Improving red blood cell orders, utilization, and management with point-of-care clinical decision support

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BACKGROUND: The computerized order for red blood cell (RBC) transfusion within our electronic health record was redesigned with integrated clinical decision support (CDS) to reinforce our restrictive transfusion policy. These changes encouraged 1-unit (1U) RBC orders, clarified hemoglobin (Hb) transfusion triggers, and discouraged unnecessary orders. This study assessed whether these changes resulted in durable effects on provider practices.

STUDY DESIGN AND METHODS: The study compared three 1-year subperiods from August 2011 to August 2014, with each year corresponding to a historical control period, preintervention and postintervention years. This study analyzed ratios of 1U versus 2-unit (2U) orders and the absolute rate of RBC orders, units charged, Hb transfusion triggers, repeat transfusion orders, and selected clinical indications both institution-wide and across several subpopulations.

RESULTS: Our institution-wide ratio of 1U versus 2U orders increased from 0.50 to 1.20 ($p < 0.0001$) in the pre- to postintervention subperiods, respectively. The number of units charged per day decreased from 15.68 to 13.53 ($p < 0.001$), while rates of initial and repeat orders remained stable. Proportion of clinical indications used and mean Hb triggers demonstrated generally positive results. The changes observed between the pre- and postintervention years were far greater than changes between historical control versus preintervention years, reinforcing attribution of results to computerized physician order entry changes.

CONCLUSION: Use of computerized orders and CDS encouraged a restrictive transfusion policy, which was highly successful in changing provider practices. We also succeeded in decreasing mean Hb triggers and overall utilization of RBCs. These findings persisted across many subpopulations.

Approximately 13.5 million red blood cell (RBC) units were transfused annually in the United States in 2011. RBC transfusions have measurable risks, and 51,000 adverse events were reported in the US in 2011.[1,2] Contemporary reviews of RBC transfusion triggers emphasize that use of restrictive transfusion thresholds, namely, below a hemoglobin (Hb) concentration of less than or between 7 and 10 g/dL with specific indications at specific thresholds, may maximize clinical efficacy while minimizing risk.[3-6] In conjunction with lowering thresholds, RBC management can be improved by moderating the number of units ordered before rechecking a Hb level and by using a restrictive transfusion policy.[6-9] Specifically, the AABB recommends single-unit transfusions in patients without active bleeding, an outcome studied more frequently in RBC transfusion studies.[7,9-12] "Appropriate blood management in inpatient services" has

ABBREVIATIONS: 1U, 2U = 1-unit, 2-unit (red blood cell order); CDS = clinical decision support; CPOE = computerized physician order entry; Ctrl = control (subperiod); EHR = electronic health record; Pre = preimplementation (subperiod); Post = postimplementation (subperiod).

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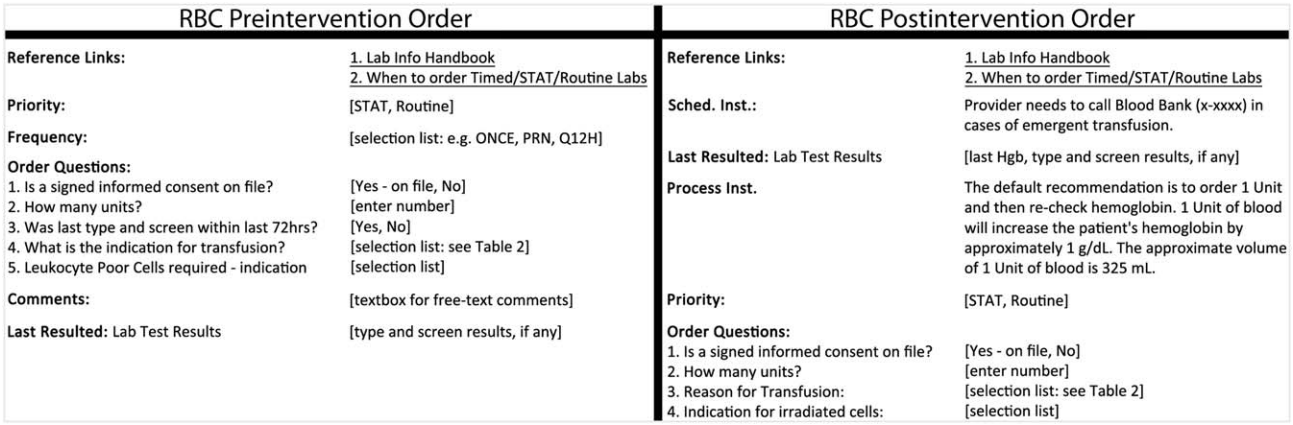

Fig. 1. Mock-up of preintervention and postintervention RBC orders from within EHR.

been specified as one of the top five hospital-based interventions in the process of delivering clinical care efficiently and cost-effectively highlighted in the Choosing Wisely campaign.[10,13]

