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On-Line Autotransfusion Waste Calculator

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Abstract: Cell concentrating and washing techniques are widely accepted and believed to be beneficial to cardiac surgery patients. During cell processing, platelets, proteins, and clotting factors are wasted as the plasma is washed away by saline. Beneficial and costly plasma constituents are sacrificed for the sake of removing potentially harmful drugs, debris, and naturally activated cells and chemical mediators. An interactive Microsoft Excel spreadsheet was designed to input patient and autotransfusion system (ATS) reservoir blood values, processed centrifugal bowl data, and hospital allogeneic blood product concentration and cost information. The spreadsheet calculates the number of wasted platelets, grams of protein, and milligrams of fibrinogen. The calculator further estimates the number of units and cost of allogeneic blood products needed to replace the wasted blood components. The simulation allows for variable levels of platelet activation and protein removal during centrifugal cell processing. Specific case scenarios may be simulated with the calculator. If a known volume of residual extracorporeal circuit blood with a known hematocrit, platelet count, and protein concentration is diverted to the ATS reservoir to be processed and washed after bypass, the number of units of fresh frozen plasma, platelet packs, and albumin concentrate needed to replace the wasted proteins and platelets may be calculated. When typical end-bypass patient and blood bank product values are input, the cost to replace the wasted blood components in 1550 mL of residual circuit blood with allogeneic blood products is about US $2097. There are risks and costs associated with replacing the platelets, proteins, and clotting factors wasted during cell washing compared with other techniques such as whole blood ultrafiltration. **Keywords:** cell processor, autotransfusion, cell washing, hemofiltration, ultrafiltration, Internet, ethics, blood salvaging, blood management. *JECT 2007;40:68–73*

Collection of whole shed autologous blood, concentrating and washing the red cells, and re-infusing the cells to the patient is an effective means of extracorporeal hemoconcentration and preservation of the patient's red cell mass during high blood loss surgical procedures (1). It is well established that whole blood centrifugation and cell washing wastes the buffy coat (BC), the plasma, and their cellular and proteineous constituents (2).

The wasted cellular and plasma blood components are sacrificed during cell washing because clinicians believe that potentially undesired plasma vasoactive and immunologically reactive substances need to be washed from the red blood cells that normally would have been discarded with shed suction blood (3). Studies have analyzed the contents of collected shed blood and have studied the physiologic benefits of the reinfusion of filtered surgical shed blood (4).

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Our purpose for creating the computer spreadsheet was to simulate the potential for retrieval of blood cells and proteins during the collection and washing of surgically shed autologous whole blood. Although the autologous red blood cell (RBC) volume saved may reduce the need, risks, and cost of allogeneic blood (5), the replacement of wasted BC, plasma cells, and proteins during large volume cell washing is costly (6).

The spreadsheet model (SM) allows clinicians to simulate the effect of changing several variables associated with autotransfusion and cell washing, inserting values from their own local or regional experiences. The SM predicts the amount and replacement cost of valuable wasted plasma and BC constituents. This article focuses on the specific clinical strategy of washing residual cardiopulmonary bypass (CPB) extracorporeal circuit contents vs. ultrafiltrating the circuit blood to preserve BC and plasma components (7).

MATERIALS AND METHODS

Well-known variables and mathematical expressions to estimate cell volumes and protein weights in shed autolo-

gous or residual extracorporeal circuit (ECC) blood were entered into a Microsoft Office Excel 2003 spreadsheet (Microsoft Corp., Redmond, WA). The Excel spreadsheet was converted to an interactive web page using SpreadsheetConverter (Framtidsforum I&M AB, Uppsala, Sweden).

The cells on the spreadsheet are color-coded so the user knows which cells are for user entry and which cells are calculated. When the user hovers the mouse cursor over the cell number, the definition and equation for the cell value appear in a comment box. After the user enters their simulation values, the user presses the "update" button and the SM calculates the estimated cell values based on the user's input. The results of the simulation may be printed or reset. A second Internet page (Table 1) is available that reports cell definitions and the equations used in each estimated spreadsheet cell.

The SM first allows the user to characterize the contents of the autotransfusion system (ATS) reservoir by entering the shed blood hematocrit, platelet count, and protein concentrations. The user enters the wound irrigant volume and anticoagulant solution volume, if any. The spreadsheet calculates the volume of autologous blood in the reservoir. The SM estimates the RBC mass (RBCM) and the plasma mass in cubic centimeters.

The user enters the ATS bowl volume and the expected percent bowl hematocrit. The SM returns the predicted number of processed bowls and the volume of the washed RBCs expected in the anesthesia reinfusion bag based on the RBCM in the ATS reservoir and the bowl characteristics. The SM predicts the millions (M) of wasted platelets, total milligrams (mg) of fibrinogen, and total grams (g) of protein wasted during cell washing after the user enters their estimated percent platelet activation or loss and the percent efficiency of protein removal by their ATS.

