperative same day	3 (3.0%)	1 (0.6%)	0.149
Postoperative Day 1	9 (9.0%)	6 (3.6%)	0.063
Postoperative Day 2	6 (6.0%)	7 (4.2%)	0.563
Any postoperative	18 (18.0%)	14 (8.4%)	0.0199
Any perioperative	33 (33.0%)	51 (30.5%)	0.675

Table 1: Characteristics of historic and study groups. Ranges are 95% confidence intervals.

The formula using measured blood loss in the study group (n=167) was a better predictor of the actual postoperative day one hemoglobin value (R^2=0.822) than was the same formula using visually estimated blood loss used in the historical group (n=100) (R^2=0.615). Additionally, the mean absolute bias of postoperative Day 1 hemoglobin level in the study group was statistically significantly lower than the mean bias of the historical group (mean 0.4, 95% CI 0.2 to 0.5 g/dL in Study and 0.9, 95% CI 0.7 to 1.2 g/dL in Historical group, p<0.001). Cases that had red cell transfusion at any time during the day of surgery (historical group=27, study group=43) and those cases that did not have red cell transfusion on the day of surgery (historical group=73, study group=124) were also analyzed separately. For each of these subgroups, the measured blood loss in the study group was similarly more predictive of actual values (Table 2). This is graphically demonstrated for the transfused subgroup (Figures 2 and 3).

	Historical Group	**Study Group**	**P Value**
All Procedures	**N=100**	**N=167**	
PPOHgb bias (g/dl)	0.9 (0.7 to 1.2)	0.4 (0.2 to 0.5)	<0.001
Lower limit of agreement (g/dl)	-1.6 (-2.1 to -1.2)	-1.5 (-1.8 to -1.3)	
Upper limit of agreement (g/dl)	3.5 (3.0 to 3.9)	2.2 (2.0 to 2.5)	
Correlation, R	0.784 (0.695 to 0.849)	0.906 (0.875 to 0.929)	
Procedures with Operative Day Transfusion	**N=27**	**N=43**	
PPOHgb Bias (g/dl)	1.6 (1.0 to 2.2)	0.5 (0.2 to 0.7)	0.001
Lower limit of agreement (g/dl)	-1.3 (-2.3 to -0.3)	-1.1 (-1.5 to -0.7)	
Upper limit of agreement (g/dl)	4.5 (3.5 to 5.5)	2.0 (1.6 to 2.4)	
Correlation, R	0.559 (0.228 to 0.774)	0.734 (0.557 to 0.847)	
Procedures without operative day transfusion	**N=73**	**N=124**	
PPOHgb Bias (g/dl)	0.7 (0.4 to 0.9)	0.3 (0.1 to 0.5)	0.027
Lower limit of agreement (g/dl)	-1.6 (-2.0 to -1.1)	-1.6 (-2.0 to -1.3)	

Upper limit of agreement (g/dl)	2.9 (2.4 to 3.4)	2.3 (2.0 to 2.6)	
Correlation, R	0.844 (0.762 to 0.899)	0.906 (0.869 to 0.933)	

Table 2: Prediction of hemoglobin level on post-operative day 1. Ranges are 95% confidence intervals.

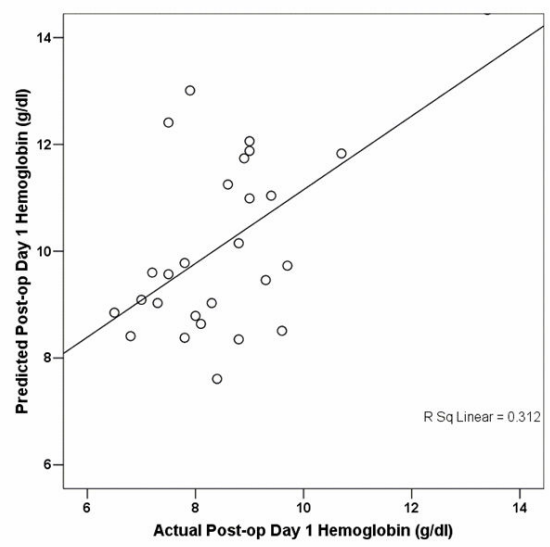

Figure 2: Comparison between the actual and predicted postoperative day one hemoglobin concentrations for transfused procedures in the historical group using estimated blood loss (N=27).

