

Activity-based costs of blood transfusions in surgical patients at four hospitals

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BACKGROUND: Blood utilization has long been suspected to consume more health care resources than previously reported. Incomplete accounting for blood costs has the potential to misdirect programmatic decision making by health care systems. Determining the cost of supplying patients with blood transfusions requires an in-depth examination of the complex array of activities surrounding the decision to transfuse.

STUDY DESIGN AND METHODS: To accurately determine the cost of blood in a surgical population from a health system perspective, an activity-based costing (ABC) model was constructed. Tasks and resource consumption (materials, labor, third-party services, capital) related to blood administration were identified prospectively at two US and two European hospitals. Process frequency (i.e., usage) data were captured retrospectively from each hospital and used to populate the ABC model.

RESULTS: All major process steps, staff, and consumables to provide red blood cell (RBC) transfusions to surgical patients, including usage frequencies, and direct and indirect overhead costs contributed to per-RBC-unit costs between \$522 and \$1183 (mean, \$761 ± \$294). These exceed previously reported estimates and were 3.2- to 4.8-fold higher than blood product acquisition costs. Annual expenditures on blood and transfusion-related activities, limited to surgical patients, ranged from \$1.62 to \$6.03 million per hospital and were largely related to the transfusion rate.

CONCLUSION: Applicable to various hospital practices, the ABC model confirms that blood costs have been underestimated and that they are geographically variable and identifies opportunities for cost containment. Studies to determine whether more stringent control of blood utilization improves health care utilization and quality, and further reduces costs, are warranted.

The Cost of Blood Consensus Conference (COBCON), initiated by investigators and convened in 2003, set out to devise a comprehensive, standardized, and generalizable method to estimate the cost of blood that would be useful for payers,

ABBREVIATIONS: ABC = activity-based costing; AKH = General Hospital Linz; CHUV = Centre Hospitalier Universitaire Vaudois; COBCON = Cost of Blood Consensus Conference; EHMC = Englewood Hospital Medical Center; RIH = Rhode Island Hospital.

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various health care system configurations, and society as a whole.¹ Whereas previous attempts over the past three decades to assign a dollar amount to a unit of blood have been informative, methods have generally been limited in scope and detail,²⁻¹² leaving questions about their generalizability and applicability.

Hospital providers as well as the public health sector work with limited resources, and funds allocated for transfusions divert funding from competing clinical strategies. In some institutions use of hemostatic agents or factor concentrates to avoid ongoing blood loss or use of erythropoietic agents (with or without iron supplementation) to optimize perioperative red blood cell (RBC) mass is rejected because of cost, while funding for transfusions continues without question. An Austrian benchmark study has shown that there is a substitutive relationship between perioperative blood management modalities and transfusion utilization, that is, the calculated amount of perioperative blood loss and nontreatment of preoperatively existing anemia contributed to approximately 65% of all transfusions in elective surgery.¹³ Particularly if health care system administrators operate under the misperception that blood transfusions are relatively inexpensive, clinical alternatives or other essential services may be overlooked that could affect the quality of care. Therefore, decision making and resource allocation in health care systems would be better informed if the actual cost of blood plus all transfusion-related activities were known.

Data from four systematic studies²⁻⁵ estimated the cost per unit of transfused RBCs from \$332 to \$717 adjusted for inflation to 2008.¹⁴ Suspecting that these figures substantially underestimate actual blood costs,¹⁵ and recognizing the implications of blood cost undercounting, the COBCON participants set out to standardize a method and to provide more granular descriptions of processes and cost elements that improve upon prior estimates.¹ Correcting obvious inefficiencies in health care delivery is more relevant and urgent than ever. Given current global economics, accurate cost data are necessary to develop forward-looking solutions toward health care cost-containment.

Recognizing the complex steps leading up to and after a blood transfusion, COBCON previously reported all the process-flow elements and interdependencies contributing to the cost per unit of blood.¹ The next iteration performed by COBCON was to develop an activity-based costing (ABC) model to comprehensively account for the cost of blood.¹⁵ In contrast to methods used in previous studies,²⁻¹² the ABC model precisely maps all technical, administrative, and clinical processes occurring sequentially and in parallel. Each process step involves diverse personnel, capital, and consumable resources that are then multiplied by their usage frequencies. The ABC model has since been converted into a software tool, delivering as output a dollar amount for the cost per RBC unit, and the

cost per patient transfused. Tasks, resource consumption, and usage factors to populate the model were collected in the real-world surgical setting at four different hospitals, two in the United States and two in Europe. The ABC model describes in detail their blood usage trends and transfusion costs.