The user enters information about their blood bank's volume, platelet, and fibrinogen concentrations and costs

Table 1. Spreadsheet cell definitions and model equations.

1	The average patient (pt) hematocrit (hct) during shed blood collection
2	The average patient platelet count (plt cnt) during shed blood collection
3	The average patient total protein (port) concentration (conc) during shed blood collection
4	The average patient fibrinogen (fib) concentration during shed blood collection
5	Total volume in the reservoir before processing red cell mass (RBCM)
6	Surgical field irrigant volume (vol)
7	Heparinized saline volume
8	Total patient shed blood volume in reservoir [= reservoir – irrigant – hep saline vol]
9	RBCM in shed blood reservoir to be processed in bowl [= (hct/100) * reservoir vol]
10	Patient plasma volume in the reservoir [= patient shed vol – RBCM]
11	ATS device bowl volume
12	Expected ATS bowl end-processing hct
13	Number of bowls to be filled to process reservoir RBCM [= reservoir RBCM/(bowl vol * (bowl hct/100))]
14	Total bowl volume transferred to anesthesiologist patient transfusion bag [= # of bowls * bowl vol]
15	The percent of platelets that are activated by the ATS process—if not wasted
16	If there are 1,000 mm3 in one cc of plasma, the total number of platelets wasted [= (pt shed vol * 1000 mm3/cc * plt cnt)/10^6) * (100 – % plt activation)]
17	The percent of the proteins that are removed by the ATS process
18	The total number of mg of fibrinogen that are discarded [= pt shed vol/100 dl/l * fib conc * (% prot removal)]
19	The total number of gm of protein that are discarded other than the fibrinogen mg [= (pt shed vol/100 dl/l * prot conc * % prot removal) – (fib mg/1000)]
20	The volume in a platelet pack to determine the cost of platelets
21	The concentration of platelets in the platelet pack
22	The total number of platelets in the platelet pack example [= (plt pack vol * 100 mm3/cc * plt conc)/106]
23	The cost of the volume of platelets in the platelet pack
24	The volume in a unit of allogeneic fresh frozen plasma (FFP)
25	The concentration of fibrinogen in the FFP unit
26	Total number of mg of fibrinogen in the FFP unit example [= (FFP vol/100) * fib conc]
27	The cost of the FFP unit
28	The volume of the protein concentrate
29	The concentration by volume of the protein concentrate
30	Total number of gm of protein in the protein concentrate [= (prot conc/100) * prot vol]
31	Cost of the protein concentrate example
32	Number of platelet packs required to replace wasted platelets [= M wasted platelets/M of platelets in plt pack]
33	Cost to replace the total number of platelets expected to survive that were wasted during ATS [= # plt pack replacement * cost of plt pack]
34	Number of FFP units required to replace wasted fibrinogen [= mg wasted fibrinogen/mg in one FFP unit]
35	Cost to replace the total number of mg fibrinogen that are wasted during ATS [= # FFP unit replacement * cost of one FFP unit]
36	Number of protein vials required to replace wasted protein [= gm wasted protein/gm in one protein vial]
37	Cost to replace the total number of gm protein (minus fibrinogen) that are wasted during ATS [= # prot vials replacement * cost of one protein vial]
38	Total cost to replace fibrinogen, protein and platelets lost during ATS processing [= sum of plt pack cost + FFP unit cost + prot conc cost]
39	Cost of the Hemobag® and hemoconcentrator
40	Total cost of recovered waste minus cost of Hemobag® and hemoconcentrator [= cost of waste – cost of Hemobag® and HC]

for allogeneic platelet packs and fresh frozen plasma (FFP). If the user does not have information regarding their blood bank products, values from the literature are available such as found in Table 2 (8). The SM requires input for the volume, concentration, and cost of the user's routinely used protein substitute. The SM next estimates the total number and cost of platelet packs, FFP packs, and protein vials needed to replace the wasted BC and plasma components estimated by the user for a specific clinical scenario. The total cost is calculated.

Although not included in the SM, Equation 1 may be used to calculate the cost savings for avoiding the use of allogeneic packed red blood cells while cell centrifugation and washing or by concentration with ultrafiltration.

$$US\$ = \left[\frac{RBCM_{\mathrm{ATS}}}{Vol_{\mathrm{PRBC}} * (Hct_{\mathrm{PRBC}}/100)} \right] * US\$_{\mathrm{PRBC}} \qquad \text{Eq. 1}$$

where $RBCM_{ATS}$ = 100% Hct red blood cell mass (mL) saved by ATS; Vol_{PRBC} = average volume (mL) in one unit of PRBCs; Hct_{PRBC} = average Hct for unit of PRBCs; and $US\$_{PRBC}$ = average cost of one unit of PRBCs.