Widescale use of health information technology has been shown to increase clinician adherence to clinical guidelines, particularly through the use of clinical decision support (CDS) and alerting systems.[14] Although CDS interventions within electronic health record (EHR) systems using computerized physician order entry (CPOE) to change clinical practices have demonstrated benefit in many studies, strong generalizable empirical evidence of their efficacy is somewhat lacking, but the evidence grows continually.[15-17] Nevertheless, such interventions have increasingly demonstrated benefits to patient outcomes, blood utilization, and diminution of cost by aiding compliance with restrictive transfusion policies.[8,12,18-22]

MATERIALS AND METHODS

Our institution is a 455-bed Level 1 trauma center and safety net hospital with a transfusion service supplied and supported by a local nonprofit blood center. Our institution's transfusion medicine committee approved a more restrictive transfusion policy in 2012, consistent with published AABB guidelines. This policy was supported by a CDS-oriented redesign of the existing CPOE adult RBC order in our institution's EHR in August 2013. The focus of this redesign was to provide point-of-care decision support with respect to both institutional practice and patient-specific data. This retrospective study assesses the 1-year success of this intervention with respect to provider ordering practices and overall RBC utilization.

The outcome of this study and intervention is to assess change in the ratio of 1-unit (1U) to 2-unit (2U) RBC orders throughout our institution. Additional outcomes include measuring: 1) changes in total number of orders, units ordered, or units charged per day; 2) change in mean antecedent measured Hb values (Hb "trigger") for 1U versus 2U orders; and 3) change in repeat RBC orders within 8 hours of a prior order.

Summary of EHR order changes

An existing CPOE RBC order in our institution's EHR was modified with input from transfusion medicine, clinical informatics, and clinical departments with the highest use of RBCs. No additional provider education was disseminated beyond existing practices and any education generated from development of this project, with a single exception. The institution is the site of many residency programs and annual training of the new residents encouraged evidence-based usage of RBCs including considering single-unit orders. While many residents begin in the end of June or July, many others rotate through from various multi-institutional programs. Our pre- versus postimplementation RBC CPOE order contained several data elements and choices for the user as specified in Fig. 1. The postimplementation changes can be summarized as: 1) addition of CDS text, 2) addition of last measured Hb, 3) removal of choice for ordering frequency, 4) reordering of existing order elements, 5) modification of order questions, and 6) removal of free-text general comment field. Consistent with recommendations for restrictive transfusion thresholds, the indications for transfusion were modified as described in Table 1.

The RBC ordering changes were implemented in the EHR (Epic Systems Corporation, Verona, WI) and became available to clinicians on August 6, 2013. Our EHR's respective versions at the points of implementation and analysis were Epic 2012 and Epic 2014.

Data collection and analysis

Standard query language queries ran on the EHR's extracted relational database (Epic Clarity) to obtain all analyzed data sets. The study period consisted of a 3-year period from August 6, 2011, to August 6, 2014, with the

TABLE 1. Indication choices within RBC CPOE order before and after order redesign

Preintervention transfusion indications	Postintervention transfusion indications
Acute hemorrhage (>15% EBL)	Acute hemorrhage (>15% EBL)
Anemia, Hb 7-10 g/dL	Hb < 7 g/dL
Anemia, Hb < 7 g/dL	Hb 7-8 g/dL: consider in postoperative surgical patients or existing CV disease
Impaired tissue oxygenation	Hb 8-10 g/dL: consider in symptomatic anemia or symptomatic CV patients
Other (specify in comments)	Hb > 10 g/dL: no indication unless exceptional circumstances (note in comments)
	Other (specify in comments)

CV = cardiovascular; EBL = estimated blood loss.

first year considered the control (Ctrl) subperiod, the second year the preimplementation (Pre) subperiod, and the third year the postimplementation (Post) subperiod. The inclusion of a control period was to determine baseline changes in clinical practice independent of our EHR intervention over an equivalent period of time. Specifically, as a teaching institution, there was ongoing effort to encourage evidence-based blood management by various means, including provider feedback for orders not appearing to meet guidelines. By having the comparison to a prior period, changes before and after CDS intervention could be distinguished from practices changing over time.

The primary RBC order data set included all inpatient RBC orders identified retrospectively that occurred during the study period, excluding patients not discharged by the end of August 2014. The primary RBC orders data set included both order-specific and patient-specific data. Order-specific data included the number of units ordered, the indication for transfusion, and whether the patient had RBCs previously ordered within the past 8 hours. Patient-specific data included primary clinical service, the patient's location at the time of the order, and the time and value of the most recent Hb value before the order (the presumed transfusion trigger, if one existed).

