

Clinical Efficacy of Intraoperative Cell Saver Autologous Blood Salvage in Emergency Thoracoscopic Surgery for Massive Hemothorax.

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Abstract

Objectives: The objectives of this study were to investigate the efficacy of intraoperative Cell Saver autologous blood salvage in emergency thoracoscopic surgery for massive hemothorax.

methods: Nine consecutive cases, including 8 idiopathic hemopneumothoraxes and 1 late-onset traumatic hemothorax, for which emergency surgery was performed at Uji Tokushu-kai Hospital between 2009 and 2016, were retrospectively reviewed.

Results: The median total blood loss was 2200 cc (range, 840–4170 cc). Intraoperative Cell Saver autotransfusion with a median volume of 820 cc was performed in the last 7 patients. The first 2 patients who did not receive an autotransfusion required substantially more allogeneic blood transfusion (10 and 14U, respectively), while the other 7 autotransfusion patients required much smaller amounts of allogeneic transfusion (4 U in 3 and 0 U in 4). Four autotransfusion patients who did not undergo preoperative chest tube drainage and/or who had drainage of < 150cc received a greater amount of intraoperative autotransfusion (mean, 1162 ± 414 cc) than the other 3 patients who had a chest tube drainage of ≥ 150 cc (mean, 666.7 ± 150 cc; $P = 0.0574$). Torn and bleeding arteries were thoracoscopically clipped in 7 patients. One patient with right lung collapse over 2.5 days developed severe acute respiratory distress syndrome intraoperatively, but fully recovered.

Conclusions: Utilizing intraoperative autologous blood salvage with the sparing of preoperative chest tube drainage to the maximum possible extent is an efficient strategy to reduce both overall blood loss and allogeneic blood transfusion in emergency thoracoscopic surgery for massive hemothorax.

Introduction

Massive hemothorax is one of the most common thoracic emergencies in clinical practice. Patients with massive hemothorax may deteriorate quickly with hemodynamic instability resulting from progressive blood loss into the pleural cavity. Urgent chest tube drainage is usually performed especially when tension thorax is suspected. If the patient has persistent hemodynamic instability and suspected continuous bleeding, emergency surgical intervention and immediate blood transfusions are required. In such patients, blood transfusions by intraoperative autologous blood salvage (IABS) could limit the overall blood loss and reduce the need for allogeneic transfusion, which is associated with known morbidities and mortalities. In the present study, we retrospectively evaluated a series of consecutive patients who presented with massive hemothorax and were treated with emergency thoracoscopic surgery, with a focus on the use of the Cell Saver IABS and the reduction of allogeneic blood transfusion.

Materials And Methods

The cases were comprised of 8 idiopathic hemopneumothoraxes and 1 late-onset traumatic hemothorax. All the patients had a total blood loss of ≥ 800 cc (mean, 2524 ± 1232 cc; range, 840–4170 cc) and underwent emergency complete thoracoscopic surgery in which the surgeon's vision was only through

video monitoring at Uji Tokushu-kai Hospital between 2009 and 2016. In the last 7 cases, the Cell Saver autotransfusion device (Cell Saver 5+; Haemonetics Japan, Tokyo, Japan), a red blood cell recovery system, was used intraoperatively for blood transfusion.

Statistical Analyses

Data were collected and analyzed using the GraphPad Prism version 5.04 software (GraphPad Software, Inc., San Diego, CA, USA) by means of an unpaired *t*-test with Welch's correction. All data are expressed as mean \pm standard deviation. Statistical significance was set at $P < 0.05$.

Results

The presented cases consisted of 8 men and 1 woman, with a mean age of 35 ± 13 years. Five of the 9 patients were active smokers. Hemothorax was on the right and left sides in 3 and 6 patients, respectively. Seven patients (78%) showed signs of hypovolemic shock in the form of tachycardia and/or hypotension upon admission (Table 1). The chest radiographs taken on the initial hospital visits showed a significant mediastinal shift in all the patients, except for Patient 6, who had the lowest total blood loss (840 cc; Table 1). Except for Patient 6, all the other patients were transferred to our institution after their initial visit to another hospital. In 5 of the 8 patients, chest tube drainage was performed at the initial visit. Patients 5, 6, and 8 did not have preoperative chest tube placement. In Patients 2, 3, 4, and 9, who had chest tube drainage, tubes were clamped after blood volume ranging from 100 to 1900 cc had been drained. Patient 1 had an ineffective chest tube with no drainage since placement. Patient 7 underwent chest tube drainage twice; initial chest tube was occluded by clot after 600 cc of blood was drained, and the second chest tube was placed upon arrival at our hospital with a subsequent drainage of 1400 cc prior to clamping. The mean total preoperative chest tube drainage in Patients 2, 3, 4, 7, and 9 was 1190 ± 825 cc (range, 100–2000 cc). Except for Patients 1 and 2, all the other patients underwent IABS using the Cell Saver 5+ autotransfusion device, with a mean autologous blood volume of 950 ± 404 cc (range, 520–1700 cc). Patients 1 and 2, who did not undergo IABS, required substantially more allogeneic blood transfusion (10 and 14U, respectively), while the other 7 IABS patients required far smaller amounts of allogeneic transfusion (4 U in 3 and 0 U in 4 patients). Among the 7 IABS patients, 3 who did not undergo preoperative chest tube drainage (Patients 5, 6, and 8) and/or one who had a chest tube drainage of < 150 cc (Patient 3) tended to receive greater amount of IABS transfusion (mean, 1162 ± 414 cc; range, 720–1700 cc) than the 3 patients who had a preoperative chest tube drainage of ≥ 150 cc (Patients 4, 7, and 9) with a mean IABS transfusion volume of 666.7 ± 150 cc (range, 520–820 cc; $P = 0.0574$; Fig. 1). By contrast, in 3 IABS patients (Patients 3, 5, and 8), who received autologous transfusions of ≥ 1000 cc, the amount of preoperative chest tube drainage (mean, 33.3 ± 57.7 cc; range, 0–100 cc) showed a decreasing trend, as compared with that in the other 4 IABS patients (Patient 4, 6, 7, and 9; mean, 1125 ± 984 cc, range 0–2000 cc) who had autotransfusions of < 1000 cc ($P = 0.0569$, Table 2).