MATERIALS AND METHODS

Project overview: objectives and limitations

The objective of this project was to analyze the total cost of blood, accounting for all of the processes involved in administering an RBC transfusion in the surgical setting. The process begins with the arrival of the surgical patient to the physician's office or hospital for assessment, that is, when a transfusion might be anticipated, and continues through the consent procedure, the actual ordering and logistic processing of RBC units, all necessary laboratory services, and finally, the administration of the transfusion. Follow-up of acute transfusion-related reactions was included in the ABC model, although treatment of long-term complications and rehabilitation associated with a transfusion-transmissible disease, litigation, and reimbursement/indemnification for adverse events were omitted, because these events are rare or were beyond our scope. The impact of transfusions on hospital length of stay was also not evaluated. Data on transfusion-related activities and costs were collected only in the surgical setting to avoid the variability introduced by the transfusion decision, which can be highly specific to medical conditions. No attempt was made during collection of usage data to distinguish between different types of surgery. The data therefore represent a mean over all inpatient surgeries. Four hospitals, Englewood Hospital Medical Center (EHMC; Englewood, NJ), Rhode Island Hospital (RIH; Providence, RI), Centre Hospitalier Universitaire Vaudois (CHUV; Lausanne, Switzerland), and General Hospital Linz (AKH; Linz, Austria), served as data collection sites. As a criterion for participation, contractual arrangements were made with each hospital to supply financial data relevant to its transfusion-related activities.

Cost model

The process-flow model constructed by the COBCON participants (experts in transfusion medicine from blood collection facilities, government agencies, academia, hospitals, and clinical practice; listed in Appendix S1, available as supporting information in the online version of this paper) has been previously described.¹ The first iteration of the COBCON model expanded upon items previously outlined by the Lewin Group¹⁶ and included cost elements and interdependences associated with collecting, processing, and transfusing blood; donor

recruitment; and follow-up of transfusion sequelae from a societal perspective.¹ The subset of processes included in the present ABC model takes into account the cost of acquiring, delivering, administering, and monitoring RBC transfusions from a hospital perspective. Most importantly, the ABC model¹⁷ incorporates the frequencies of each process step occurring before, during, and after the actual transfusion is administered.

Data collection and process validation

All diagnostic, therapeutic, technical, laboratory, logistic, administrative, informational, educational, and quality activities associated with an RBC transfusion ordered for surgical patients (excluding pediatrics and transfusions administered in the emergency room) were observed and documented by trained study staff. For the purpose of this model, the term RBC unit refers primarily to allogeneic RBC units; however, autologous RBCs and whole blood units (together, these represent just 4.2% of all units transfused) were also accounted for. Costs associated with leukoreduction of all allogeneic RBC units were included as applicable. In Switzerland and Austria, the use of leukoreduced RBCs is mandatory.

To map all processes, discreet paths were followed: 1) that of a patient who was the potential recipient of the RBC transfusion and 2) that of a unit of blood beginning when the product was ordered from the local blood service and ending when the empty or unused outdated bag was discarded. The steps in each path and the personnel requirements were established by a consensus reached by the COBCON group. The patient path involved staff from surgical, medical, phlebotomy, clerical, nursing, transport, laboratory, and transfusion services and activities throughout all major clerical and medical pre-, intra-, and posttransfusion-related processes. The blood unit path involved the hospital's blood bank and related clerical, transport, laboratory, and quality control personnel and activities. The type of personnel performing activity steps, their experience level and salary grade, materials and third-party services consumed, and the frequency and activity time of equipment used per step were recorded.

Each major process was broken into discreet serial and parallel activity steps, mapped with time-in-motion methods using a stopwatch when applicable, and counted to determine the frequencies of occurrence within each activity step. Time-in-motion studies were performed in duplicate (at a minimum) and the times were averaged. In most cases, the variability was on the order of seconds, with some expected variation from the work speed of the practitioner. Differences between day and evening shifts were not considered. Major processes included minor subactivities whose time to complete and frequencies of occurrence were accounted for. Every process was laid out in the form of a flow chart and one or more experienced

staff member within each of the four hospitals was consulted before finalization and sign off on the flow charts. After performing the time-in-motion studies, each of these staff members reviewed the data for appropriateness. The validity of the time-in-motion studies for several of the main processes was tested by comparing the mean number of processes performed per staff members wherever possible (e.g., phlebotomists were asked how many procedures could be carried out per full working day), thus deriving the time spent per activity. Except for processes in the hospital blood banks, an estimated total of 20% was added to the process-captured times to account for the following: standby time during normal work hours and night shifts and non-patient-related labor time for continuous education, general administrative or clerical work, work-flow interruptions, waiting, breaks, and so forth. The amount of standby and non-patient-related labor time in the EHMC and RIH blood banks was calculated by deducting the cost of all major blood bank processes (e.g., product logistics, donor and patient blood-related tests) from the total RBC-related cost of the hospital blood bank, derived from the hospital's own 2006 blood bank cost center data, and adjusted to 2008 cost rates. As per common practice in Europe, at CHUV and AKH, all blood bank activities were outsourced to independent commercial entities and easily identified as third-party services invoiced to and paid for by these hospitals.

Actual local hospital costs were retrieved for the various materials, labor, service, and capital elements to compute costs for each major process ($pc_1, pc_2, \dots pc_n$) using the ABC software (see below). Usage factors (u_n), defined as the frequency of each major process occurring in 1 year, were derived from the hospitals' information, laboratory, and blood banking systems. Financial data from each hospital were used to cross-verify transfusion and usage data. Direct overhead costs (e.g., pathologist; blood bank, laboratory, and nursing staff; training and education; license fees for software) were either estimated or added directly from the hospitals' finance departments. Indirect (overhead) costs such as administrative and general expenditures, depreciation on buildings and fixed assets, employee benefits, operations of plant, laundry, housekeeping, nursing administration, central services/supplies, and others were added as a percentage of the process costs (administration and general expenditures included financial administration, telecommunications, information technology, executive offices, purchasing, human resources development, and others). The percentage of indirect costs relative to process costs was derived from each hospital's overall ratio between indirect costs (non-patient-related costs) and direct or operational (patient-related) costs. The necessary cost information was obtained from the accounting/financial departments of EHMC, CHUV, and AKH. The costs at RIH were estimated based on EHMC data.