Due to limitations of the interfaces between the hospital's EHR and laboratory information system, RBC administration data can only be assessed via the EHR. Specifically, transfusion events in the EHR are documented inconsistently by nursing as either volume infused in milliliters or as RBC units. Validation of EHR billing data against laboratory information system administration data was conducted manually on approximately 1% of the total study data. Secondary analysis linked hospital billing data to the primary RBC orders data set to provide surrogate RBC administration data in the form of hospital charges per patient and per day.

Statistical analysis

Data were analyzed, and charts and graphs were created in a computer spreadsheet (Microsoft Excel, Version 15.0, Microsoft Corporation, Redmond, WA). Significance testing was performed in statistical software (SAS, Version 9.3, SAS Institute, Cary, NC). Comparisons of frequencies and proportions were conducted using chi-square analyses, and comparisons of means occurred via analysis of variance for repeated measures, with pairwise differences estimated by least-squares means for subperiod comparisons. Significance was considered with an alpha of 0.05. Study subperiod comparisons were performed on pairs of Ctrl-Pre and Pre-Post subperiods separately. Data are presented as raw counts/rates, mean rates ± standard deviation (SD), or as percentages. p values below 0.01 are displayed as below each subsequent lower order of magnitude. Daily rates were calculated with sums and counts of data elements grouped by the date of service. Significance testing was not undertaken for analysis of indications as they were changed as part of this intervention. Qualitative analysis of indications compared across subperiods was conducted with indications grouped into generalized categories, either by Hb threshold levels or by nature of indication.

RESULTS

RBC orders at our institution were most often 1U or 2U orders, with 17.7% to 20.6% of orders per subperiod specifying 3 or more units. This is consistent with our status as a Level 1 trauma center, with many transfusions being utilized during more than 100 massive transfusion events per year. Of the 3 or more unit orders, 90.4% to 94.7% indicated 3 or 4 units. Further analyses by number of units ordered were performed with orders of more than 2U grouped into a single category, as orders for 3 units or greater did not vary across subperiods. Counts of data elements of interest per subperiod are provided in Table 2.

Daily rates per subperiod demonstrated no significant difference between units charged, distinct patient encounters, nor distinct patients for the Ctrl versus Pre subperiods, yet very statistically significant differences for the same elements across the Pre versus Post subperiods (Table 3). The total number (not only related to RBC ordering; data not included) of distinct inpatients and inpatient encounters were not different across each subperiod. The number of units per day did not change significantly across all three subperiods. The number of repeat RBC orders within 8 hours did not significantly change across all three study subpopulations (Table 3). Specifically, this addresses physicians not simply ordering

TABLE 2. Counts of patients, encounters, orders, and units by study subperiod

Subperiod	Subperiod start	Subperiod end	Distinct patients	Distinct encounters	Orders	Units ordered	Units charged	1U orders	2U orders
Ctrl	Aug 6, 2011	Aug 6, 2012	1431	1699	3577	6667	6161	847	2509
Pre	Aug 6, 2012	Aug 6, 2013	1408	1661	3600	6476	5723	1122	2254
Post	Aug 6, 2013	Aug 6, 2014	1307	1506	3447	5452	4939	1771	1482
Totals*	Aug 6, 2011	Aug 6, 2014	3862	4845	10624	18595	16823	3740	6245

* For patients and encounters, totals are distinct totals for the entire study period, not totals of the subperiods.

an additional unit later to circumvent the single-unit order process.

The ratio of 1U:2U orders was measured on both a study subperiod scale and a monthly scale. The subperiod comparison of 1U:2U orders demonstrated a significant increase across all three study subperiods (Table 3). The monthly changes to the 1U:2U order ratio demonstrated a dramatic change in the ratio of 1U:2U orders temporally associated with the change to the RBC order (Fig. 2). The ratio of 1U:2U orders across services and locations demonstrated significant changes between both the Ctrl versus the Pre and the Pre versus Post subperiods for nearly all services (Table 4), locations (not included), and provider types (Table 4), with larger changes for the Pre versus Post comparisons.

The Hb triggers for each subperiod demonstrated significant changes. A decrease in Hb was most notable for 1U orders across each subperiod (Table 3). Hb triggers for all orders by generalized indication category showed a large decrease in the Hb trigger for the "other" indication, with otherwise increases in the Hb trigger for threshold-related indication categories, although all threshold-related Hb triggers were within the threshold for all study subperiods (Fig. 3). Hb trigger analysis by 1U versus 2U orders by primary clinical services demonstrated decreases across nearly all subperiods for 1U orders, but mixed for 2U orders (Fig. 4). Data evaluating proportions of RBC orders above the Hb thresholds of 7, 8, and 10 g/dL (not included here) demonstrated a large decrease (50.7% vs. 43.9% Pre to Post) in the proportion of orders with Hb level of more than 7 g/dL, but otherwise small changes for the higher thresholds.