Postoperative day two hemoglobin values were available for 48 procedures in the historical group (31 transfused either on the day of surgery or on the first postoperative day) and 78 procedures in the study group (46 transfused). For the entire group and for subgroup of cases according to transfusion up to day 1, the bias of predictions using measured blood loss versus the actual hemoglobin was smaller in the study group compared with the historical group. However, the correlation between the predicted and actual day 2 hemoglobin was stronger in transfused subset of cases in study group and untransfused subset cases in historical group (Table 3).

Postoperative day three hemoglobin values were available for 61 patients in the historical group (27 transfused) and 74 patients in the study group (35 transfused). For the transfused subgroups and the groups as a whole, the measured blood loss in the study group was a better predictor of actual postoperative day three hemoglobin values (indicated by smaller bias) than the traditionally estimated blood loss, but the difference in bias was not significant in the subgroup of cases without transfusion (Table 4).

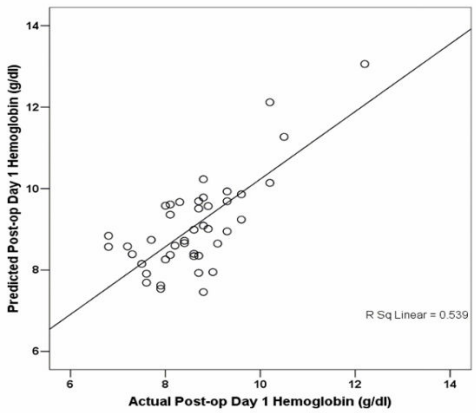

Figure 3: Comparison between the actual and predicted postoperative day one hemoglobin concentrations for transfused procedures the study group using measured blood loss (N=43).

	Historical Group	Study Group	P Value
All Procedures	**N=48**	**N=78**	
PPOHgb Bias (g/dl)	1.5 (1.1 to 1.9)	0.6 (0.3 to 0.9)	<0.001
Lower limit of agreement (g/dl)	-1.2 (-1.9 to -0.5)	-2.0 (-2.5 to -1.5)	
Upper limit of agreement (g/dl)	4.3 (3.6 to 5.0)	3.2 (2.7 to 3.7)	
Correlation, R	0.619 (0.407 to 0.768)	0.686 (0.547 to 0.788)	
Procedures with transfusion prior to POD 2	**N=27**	**N=32**	
PPOHgb Bias (g/dl)	2.0 (1.4 to 2.6)	1.1 (0.6 to 1.7)	0.038
Lower limit of agreement (g/dl)	-1.1 (-2.2 to 0.0)	-1.6 (-2.5 to -0.7)	
Upper limit of agreement (g/dl)	5.1 (4.0 to 6.2)	3.9 (3.0 to 4.8)	
Correlation, R	0.314 (-0.074 to 0.62)	0.608 (0.330 to 0.789)	
Procedures without transfusion prior to POD 2	**N=21**	**N=46**	
PPOHgb Bias (g/dl)	0.9 (0.5 to 1.3)	0.2 (-0.1 to 0.6)	0.017
Lower limit of agreement (g/dl)	-0.7 (-1.3 to 0.0)	-2.0 (-2.6 to -1.4)	
Upper limit of agreement (g/dl)	2.5 (1.9 to 3.1)	2.5 (1.9 to 3.0)	
Correlation, R	0.907 (0.782 to 0.962)	0.785 (0.641 to 0.875)	

Table 3: Prediction of hemoglobin level on post-operative day 2. Ranges are 95% confidence intervals.