ABC software and output

The complexity of the process and subprocess steps, occurring sequentially and in parallel, required development and utilization of custom ABC software. The software modules were developed by the Medical Society for Blood Management (Laxenburg, Austria) in collaboration with IDS-Scheer AG (Saarbrücken, Germany) and based on ARIS Business Architect Version 7.2 and ARIS Business Optimizer Version 7.2, both standard software packages from IDS-Scheer AG. Steps taken to populate the modules in accordance with elements of the ABC cost analysis are described in Table 1. Data collected using these steps provided input for broadly applicable and practical cost-calculating equations (Fig. 1) that were used to

compute individual process costs and total cost per RBC unit transfused in the surgical setting. The mean total process cost per unit of RBCs was obtained by dividing the total process cost at each institution by the number of RBCs transfused per year per site. Costs are presented as US dollars (\$USD). The mean exchange rate for the prior year (May 2008 to May 2009) was used to convert to \$USD from Swiss Francs (\$1 = SFr 1.12) and Euros (\$1 = €0.72). Costs captured before 2008 were adjusted for 2008 \$USD using Medical Care Service Price Indices from the US Bureau of Labor Statistics for the two US hospitals and using the Swiss Federal Health Insurance Index (CHUV) and actual cost rates from Human Resource Department (AKH). Small differences in calculated figures may have been introduced by rounding.

TABLE 1. Steps to calculate RBC cost using ABC method

Step	Description
1.	Identify each main process of the transfusion chain
2.	Identify the frequency or usage factor of each main process along the transfusion chain (e.g., administering and monitoring transfusion in the hospital unit)
3.	Identify all activity steps behind each main process along the transfusion chain
4.	Identify the usage factor of each activity step relative to the main process
5.	Capture the time required for each activity step
6.	Identify the costs of all resources consumed in each activity step
7.	Populate database with all information captured
8.	Apply formula (Fig. 1A) to determine the process cost per each RBC unit transfused
9.	Transfer the database electronically into ARIS Business Optimizer and compute the process cost of transfusion by <ul style="list-style-type: none"> • Labor cost • Material cost • Third-party cost • Capital cost
10.	Add all transfusion-related direct overhead costs (e.g., blood bank accreditation fees, undergraduate and postgraduate education)
11.	Add all hospital indirect overhead costs (derived from percentage of the hospital's nonmedical vs. medical costs)
12.	Apply formula for total cost per RBC unit transfused (Fig. 1B).

(A) Mean process cost per RBC unit transfused

$$pc_{ut} = \frac{u_1pc_1 + u_2pc_2 + \dots + u_npc_n}{x}$$

Where:

pc_{ut} = mean process cost per RBC unit transfused

u_n = usage factor of process n

pc_n = process cost of main process n

x = total number of RBC units transfused

(B) Total cost per RBC unit transfused

$$tc_{ut} = pc_{ut} + \frac{(c_{do} + c_{io})}{x}$$

Where:

tc_{ut} = mean total cost per RBC unit transfused

pc_{ut} = mean process cost per RBC unit transfused

c_{do} = transfusion-related direct overhead cost

c_{io} = transfusion-related indirect overhead cost

x = total number of RBC units transfused

Fig. 1. ABC equations. The usage factor of process n (u_n) is defined as the frequency of process n observed during 1 calendar year. The process cost of process n (pc_n) is a composite of labor cost, material cost, third-party cost, and cost for equipment utilization including capital cost used for one throughput of process n .

TABLE 2. Characteristics of participating hospitals

Characteristic	EHMC	RIH	CHUV	AKH
Location	Englewood, NJ	Providence, RI	Lausanne, Switzerland	Linz, Austria
Description of hospital	Acute care community teaching	University teaching	University-associated acute care	Tertiary care and teaching
Licensed beds	525	719	884	986
Inpatients/year	18,545	33,177	32,016	53,744
Inpatient surgeries/year	4,876	11,233	10,377	17,709
Computerized cell analyzer used in blood bank	No	Yes	Yes	Yes
Blood banking outsourced	No	No	Yes	Yes
Autologous blood collection program	No	Yes	No	No

TABLE 3. Surgical patient and RBC transfusion statistics*

Variable	EHMC	RIH	CHUV	AKH
Surgical patients				
Typed and screened	2413	7003	4470	6218
Crossmatched	1189	5009	2673	3623
Transfused	451	2237	1374	1498
Percentage of surgeries in which patients were transfused	9.2	19.9	13.2	8.4
Patients typed and screened/patients transfused	5.4	3.1	3.3	4.2
RBC units				
Total RBC units transfused in surgical patients†	1368	8306‡	5833	6107
Mean number of RBC units per transfused surgical patient	3.03	3.71	4.25	4.08
Crossmatched units/units transfused	2.9	2.3	2.3	2.9
Allogeneic (%) leukoreduced RBCs	30%	100%	>99%	>99%
	leukoreduced; 2% leukopoor	leukoreduced	leukoreduced by in-line filtration	leukoreduced by in-line filtration
Wasted/discarded units	27	180	74	98
Additional services§	54	71	239	1370

* Transfusions administered to pediatric surgical patients and those administered in an emergency room are excluded. Obstetric and gynecologic surgeries also excluded from CHUV site.