The SM was further designed to allow clinicians to enter the cost of the alternative therapy to washing residual ECC blood, the Hemobag technique (Global Blood Resources, Somers, CT), and to calculate the potential savings if the BC and plasma components are not washed away.

RESULTS

Table 3 presents a completed spreadsheet model for an ATS procedure where 2200 mL of 28% hematocrit autologous shed blood is mixed with 400 mL of heparin solution and 250 mL of wound irrigant. Realistic shed blood platelet count (150/mm^3), fibrinogen (125 g/dL), and protein concentrations (4.5 g/dL) are entered (9). A 225-mL bowl and a wash process that yields a hematocrit of 55% with 90% protein removal and 10% platelet retention are simulated. Values for the SM allogeneic blood product volumes, concentrations, and costs come from the Transfusion Medicine Department at The Ohio State University (M. Kennedy, personal communication, April, 2007; Table 2). The SM predicts that the replacement cost of the wasted BC and plasma cells and proteins would be US $3089 if the shed blood is ultrafiltrated rather than cell washed.

Table 2. Allogeneic blood component composition and cost.

Component	$ Cost	Vomume (mL)	Concentration	Note
Platelet pack	350	220	3.2×10^{11}/L	Platelet count
FFP	140	240	500 mg/dL	Fibrinogen concentration
Albumin	225	50	25%	Albumin concentration
pRBCs	195	360	57%	Percent hematocrit

$ Cost, cost to hospital; pRBCs costs, non-irradiated and not leukodepleted; all other values reported are mean values from quality monitoring.

Table 4 presents a completed spreadsheet model for not cell washing 1550 mL of residual CPB circuit blood transferred from the ECC to the ATS reservoir. The residual circuit blood values were derived from prior reports (7). The values for the bowl dynamics and the ATS preservation of proteins and platelets are similar to the values used in Table 2. The same allogeneic blood product volumes, costs, and concentrations used in Table 2 are repeated in Table 4. The SM predicts the cost to replace the residual circuit BC and plasma constituents is US $2097. Subtracting US $236 for a Hemobag and hemoconcentrator predicts a savings of US $1861 if the ECC blood is ultrafiltrated and not washed.

More than 800 international individuals have visited the ATS waste calculator website since it was activated in November 2006.

DISCUSSION

The on-line Excel spreadsheet model described here allows clinicians to evaluate the cost of their ATS waste using assumptions specific to their equipment and their institutional blood bank products and costs. According to the SM, the cost to replace the BC and plasma cellular and protein components is substantial and often is evaluated to thousands of dollars for routine ATS and post-CPB cell washing scenarios (Table 2). The SM dramatically shows (Table 4) that the use of the Hemobag technique to concentrate the residual CPB circuit blood will conserve the equivalent of thousands of dollars worth of allogeneic blood products for each individual patient where it is used.

Table 3 presents a simulated routine ATS procedure and raises an interesting point. The cost of the replacement blood products in the ATS procedure represents the possible savings if the shed blood and plasma were hemoconcentrated instead of centrifuged and washed. The reinfusion of unwashed shed blood is controversial, and many studies have shown that there is no significant measurable physiologic response to the immunologically active substances found in shed blood (10). There are clinical situations where the ATS reservoir shed blood volume may be ultrafiltered and safely reinfused as opposed to centrifuged and washed. The ATS waste calculator evaluates the financial motivation for reinfusion of shed autologous whole blood.

The SM has limitations in that clinicians are required to

Table 3. ATS waste cost estimator for typical ATS surgical procedure.

Patient's ECC Values			**Allogeneic Platelet Packs**		
Hematocrit %	28	1	Platelet volume cc	220	20
Platelet count K/mm^3	150	2	Platelet K/mm^3	320	21
Protein gm/dL	4.5	3	Platelet M	70.40	22
Fibrinogen mg/dL	125	4	Cost $	350	23
ATS Blood Reservoir			**Allogeneic FFP**		
Reservoir volume cc	2,850	5	FFP volume cc	240	24
Irrigant cc	250	6	Fibrinogen mg/dL	500	25
Heparinized saline cc	400	7	Fibrinogen mg	1,200	26
Patient's shed blood cc	2,200	8	Cost $	140	27
RBC Mass			**Protein Substitute**		
RBC Mass to process cc	616	9	Protein volume cc	50	28
Plasma mass cc	1,584	10	Protein conc %	25	29
			Protein gm	12.5	30
ATS Bowl			Cost $	225	31
Bowl volume cc	225	11			
Bowl hematocrit %	55	12	**ATS Waste Replacement Cost**		
Processed bowls #	5.0	13	Platelets packs	4.2	32
Anesthesia pRBC cc	1,120	14	Platelets $	$1,477	33
			FFP units	2.1	34
ATS Waste Components			Fibrinogen $	289	35
Platelet activation %	10	15	Protein vials	6.9	36
Wasted platelets M	297.0	16	Protein $	$1,559	37
Protein removal %	90	17	Total replacement $	$3,325	38
Wasted fibrinogen mg	2,475	18	HB / UF Costs	$236	39
Wasted protein gm	87	19	Recovered Savings	$3,089	40