Proportions of indications used demonstrated large decreases for indications with a Hb trigger of more than 7 g/dL and an increase for the indications triggering at less than 7 g/dL (Table 5). Usage of the acute hemorrhage indication increased for both 1U and 2U orders across all subperiods. For the indications specifying low likelihood of clinical indication for transfusion, usage was extremely low for all subperiods with little change. Usage of the "other" indication and orders with associated comments were much more prevalent in the Post subperiod.

DISCUSSION

Overall 1U:2U ratio

Our institution-wide ratio of 1U:2U orders increased significantly, consistent with the study of Yerrabothala and colleagues[12] on CPOE affecting transfusion practices. Comparison of 1U:2U order ratio is limited by the fact that they excluded cases with active bleeding. Similar success of improving 1U:2U ratios has also been reported in restrictive blood management strategies independent of using health information technology.[9]

TABLE 3. Mean transfusion and Hb trigger rates by study subperiod*

Metric	Mean rates			p value	
	Ctrl	Pre	Post	Ctrl vs. Pre	Pre vs. Post
Patients/day	9.18 ± 3.15	9.06 ± 3.11	8.37 ± 3.10	0.61	<0.01
Patient encounters/day	9.29 ± 3.21	9.13 ± 3.14	8.46 ± 3.16	0.49	<0.001
Orders/day	9.77 ± 4.04	9.84 ± 3.99	9.44 ± 4.05	0.83	0.18
Units ordered/day	18.22 ± 7.95	17.74 ± 7.76	14.94 ± 7.14	0.40	<0.0001
Units charged/day	16.83 ± 8.09	15.68 ± 7.45	13.53 ± 9.76	0.07	<0.001
1U orders/day	2.68 ± 1.60	3.36 ± 1.87	4.93 ± 2.57	<0.001	<0.0001
2U orders/day	6.89 ± 3.15	6.23 ± 2.89	4.24 ± 2.37	<0.0001	<0.0001
>2U orders/day	1.29 ± 0.52	1.31 ± 0.53	1.15 ± 0.56	0.97	0.68
Hb trigger	7.58 ± 1.60	7.46 ± 1.58	7.45 ± 1.73	<0.01	0.75
1U Hb trigger	7.55 ± 1.08	7.37 ± 1.07	7.24 ± 1.23	0.02	0.03
2U Hb trigger	7.59 ± 1.74	7.50 ± 1.78	7.71 ± 2.16	0.06	<0.001
>2U Hb trigger	7.74 ± 3.12	7.64 ± 2.53	8.16 ± 2.79	0.58	<0.01
Repeat orders/day	1.04 ± 1.39	0.96 ± 1.32	1.00 ± 1.37	0.45	0.72

* Data are reported as mean ± SD. Daily rates indicate the rates for these metrics in which RBC orders were placed per day.

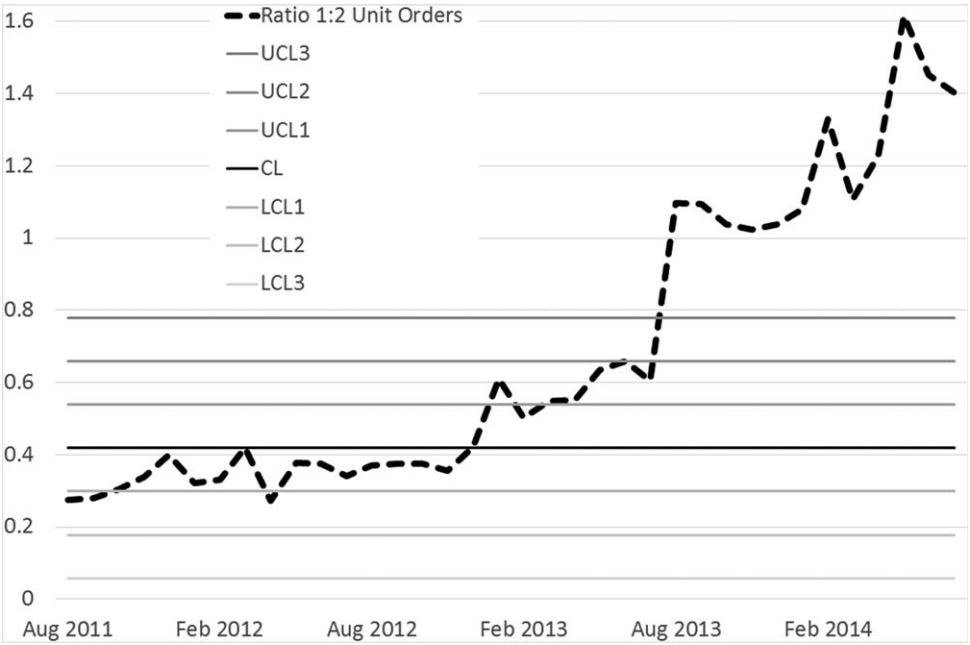

Fig. 2. Control chart of ratio of 1U:2U orders per month, using August 2011 to July 2013 as referent period. Mean ratios per study subperiod: Ctrl, 0.34; Pre, 0.50; Post 1.20. CL = control limit (mean of referent period); UCL = upper control limit X (mean + X × SD); LCL = lower control limit X (mean – X × SD).