	Historical Group	Study Group	P Value

All procedures	**N=61**	**N=74**	**0.028**
PPOHgb Bias (g/dl)	1.2 (0.8 to 1.7)	0.6 (0.3 to 0.9)	
Lower limit of agreement (g/dl)	-2.2 (-3.0 to -1.4)	-2.0 (-2.5 to -1.5)	
Upper limit of agreement (g/dl)	4.7 (3.9 to 5.5)	3.3 (2.7 to 3.8)	
Correlation, R	0.519 (0.308 to 0.681)	0.729 (0.601 to 0.820)	
Procedures with transfusion prior to POD 3	**N=27**	**N=35**	
PPOHgb Bias (g/dl)	2.2 (1.4 to 2.9)	1.1 (0.6 to 1.6)	0.016
Lower limit of agreement (g/dl)	-1.6 (-2.9 to -0.3)	-1.9 (-2.8 to -1.0)	
Upper limit of agreement (g/dl)	6.0 (4.6 to 7.3)	4.1 (3.2 to 5.0)	
Correlation, R	0.174 (-0.220 to 0.519)	0.436 (0.121 to 0.671)	
Procedures without transfusion prior to POD 3	**N=34**	**N=39**	
PPOHgb Bias (g/dl)	0.5 (0.1 to 0.9)	0.2 (-0.1 to 0.5)	0.28
Lower limit of agreement (g/dl)	-1.9 (-2.7 to -1.2)	-1.8 (-2.4 to -1.2)	
Upper limit of agreement (g/dl)	2.9 (2.2 to 3.7)	2.2 (1.6 to 2.8)	
Correlation, R	0.800 (0.634 to 0.895)	0.872 (0.768 to 0.931)	

Table 4: Prediction of hemoglobin level on post-operative day 3. Ranges are 95% confidence intervals.

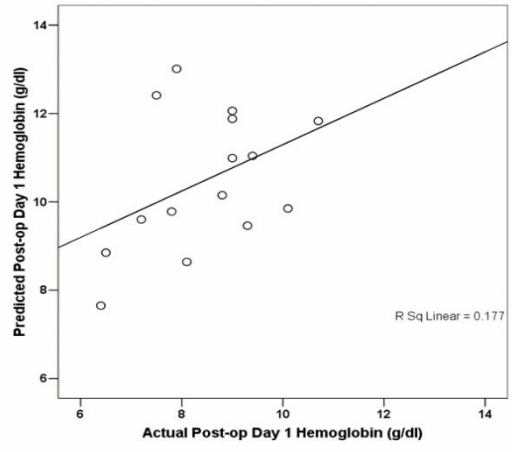

Figure 4: Comparison between the actual and predicted postoperative day one hemoglobin concentrations for transfused procedures in the Historical Group using estimated blood loss (N=15) for patients where estimated blood loss was ≥ 500 ml.

Interestingly, of the 167 procedures in the study group, 43 (25.7%) had a measured blood loss of 500 ml or greater. In the historical group the estimated blood loss equaled or exceeded 500 ml in only 15 of the 100 cases (15%). In these higher blood loss cases, the predicted postoperative day one hemoglobin value using the measured blood loss in the study group was more closely correlated with the actual value (R=0.729) than was the same prediction using the estimated blood loss in the historical group (R=0.421) (Figures 4 and 5).

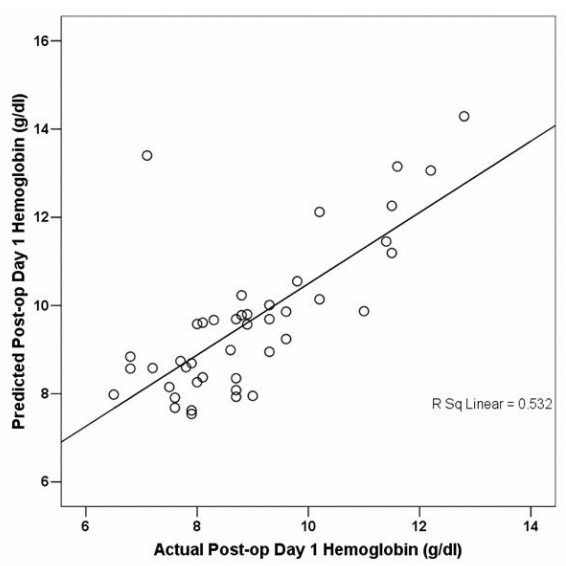

Figure 5: Comparison between the actual and predicted postoperative day one hemoglobin concentrations for transfused procedures in the study group using measured blood loss (N=43) for patients where measure blood loss was ≥ 500 ml.