† Includes mostly allogeneic RBCs and a small number of irradiated and whole blood units (EHMC, CHUV, and AKH).

‡ Includes 895 autologous RBC units and no whole blood.

§ Where applicable, includes irradiating, washing, warming, and testing RBC units for cytomegalovirus.

RESULTS

Characteristics of participating hospitals

Data collection and process validation took place at two hospitals in the United States and two in Europe, whose hospital characteristics are detailed in Table 2. Participating hospitals varied in size, the number of surgical procedures performed, and the technical standards used in the blood banks; thus, the cost data collected reflect different scenarios and are broadly applicable.

Transfusion-related statistics in the surgical setting at participating hospitals as well as blood product wastage and other services are listed in Table 3. At the four hospitals combined, 21,614 RBC units were transfused in surgical patients in the year that data were collected (2007), of which 95.8% were allogeneic RBCs. Given the number of inpatient surgical procedures at the respective institutions, and assuming the simplest case that one patient underwent one surgical procedure, transfusions were administered in 12.6% of cases overall. On average, each surgical patient who was transfused received 3.03 (EHMC), 3.71 (RIH), 4.25 (CHUV), and 4.08 (AKH) units of RBCs.

Of the 20,104 surgical inpatients who had their blood typed and screened in preparation for a transfusion, 27.9% received a transfusion. Nontransfused surgical patients therefore contribute substantially to the overall cost of blood by consuming resources associated with pretransfusion processes, blood testing, and informed consent. The ratio of surgical patients with transfusion-related blood tests to the number of surgical patients transfused was 3.6 but varied by hospital. Fewer than 20% of surgical patients with transfusion-related blood tests at EHMC received a transfusion compared to 32, 31, and 24% at RIH, CHUV, and AKH, respectively. The ratios of surgical patients whose blood was crossmatched to the number of surgical patients transfused were similar among the four hospitals, as were the ratios of crossmatched to transfused units. Of the four hospitals, only RIH has an active autologous RBC collection program. Accordingly, more RBC units were wasted (2.1%) at RIH than at the other hospitals.

Product acquisition costs and usage

Mean blood product acquisition costs for each of the four hospitals are shown in Fig. 2. These costs include wasted

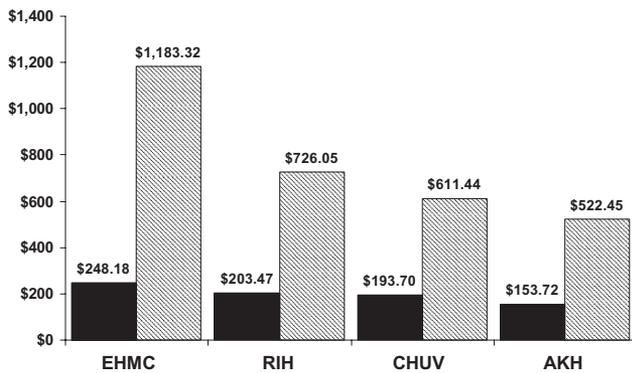


Fig. 2. Mean acquisition costs (■) and total ABC model costs (▨) per unit of blood. Mean per-unit acquisition costs included units that were wasted and additional services provided (e.g., irradiation, washing, cytomegalovirus testing) as described in the text. European currencies converted from the 1-year mean beginning May 2008 (CHUV conversion of \$1 = Sfr 1.12; AKH conversion of \$1 = € 0.72).

blood products and additional services such as irradiating, washing, and warming RBC units.

At EHMC, the mean acquisition cost per unit of RBCs was \$248, ranging between \$230 and \$265, depending on whether the unit was/was not leukoreduced. With 1368 units transfused in 2007, EHMC's overall product acquisition cost was \$339,509, comprising 21% of EHMC's blood-related expenditures for surgical patients.

The mean cost of each unit of RBC supplied at RIH was \$203 (range, \$197 to \$208). The acquisition cost of autologous blood at RIH, used less frequently than in-line-filtered leukoreduced RBCs, was \$10 more per unit, presumably because of extra handling and storage costs. RIH transfused 8306 RBC units in surgical inpatients in 2007, with overall product acquisition costs of \$1.69 million, or 28% of its expenditures related to blood transfusions.

The mean acquisition cost per RBC unit at CHUV was \$194, ranging from \$190 for in-line-filtered leukoreduced RBCs to \$225 for autologous blood. Total acquisition costs at CHUV for 5833 units transfused were \$1,129,854, or 32% of CHUV's blood-related expenditures for surgical patients.

The lowest blood product acquisition costs were recorded at AKH. In-line-filtered leukoreduced RBCs cost \$150 per unit. Autologous blood at AKH was less costly than a standard unit at \$135. The mean cost per unit was \$154, yielding a total acquisition cost for the 6107 units transfused of \$938,796. This amounted to 29% of blood-related expenditures for surgical patients at AKH.