Decreased utilization

The institution-wide number of units ordered and number of units charged strongly demonstrates a change in RBC utilization as a function of our intervention. Although additional blood management efforts including resident education continued across these periods, the dramatic temporal change pre- and post-CPOE intervention is consistent with the findings of Goodnough and colleagues[21] wherein CPOE and CDS were used to decrease blood utilization.

Hb triggers

Our institution-wide changes in our mean Hb trigger values showed mixed results with respect to direction of change and significance. The lack of change in the overall Hb trigger from the Pre to Post subperiods may indicate that overall appropriate blood use had improved before our intervention and that changes within subpopulations per indication are a better measure of success. Although there was a significant increase for the indication of Hb level of less than 7 g/dL, overall Hb at time of transfusion

TABLE 4. Ratio of 1U to 2U orders per service by study subperiod and provider type

		Ratio 1U:2U orders			p value	
Service	Total study orders*†	Ctrl	Pre	Post	Ctrl vs. Pre	Pre vs. Post
Burn/plastic surgery	973 (9.2%)	0.10	0.21	0.60	<0.01	<0.0001
Emergency medicine	713 (6.7%)	0.11	0.16	0.63	0.21	<0.0001
Hospitalist	581 (5.5%)	0.39	0.55	0.82	0.10	0.0711
Internal medicine	1194 (11.2%)	0.53	0.83	1.96	<0.01	<0.0001
MICU	1593 (15.0%)	0.66	0.94	2.17	<0.01	<0.0001
Orthopedics	538 (5.1%)	0.26	0.52	0.71	<0.01	0.1506
Renal	1026 (9.7%)	0.58	0.69	2.16	0.28	<0.0001
Surgery	1637 (15.4%)	0.12	0.22	0.76	<0.01	<0.0001
Provider type						
Staff physician	977 (9.2%)	0.47	0.40	0.95	0.76	<0.0001
Physician assistant	675 (6.4%)	0.13	0.29	0.67	0.02	<0.0001
Resident physician	8520 (80.2%)	0.34	0.54	1.35	<0.0001	<0.0001

* Percent of orders for all services.
† Percent of total orders for all provider types.
MICU = medical intensive care unit.

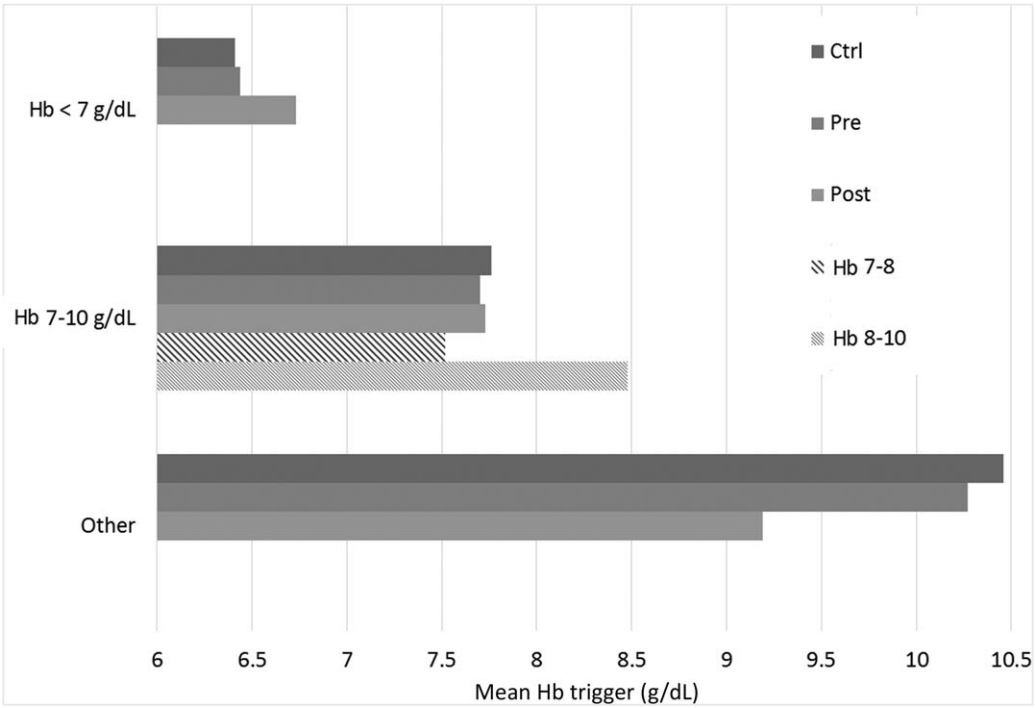

Fig. 3. Mean Hb triggers by generalized indications. Hb 7 to 8 and Hb 8 to 10 g/dL, as discriminated in Post subperiod only, included within Hb 7 to 10 g/dL category separately and in conjunction as Post column for that category.