Discussion

Transfusion of allogeneic red cells is a costly medical procedure with potentially serious adverse consequences [18,19]. Restrictive red cell transfusion policies are recommended since they help avoid unneeded transfusions, conserve the limited blood resource and save money while resulting in similar or better outcomes than more liberal policies [1-5]. However, the inability to accurately determine the extent of blood loss makes it difficult to appropriately manage surgical bleeding. Moreover, transfusion decision-making during and immediately following surgery is problematic not only because of the difficulty in accurately assessing blood loss, but also because of the potential for sudden substantial bleeding and the inaccuracy of the hemoglobin level in reflecting red cell mass. On one hand, evidence-based practice clearly favors limiting transfusions while, conversely, transfusion avoidance can result in inadequate oxygen delivery to vital organs and resultant morbidity and mortality. While visual estimates of surgical blood loss can theoretically be used to keep track of red cell mass, these determinations are known to be inaccurate [10].

Accurate, contemporaneous measurement of surgical bleeding could potentially alleviate these problems by providing surgeons and anesthesiologists with real-time data that, when combined with relevant clinical information, could improve transfusion decisions and overall surgical and anesthetic management. Other methods of

obtaining this information including training in visual estimation and gravimetric methods that involve weighing of surgical sponges have been investigated, but are inadequate [20,21]. While the system used in this study is accurate, the clinical relevance of the measurements obtained have not been previously evaluated.

This study demonstrates that the blood loss measurements from the novel system are a much better predictor of hemoglobin values obtained in the first three days after surgery than are traditional blood loss estimates. This confirms the relative inaccuracy of hemoglobin values in the setting of fluctuating blood volume and supports the contention that measured blood loss is more accurate than hemoglobin values in guiding transfusion therapy for patients during and immediately following surgery.

During standard clinical care, many clinicians practice transfusion avoidance intraoperatively and then transfuse postoperatively based on predetermined, evidence-based hemoglobin values. This strategy is problematic since it may lead to under or over transfusion during the most critical periods of surgical instability. Furthermore, most patients are in positive fluid balance postoperatively and experience an initial downward "hemoglobin drift" followed by recovery as this fluid is mobilized. These variations can result in hemoglobin changes of greater than 2 g/dl that occur over several days despite a stable red cell mass, making reliance on hemoglobin values alone a poor strategy [7]. Ideally, clinicians would estimate preoperative red cell mass based on the patient's weight and preoperative hemoglobin level and determine the amount of tolerable blood loss taking into account the clinical situation. Accurate measurement of surgical blood loss would then allow for indicated transfusion at the most appropriate time.

Another consideration is the cost of a transfusion episode [22]. The increased need for nursing resources associated with transfusions given outside of the operating room or recovery area, make those transfusions more costly. Therefore, if a transfusion is indicated, it is best given during or immediately following surgery for both clinical and economic reasons.

This study may be of limited value since it was done in only in procedures involving burn or other wound excisions. These patients were selected since they often have substantial blood loss and the surgical blood loss is readily captured on surgical sponges. The applicability of the system to other patient populations needs further study. Another limitation is that the study was not randomized and retrospectively compared historical data to a novel intervention. However, this approach helped to eliminate any confounding of the visual estimations that could have occurred if the device was introduced using a prospective randomized study design (provider "learning curve"). Furthermore, there were no patients treated between the end of the historical group and the introduction of the system, and the participating clinicians made no other changes in their clinical care. While further studies are needed, the novel device studied accurately measures blood loss and can potentially provide useful, real-time information to guide surgical and anesthetic care.

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