Transfusion-related processes, usage factors, and costs

Major process steps, their corresponding usage factors, and costs associated with allogeneic RBC transfusions in

the surgical setting are summarized in Table 4. Details of specific subprocesses, their usage factors, and costs can be viewed in Tables S1 through S8 (available as supporting information in the online version of this paper). The flow diagram that illustrates the sequential and parallel steps and usage factors associated with the overall process (Level 1) of administering transfusions to surgical patients may be found in Appendix S2 (available as supporting information in the online version of this paper). This overall process begins when the surgical patient arrives at the physician's office or hospital and a supply of RBCs is requested from the blood bank and ends after all transfusion-related follow-up has been completed. A second flow diagram to illustrate steps and usage factors associated with one representative major process (Level 2; administering and monitoring a transfusion on the hospital ward) is provided in Appendix S3 (available as supporting information in the online version of this paper). Beginning at the time a transfusion decision has been made and the blood has been ordered from the blood bank, this process ends when the transfusion has been completed.

Main processes were generally similar among the hospitals, with some minor exceptions. CHUV and AKH had their blood bank services outsourced to independent blood banks and therefore accrued no costs associated with blood bank supply management. These costs were assimilated into the hospital acquisition costs for RBCs. CHUV employees carried out some courier services between the blood collection center and the independent blood bank. In perspective, blood bank supply management costs comprise less than 1% of the total blood-related costs accrued at the other hospitals.

Issuing transfusion-specific consent forms is a practice unique to the United States and contributed 1.2% to 2.5% to the overall blood transfusion-related costs incurred at EHMC and RIH; neither CHUV nor AKH has process steps nor costs associated with transfusion-specific consent forms.

After blood product acquisition cost and costs attributed to indirect overhead (discussed below), the top three major process steps were patient testing, administering and monitoring transfusions, and pretransfusion processes, collectively accounting for 24% to 36% of hospitals' spending on transfusion-related activities. The relative contribution of these three cost elements differed among the hospitals. For example, at EHMC, costs of administering and monitoring transfusions (7%) were less than for pretransfusion processes (12%) and patient blood testing (12%). At AKH, patient blood testing costs were highest (17%) followed by administering and monitoring transfusions (12%) and pretransfusion processes (7%). RIH and CHUV both had higher costs for administering and monitoring transfusions (11 and 14%, respectively)

TABLE 4. Major processes related to allogeneic RBC transfusions identified in the surgical setting of four hospitals with costs in US dollars and usage factors

In-hospital processes	EHMC		RIH		CHUV		AKH	
	Hospital cost per process step	Number of processes	Hospital cost per process step	Number of processes	Hospital cost per process step	Number of processes	Hospital cost per process step	Number of processes
Hospital blood bank supply management for RBCs	\$10,692	4,427	\$24,386	17,171	\$9,740	1,220	\$0.00	0
Pretransfusion processes	\$191,318	26,467	\$283,355	58,648	\$106,447	13,499	\$222,883	44,902
Patient blood testing processes	\$191,795	12,527	\$495,052	40,698	\$479,439	45,480	\$531,267	39,726
Specific transfusion consent form	\$18,621	13,860	\$150,614	12,462	\$0.00	0	\$0.00	0
Issuing and delivering components from blood bank to transfusion sites	\$5,594	1,779	\$45,792	7,735	\$37,899	3,051	\$17,280	3,987
Administering and monitoring transfusions	\$107,481	1,368	\$634,917	22,522	\$504,849	14,907	\$375,462	30,228
Managing acute transfusion reactions and hemovigilance	\$14,300	22	\$68,250	105	\$75,871	89	\$77,328	87
Posttransfusion logistics	\$5,150	1,644	\$1,404	260	\$1,469	520	\$167	75

Subprocesses for each in-hospital process listed above are detailed in Tables S1 through S8 (available as supporting information in the online version of this paper).

than on patient blood testing (8 and 13%, respectively) or pretransfusion processes (5 and 3%, respectively).

Managing acute transfusion reactions and hemovigilance were found to contribute minor costs, but relatively more is spent in Europe on these activities than at US hospitals (approx. 2% vs. 1%). Blood bank supply management, issuing and delivering components from the blood bank to the transfusion site, and posttransfusion logistics comprise less than 1.5% of institutional blood-related costs.

Direct and indirect overhead costs

Direct overhead costs include such elements as the blood bank staff (manager, laboratory technician, secretary); related overhead costs for the blood bank, laboratory, and nursing staff; costs attributable to a pathologist (part time); and costs to cover staff time at transfusion committee rounds. The direct overhead costs contributed only a very small percentage to the overall blood-related costs at the two European sites because their blood bank services are outsourced. Direct costs contribute approximately 3 and 5% at RIH and EHMC, respectively.

The elements contributing to indirect overhead, as described under Materials and Methods, are necessary to support the complex transfusion process. The percentage of indirect costs relative to the overall process cost was derived from the ratio of non-patient-related to patient-related costs at each hospital. Indirect costs consistently contributed the highest proportion of expenditures related to blood at all institutions, ranging from 32% to 33% in Europe to 40% to 41% in the United States.