remained well below 7 g/dL. Of note, the indication of "other" demonstrated a large (10.27 to 9.19 g/dL) decrease in the mean Hb trigger, which may indicate better transfusion practices in the cases not meeting the specified indications. When assessing the older indication of Hb level of 7 to 10 g/dL versus the new indications specifying

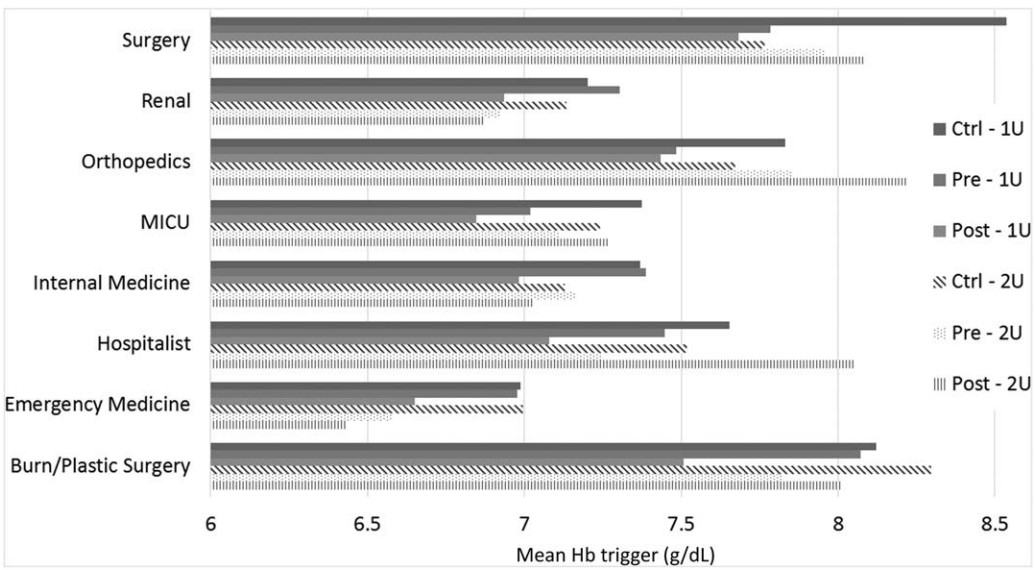

Fig. 4. Mean Hb triggers for 1U and 2U orders, by highest-usage clinical services. MICU = medical intensive care unit. Services with significant change from Ctrl to Pre subperiods only for 1U orders: MICU, surgery. Services with significant change from Pre to Post subperiods only for 1U orders: burn/plastic surgery, internal medicine, renal. Services with significant change from Ctrl to Pre subperiods only for 2U orders: burn/plastic surgery, emergency medicine. Services with significant change from Pre to Post subperiods only for 2U orders: hospitalist.

TABLE 5. Percent indication of total orders by 1U versus 2U orders and subperiod

Number of units:			1			2		
General indication	Ctrl/Pre indications	Post indications	Ctrl	Pre	Post	Ctrl	Pre	Post
Acute hemorrhage	Acute hemorrhage	Acute hemorrhage (> 15% EBL)	7.76%	9.91v	11.81%	20.10%	18.23%	22.76%
Hb < 7 g/dL	Anemia, Hb < 7 g/dL	Hb < 7 g/dL	28.59%	38.57%	60.37%	31.48%	39.59%	50.20%
Hb 7-10 g/dL, with specific indication	Anemia, Hb 7-10 g/dL	Hb 7-8 g/dL	62.47%	50.27%	17.41%	43.79%	35.43%	9.49%
		Hb 8-10 g/dL			4.52%			3.18%
Not necessarily indicated	Impaired tissue oxygenation	Hb > 10 g/dL	0.24%	0.09%	0.06%	0.08%	0.00%	0.20%
Other	Other (specify in comments)	Other (specify in comments)	0.94%	1.16%	5.82%	4.55%	6.75%	14.16%
Comments entered			3.88%	5.44%	7.69%	7.35%	5.09%	13.48%

EBL = estimated blood loss.

thresholds of 7 to 8 and 8 to 10 g/dL, the mean Hb trigger did not change when considering all new indication orders in conjunction, but showed a decrease for the lower new threshold and an increase for the higher new threshold. As both of the new 7 to 8 and 8 to 10 g/dL mean Hb triggers were within the threshold range, these findings demonstrate the improved specificity of the new indications. The fact that the Hb trigger by indication did not differ much for 1U versus 2U orders may imply that these improved indications were not the cause of changes in ordering 1U versus 2U. A possible limitation of these data are the inclusion of all RBC orders in this study rather than limiting these analyses to those cases where acute bleeding was not occurring as done in similar studies assessing Hb triggers showing much more positive results in a limited population.[18,20] Our data assessing proportions of orders below a Hb threshold of 8 g/dL (not included in this report) differ from those presented by Goodnough and colleagues,[21] which may be attributed to our lower baseline proportion for the Hb level of more than 8 g/dL population (20.7% in the Pre subperiod) compared to their study (57%) and again to our largely inclusive analysis.