enter values for parameters that they may not know. The morbidity and costs of treating diseases associated with transfusions, which can be very high, are not included in the SM. Clinicians may not know the shed blood hematocrit, platelet, fibrinogen, and protein concentrations. The clinician must also estimate the bowl hematocrit, which they may or may not have measured. The other parameters that are difficult to estimate are the platelet loss or retention and the protein removal in the ATS washing process, unless the clinicians have measured the values. To predict the number of replacement allogeneic blood product packs, assumptions are made about donor pack volumes and concentrations that are variable. Despite these limitations, it is easy to simulate the final cost consequences of small changes in any one parameter in the SM if there is concern regarding the accuracy of one scenario estimate.

The cost of replacing wasted shed plasma during cell washing is even greater when the loss of factors VII, VIII, IX, X, and XIII are considered in the replacement model,

Table 4. ATS waste cost estimator for residual CPB circuit blood.

Patient's ECC Values			**Allogeneic Platelet Packs**		
Hematocrit %	23	1	Platelet volume cc	220	20
Platelet count K/mm^3	140	2	Platelet K/mm^3	320	21
Protein gm/dL	3.8	3	Platelet M	70.40	22
Fibrinogen mg/dL	125	4	Cost $	350	23
ATS Blood Reservoir			**Allogeneic FFP**		
Reservoir volume cc	1,550	5	FFP volume cc	240	24
Irrigant cc	0	6	Fibrinogen mg/dL	500	25
Heparinized saline cc	0	7	Fibrinogen mg	1,200	26
Patient's shed blood cc	1,550	8	Cost $	140	27
RBC Mass			**Protein Substitute**		
RBC Mass to process cc	357	9	Protein volume cc	50	28
Plasma mass cc	1,194	10	Protein conc %	25	29
			Protein gm	12.5	30
ATS Bowl			Cost $	225	31
Bowl volume cc	225	11			
Bowl hematocrit %	55	12	**ATS Waste Replacement Cost**		
Processed bowls #	2.9	13	Platelets packs	2.8	32
Anesthesia pRBC cc	648	14	Platelets $	$971	33
			FFP units	1.5	34
ATS Waste Components			Fibrinogen $	203	35
Platelet activation %	10	15	Protein vials	4.1	36
Wasted platelets M	195.3	16	Protein $	$923	37
Protein removal %	90	17	Total replacement $	$2,097	38
Wasted fibrinogen mg	1,744	18	HB / UF Costs	$236	39
Wasted protein gm	51	19	Recovered Savings	$1,861	40

because economically, there are stand alone companies offering these recombinant factors to the hospital setting at exorbitant pricing. The off-label strategic supplemental use of specific clotting factors (e.g., FVII) during hemorrhage is being widely reported (11).

Table 4 shows the theoretical and potential cost savings associated with concentrating the residual ECC blood using the Hemobag technique in place of wasting the ECC plasma. It makes sense to preserve the plasma from residual circuit blood or from surgical shed blood (12) whenever possible to avoid the possible use of costly factor therapy. Clotting factor VII, IX, and X levels in the concentrated residual ECC blood have been reported as high as 259% of baseline (13) using the Hemobag. In addition, the patient infusion of allogeneic blood products is tantamount to an organ transplant with the typical recipient responses to foreign tissue and the associated diseases and costs (6).

Current validation of the ATS waste calculator is based on a review of the evidence-based literature applied to the

ATS cell washing model and on several observation studies of outcomes related to the ultrafiltration techniques. Future validation of the ATS waste calculator model will be based on the analysis of shed and allogeneic blood component content and their related costs. Autologous whole blood is at the very crux of individual survival, and it has quickly become the most precious and personal substance on the planet. The issues of blood component conservation through conscientious blood management and allogeneic transfusion avoidance are not just based on financial reasoning, but are much more complex and have both moral and ethical consequences, as well as the looming oversight that is on the horizon that will encompass all the individuals that are directly involved with this most precious of substances (14).

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