Total estimated cost of blood

Using the ABC model to account for acquisition costs, all process steps, and all direct and indirect overhead costs, the total cost per RBC unit was \$760.82 ± \$293.74 (mean ± SD). As reflected in the SD, these costs vary widely among the participating hospitals. EHMC had the highest mean cost per unit of RBCs transfused at \$1183.32, followed by RIH at \$726.05, CHUV at \$611.44, and AKH at \$522.45. Figure 2 displays the ABC model estimate of the cost per unit of blood transfused at the four participating hospitals compared to the mean corresponding acquisition costs per unit. The ABC model estimate of total per-unit costs are between 3.2- and 4.8-fold that of product acquisition costs, even when product wastage and additional services are included in the acquisition cost.

The total cost of transfusions for surgical patients ranged from \$1.61 to \$6.03 million in 2007 (Fig. 3). All fractional cost components accounted for by the ABC model are shown, including blood product acquisition, all major process steps, and direct and overhead costs. Among the four hospitals, RIH had the largest total expenditures on

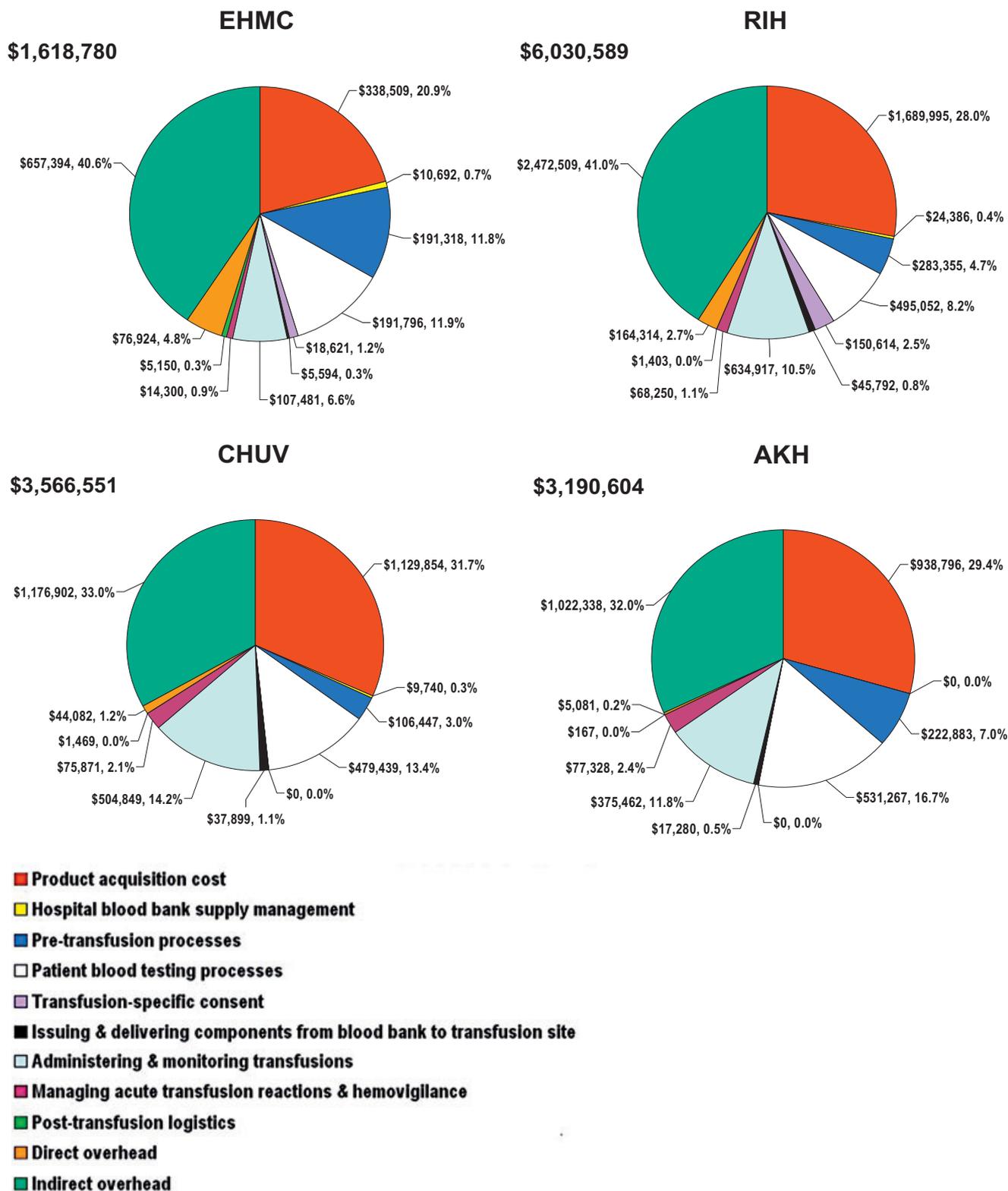


Fig. 3. Total costs of blood transfusions showing all contributing cost elements at two US and two European hospitals in 2007. Costs at CHUV (SFr) and AKH (€) converted to \$USD using 1-year currency conversion average (May 2008-May 2009). Percentages of each contributing element shown next to \$USD amount.