Mean Hb triggers by clinical service also showed positive changes particularly for 1U orders, which are presumed to represent the less acute clinical cases, although our baseline and postintervention mean Hb triggers are generally higher than those reported in Frank and colleagues,[23] which can be attributed to methodologic differences in our studies. Of note, and similar to their findings, surgical services tended to have higher mean Hb triggers. Despite this, our success of decreased Hb triggers persisted even across surgical services for 1U orders.

No change in repeat orders

The fact that the number of repeat orders did not change during the Post subperiod indicates that our implementation of a restrictive transfusion policy encouraging 1U orders did not lead to patients having additional RBC units ordered after their initial order, implying that 1U orders were often sufficient. The 8-hour window for repeat orders was chosen to capture additional orders on the same shift, the typical time period for an additional order if staff were trying to get around the recommendation for single-unit orders.

Subpopulation analyses

All 1U:2U ratios increased across all subperiods for all services, locations, and provider types, except for the locations CARE (cardiac/renal unit) for the Ctrl to Pre periods and orthopedics for the Pre to Post periods and for staff physicians for the Ctrl to Pre periods. For the subperiod intervals where the ratio increased, larger increases were observed from the Pre to Post periods as opposed to the Ctrl to Pre periods for all locations, services, and provider types, except for the orthopedics service, which may be attributable to their primarily using blood acutely in the context of surgical care.

As nearly all highest-usage services and locations demonstrated significant changes in their 1U:2U ordering rates, these data imply institution-wide success of this intervention. However, analysis by service and locations allows opportunity to target those groups lagging for further intervention. Furthermore, although some positive changes in the 1U:2U ratio were observed from the Ctrl to Pre subperiods, the changes from Pre to Post subperiods were of much greater magnitude. This finding indicates that our intervention was adjunctive to any baseline changes in clinical practice within these subpopulations. In particular, given that resident physicians comprise approximately 80% of all orders and that the changes in their ordering practices were the most substantial for all provider types, this intervention was notably efficacious in the most common case. With respect to the differences in the Post subperiod ratios of 1U:2U orders between these subpopulations, it is worth noting that lower ratios were

observed in primarily those services that are procedural in nature, and that many of their 2U orders were preprocedural to prepare RBC units if needed.

Indications

The proportion of orders with an indication of "other" in our study increased across each subperiod to a maximum proportion of just over 10%, which is much less than the 26% to 31% previously reported in similar RBC transfusion CPOE studies.[22] Of particular note is that about 80% of orders with the "other" indication either did not have a comment entered or the comment addressed a procedurally-related indication.

Generalizability

Our study may be limited in generalizability due to individual institutional factors as well as the fact that multiple CDS changes were implemented simultaneously. Nevertheless, this analysis has attempted to address potential biases by demonstrating success across several dimensions of subpopulations. The use of a control period in this analysis demonstrates measurable success independent of any gradual or acute changes to clinical practice over time due to the general or specific dissemination of transfusion guidelines, such as changes in surgical techniques or acute Hb management, as well as seasonal variation in trauma rates.[24] Furthermore, this implementation and its success share many similarities to the contemporary growing body of evidence in favor of CPOE-oriented implementations using CDS to change RBC transfusion practices.[12,21,22] The largest limitation of this study is the lacking inclusion of transfusion-associated adverse event rates, which was confounded by concurrent interventions such as a switch during the study periods to all prestorage leukoreduced RBCs, precluding such analysis.

CDS without alerts

A strength of our study is the seamless nature of our intervention to implement a restrictive transfusion policy, which did not dramatically change provider workflow for ordering RBCs. In fact, the CPOE order change actually eased single-unit ordering, thereby encouraging this practice. This is significant in the context of previously reported restrictive RBC transfusion CDS interventions, which primarily consisted of increased educational outreach and workflow-disruptive ("hard stop") point-of-care alerts, with only one study not using an alert to implement CDS-directed practice change.[8,12,21,22] Although provider satisfaction with these changes was only collected anecdotally, any feedback was overall positive.

In conclusion, as such, use of CPOE and CDS to encourage a restrictive transfusion policy was found to be highly successful at our institution in changing provider practices with respect to proportions of 1U and 2U orders. These findings persisted across the subpopulations of primary clinical service, patient location, and type of provider. We were also able to demonstrate success in decreasing mean Hb triggers and decreasing overall utilization of RBCs.