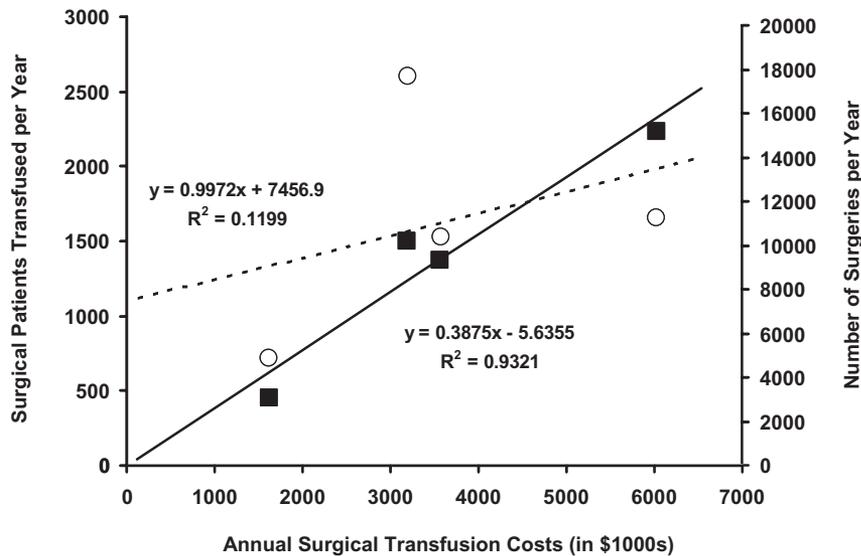


Fig. 4. Relationship of transfusion rates and surgical volumes versus total annual transfusion costs. (■) Transfusion rates versus total annual transfusion costs in surgical patients at the four hospitals (symbols left to right are EHMC, AKH, CHUV, and RIH). The solid trend line indicates a strong correlation ($R^2 = 0.93$) between transfusion rates and total annual transfusion costs. (○) Surgical volumes versus total annual transfusion costs in surgical patients at the same institutions. Broken trend line for this relationship shows little correlation ($R^2 = 0.12$) between the number of surgeries performed and total annual transfusion costs.

blood and related costs, followed by CHUV, AKH, and EHMC. Total transfusion costs were highly correlated with transfusion rate ($R^2 = 0.93$) but not with the volume of surgeries performed ($R^2 = 0.12$; Fig. 4).

DISCUSSION

ABC represents the most detailed and rigorous method utilized to date to account for the cost of blood transfusions. At project initiation, the COBCON group agreed upon the complex array of interrelated steps involved in providing blood transfusions to patients¹ and endorsed this project to evaluate total transfusion costs. ABC software modules were developed to capture blood-related costs from a hospital perspective and then populated with data collected from four hospitals. The resulting output from the ABC model yields, for the first time, a dollar amount for the cost per unit of blood that reflects the complexities of real-world blood utilization. From these data, mean transfusion costs per surgical patient and total expenditures on blood costs by institution are revealed. Importantly, contributions to total costs originating from various processes, direct and indirect overhead, and product acquisition are available for systematic review.

These results provide important insights into the actual costs of transfusions to hospitals. Product acquisition costs contribute only 21% to 32% to transfusion-

related expenditures. Mandatory transfusion-specific informed consent consumes measurable resources in the United States (i.e., 1.2%-2.5% of total expenditures) but not in Europe. Although not previously recognized, blood acquisition costs vary geographically, with regional variation noted between blood prices in Europe and in the northeastern part of the United States. The reason for these differences is not entirely clear, but warns against assuming that published unit prices of blood products are consistent across institutions.

Our study confirms that, beyond acquisition costs, the attributable cost per unit of blood has been underestimated and that costs vary across institutions and countries. The costs per unit at the four institutions exceeded those reported from even the most rigorous of previous studies, whose estimates ranged between \$332 and \$717²⁻⁵ when adjusted for 2008 dollars.¹⁴ In one of the most often cited of these studies⁵ materials plus fixed and variable labor costs contributed approximately 18% to the

total costs of blood transfusion in cancer patients. However, including all process steps and direct overhead, materials and labor appear to contribute much more to total transfusion-related costs.

Indirect overhead (including equipment, utilities, nonprofessional personnel, and property) was estimated by Cremieux and colleagues⁵ to contribute 46% to the cost of blood. We found that indirect overhead varied by institution, ranging from 32% to 41% of total expenditures, but in all cases contributed a higher proportion to total costs than blood product acquisition.

Total blood expenditures and utilization varied 2.3-fold across institutions. Total annual expenditures on blood-related activities for surgical patients at RIH were fourfold that of EHMC and twofold higher at European hospitals. These differences are not explained entirely by hospital size, number of beds, or surgical volume. Total annual blood costs are largely driven by transfusion rate, which includes such factors as the proportion of surgical patients transfused and number of RBC units per patient transfused. Reducing either or both factors has the potential to reduce costs dramatically.