CONFLICT OF INTEREST

The authors have disclosed no conflicts of interest.

REFERENCES

1. Vamvakas EC, Blajchman MA. Transfusion-related mortality: the ongoing risks of allogeneic blood transfusion and the available strategies for their prevention. Blood 2009; 113: 3406-17.
2. US Department of Health and Human Services. The 2011 national blood collection and utilization survey report. Washington (DC): Department of Health and Human Services; 2013 [cited 2014 Aug 2]. Available from: http://www.hhs.gov/ash/bloodsafety/2011-nbcus.pdf
3. Carson JL, Grossman BJ, Kleinman S, et al. Red blood cell transfusion: a clinical practice guideline from the AABB. Ann Intern Med 2012;157:49-58.
4. Carson JL, Carless PA, Hebert PC. Transfusion thresholds and other strategies for guiding allogeneic red blood cell transfusion. Cochrane Database Syst Rev 2012;4:CD002042.
5. Hogshire L, Carson JL. Red blood cell transfusion: what is the evidence when to transfuse? Curr Opin Hematol 2013;20: 546-51.
6. Salpeter SR, Buckley JS, Chatterjee S. Impact of more restrictive blood transfusion strategies on clinical outcomes: a meta-analysis and systematic review. Am J Med 2014;127: 124-31.e3.
7. Ma M, Eckert K, Ralley F, et al. A retrospective study evaluating single-unit red blood cell transfusions in reducing allogeneic blood exposure. Transfus Med 2005;15:307-12.
8. Rothschild JM, Mcgurk S, Honour M, et al. Assessment of education and computerized decision support interventions for improving transfusion practice. Transfusion 2007;47:228-39.
9. Oliver JC, Griffin RL, Hannon T, et al. The success of our patient blood management program depended on an institution-wide change in transfusion practices. Transfusion 2014;54:2617-24.
10. Callum JL, Waters JH, Shaz BH, et al. The AABB recommendations for the Choosing Wisely campaign of the American Board of Internal Medicine. Transfusion 2014;54:2344-52.
11. Hibbs SP, Noel S, Miles D, et al. The impact of electronic decision support and electronic remote blood issue on transfusion practice. Transfus Med 2014;24:274-9.
12. Yerrabothala S, Desrosiers KP, Szczepiorkowski ZM, et al. Significant reduction in red blood cell transfusions in a general hospital after successful implementation of a restrictive

transfusion policy supported by prospective computerized order auditing. Transfusion 2014;54:2640-5.

13. Combes JR, Arespacochaga E. Appropriate use of medical resources. Chicago (IL): American Hospital Association's Physician Leadership Forum; 2013.
14. Jamal A, Mckenzie K, Clark M. The impact of health information technology on the quality of medical and health care: a systematic review. HIM J 2009;38:26-37.
15. Black AD, Car J, Pagliari C, et al. The impact of eHealth on the quality and safety of health care: a systematic overview. PLoS Med 2011;8:e1000387.
16. Weir CR, Staggers N, Laukert T. Reviewing the impact of computerized provider order entry on clinical outcomes: the quality of systematic reviews. Int J Med Inform 2012;81: 219-31.
17. Hibbs SP, Nielsen ND, Brunskill S, et al. The impact of electronic decision support on transfusion practice: a systematic review. Transfus Med Rev 2015;29:14-23.
18. Rana R, Afessa B, Keegan MT, et al. Evidence-based red cell transfusion in the critically ill: quality improvement using computerized physician order entry. Crit Care Med 2006;34: 1892.
19. Fernández Pérez ER, Winters JL, Gajic O. The addition of decision support into computerized physician order entry reduces red blood cell transfusion resource utilization in the intensive care unit. Am J Hematol 2007;82: 631-3.
20. Adams ES, Longhurst CA, Pageler N, et al. Computerized physician order entry with decision support decreases blood transfusions in children. Pediatrics 2011;127:e1112-9.
21. Goodnough LT, Shieh L, Hadhazy E, et al. Improved blood utilization using real-time clinical decision support. Transfusion 2014;54:1358-65.
22. McWilliams B, Triulzi DJ, Waters JH, et al. Trends in RBC ordering and use after implementing adaptive alerts in the electronic computerized physician order entry system. Am J Clin Pathol 2014;141:534-41.
23. Frank SM, Resar LM, Rothschild JA, et al. A novel method of data analysis for utilization of red blood cell transfusion. Transfusion 2013;53:3052-9.
24. Minnesota Department of Health. Trauma system report FY2012. St Paul (MN): Minnesota Department of Health; 2014 [cited 2014 Aug 2]. Available from: http://www.health.state.mn.us/traumasystem/pubs/publications/annrptfy12.pdf