Patients who do not receive transfusions also consume resources related to blood and contribute substantially to hospital expenditures. Higher mean costs per unit arise in part from testing and preparing surgical patients for transfusions. Whether the cost of preparing

patients for transfusion but not actually transfusing them is more appropriately applied to the blood conservation program than to the cost of transfusions can be debated; these may be joint costs that should be evenly distributed between transfusion and blood conservation efforts. Regardless of how these costs are allocated, were these practices to be streamlined, total hospital costs could be reduced, allowing reallocation of resources to other essential services.

We have illustrated the complexities involved in blood transfusions, beginning when the decision to perform surgery is made through posttransfusion administration and monitoring for a short time period thereafter.^{3,5} Although our approach is comprehensive, several limitations deserve mention.

First, we included all steps that impact a hospital, yet our analysis did not include cost elements related to donor recruitment and blood collection.¹ The number of nondonating individuals (>65 years of age) relative to the donating population (18-65 years of age) is constantly growing and could create supply shortages and further escalate acquisition costs.

Second, we did not address whether reducing the use of blood transfusions can improve patient outcomes and reduce costs further. Nevertheless, data are beginning to emerge that hospitals with stringent blood management programs receive high-quality "report cards" for outcomes associated with cardiac surgery.¹⁸⁻²⁰ Brevig and colleagues²¹ recently reported that standard quality improvement methods, in conjunction with multidisciplinary cooperation and education, achieved a hospitalwide culture shift that dramatically lowered perioperative blood utilization in cardiac surgery without compromising patient outcomes.

Third, our study captured only those processes related to managing acute transfusion-related adverse events. Events with long-term consequences are among the costliest contributors to health care expenditures²²⁻³⁰ and the most difficult to quantify.^{23,24,31-35} Because such events occur with a very low probability,^{24,33,35-40} they were not practical to include here. The uncertainties associated with calculating probabilities of illness, projecting future outcomes, and discounting can lead to highly complex pharmacoeconomic analyses that were not attempted here.⁴¹ Impact on quality of life, liability, and indemnification processes also can increase blood transfusion-related costs, and such factors have yet to be incorporated into quantitative cost analyses.^{42,43} Had any of these been included, our cost estimates would have been higher still. The question as to whether reducing transfusions and transfusion-related risks translates into cost savings is of considerable interest and clearly warrants further study.

The costs reported herein did not differentiate costs by type of surgeries performed and excluded those

costs incurred by nonsurgical patients. At these four institutions, between 12,000 and 36,000 medical inpatients per year would be additional potential recipients of RBC transfusions and related services. Although most processes and overhead are likely to be similar between surgical and medical patients, activities related to obtaining informed consent or crossmatching could differ relative to the number of transfusion episodes and units transfused. How these factors would raise or lower transfusion costs per unit cannot be predicted from this study. Nevertheless, a conservative estimate of including medical patients in this accounting system would predict at least a twofold increase per institution per year based on transfusion volume alone.

The purpose of developing a comprehensive model to determine the cost of blood is severalfold. First, it facilitates future research seeking to determine the cost-effectiveness of interventions for improving blood safety and optimizing blood utilization. Second, the model may be adapted to institutions wanting to increase institutional efficiency and reduce costs at each point of care. Comparing the costs of transfusions between centers that use internal versus outsourced blood banking services not only reflects current economic realities but also could trigger an evaluation of which approach is most cost-effective. Perhaps most importantly, these data raise awareness about the economic realities of blood and about its impact on individuals, institutions, and society and hopefully will encourage practitioners to think critically about blood usage patterns. In view of the ABC results and the fact that, in the United States alone, more than 14.5 million units of RBCs and whole blood are transfused annually,⁴⁴ total RBC transfusion-related costs exceed \$10 billion. Future studies using ABC methods will need to determine how many additional dollars are spent for platelets, fresh-frozen plasma, and cryoprecipitate transfusions. Randomized controlled studies and/or the application of Bradford Hill criteria⁴⁵ to establish causation from association might help determine if and to what extent transfusion-related events translate into additional hospital and intensive care unit stay days and whether other financial burdens are attributable to transfusions.

In conclusion, arriving at dollar figures for the per-unit cost of blood was a complex and lengthy undertaking, but these efforts may help to change the way the economics of blood transfusions are perceived. The ABC model of transfusion cost is robust and generally applicable and provides the most informed estimate of blood costs to date. Our detailed ABC-driven descriptions of cost elements provide a road map for institutional administrators worldwide to evaluate hospital processes and the impetus to initiate programs to reduce and optimize blood usage. Future applications of ABC method

will facilitate decision making about the cost-effectiveness of interventions to replace blood usage, providing an appropriate benchmark for comparing costs relative to clinical benefit.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

APPENDIX S1. Alphabetical list of COBCON participants
APPENDIX S2. Activity-based costing: process flow diagram (LEVEL 1: Surgical patients—allogeneic blood transfusion)

APPENDIX S3. Activity-based costing: process flow diagram (LEVEL 2: Surgical patients—administering & monitoring transfusion on ward)

TABLE S1. Hospital blood bank supply management for RBCs

TABLE S2. Pre-transfusion processes

TABLE S3. Patient blood testing processes

TABLE S4. Specific transfusion consent form

TABLE S5. Issuing and delivering components from blood bank to transfusion sites

TABLE S6. Administering and monitoring transfusions

TABLE S7. Managing acute transfusion reactions and hemovigilance

TABLE S8. Post-transfusion logistics