Table 1
Patient characteristics

Patient	Age (years)	Sex	Side	Etiology	Hemodynamic instability on admission	Mediastinal shift on chest radiographs
1	42	M	L	SHP	+	+
2	39	M	L	SHP	+	+
3	22	M	R	SHP	+	+
4	26	M	R	SHP	-	+
5	16	M	R	SHP	+	+
6	38	F	L	SHP	-	-
7	37	M	L	SHP	+	+
8	61	M	L	traumatic	+	+
9	30	M	L	SHP	+	+

M: male, F: female, L: left, R: right, SHP: spontaneous hemopneumothorax

Table 2
The amount of blood loss and transfusion

Patient	Preoperative chest tube placement	Preoperative chest tube drainage (A)	Intrathoracic blood at surgery (B)	Total blood loss (A)+(B)	Cell Saver IABS	Autologous transfusion	Allogeneic transfusion
		(cc)	(cc)	(cc)		(cc)	(U)
1	+	none	2200	2200	-	0	10
2	+	1350	2820	4170	-	0	14
3	+	100	2030	2130	+	1227	4
4	+	600	700	1300	+	660	4
5	-	none	1530	1530	+	1000	0
6	-	none	840	840	+	720	0
7	+	2000	1630	3630	+	820	0
8	-	none	4120	4120	+	1700	4
9	+	1900	900	2800	+	520	0
IABS: intraoperative blood salvage							

The time between the onset of hemothorax and surgery (onset-to-surgery time) was variable (range, 6.6–60 hours) with a mean of 21.8 ± 17 hours. Three patients (Patients 2, 7, and 9) underwent surgery within 10 hours; 2 (Patients 1 and 8) within 20 hours; 3 (Patients 4, 5, and 6) between 20 and 40 hours; and 1 (Patient 3), at 60 hours after the onset of hemothorax (Table 3).

Table 3
Correlation between time course and blood loss

Patient	Total blood loss (A) (cc)	Onset-to-surgery time (B) (hours)	Temporal admission to the first hospital	Mean bleeding rate (A)/(B) (cc/hour)	Transfer-to-surgery time (hours)
1	2200	16	+	138	2
2	4170	9	-	463	1
3	2130	60	-	36	1.7
4	1300	28	+	46	2
5	1530	27	+	57	1.7
6	840	35	-	24	2.3
7	3630	8.5	-	427	3.2
8	4120	18	-	229	12
9	2800	6.6	-	424	1.5

The mean bleeding rate, that is, the total blood loss per hour (onset-to-surgery time), which represents the mean speed of bleeding, was widely variable (range, 24–463 cc/hour). Three patients who had a mean bleeding rate of ≥ 400 cc/hour (Patients 2, 7, and 9) simultaneously had an onset-to-surgery time of < 10 hours and further had a larger amount of total blood loss exceeding 2800 cc. These 3 patients had significantly higher mean bleeding rate (mean, 438 ± 21.7 cc/hour; range, 424.0–463.0 cc/hour; $P = 0.006$), significantly shorter onset-to-surgery times (mean, 8.03 ± 1.27 hours; range, 6.6–9.0 hours; $P = 0.0091$; Fig. 2), and significantly larger total blood loss volumes (mean, 3533 ± 690 cc; range, 2800–4170 cc; $P = 0.0246$; Fig. 3), than the other 6 patients.

All the patients underwent emergency thoracoscopic surgery within 3 hours of arriving at our institution (mean, 1.92 ± 0.64 hours), except for Patient 8, who had a traumatic hemothorax and underwent thoracoscopic surgery 12 hours after arriving (Table 3).

In 7 patients (78%), torn, bleeding arteries were identified and clipped in a complete thoracoscopic surgery (Online Resource 1). In the first 5 cases (Patients 1–5), mini-thoracotomies ≥ 3.0 cm in length were made, whereas in the last 4 cases, only ports with a length of < 2.0 cm were made to enter the thorax without a mini-thoracotomy. The incision size required for surgery has since become even smaller (Table 4). In 5 of the patients who had a higher amount of blood loss and transfusion, 2 chest tubes were effectively placed at the end of the surgery in the apex and base for prophylaxis against postoperative lung atelectasis with a basal accumulation of effusion (Table 4).

Table 4
Findings from the thoracoscopic surgery and hospital stay

Patient	Mini-thoracotomy size (cm)	Port size (mm)	Clipping of torn artery	Chest tubes	Hospital discharge (POD)
1	7	10	apex × 1	apex	16
2	5	10, 5	apex × 1	apex, base	14
3	4	10, 5	NI	apex, base	12
4	3	10, 5	apex × 1	apex, base	9
5	3	5	apex × 1	apex	7
6	none	20, 5, 5	apex × 1	apex	8
7	none	15, 15, 5	apex × 1	apex, base	9
8	none	20, 5	NI	apex, base	11
9	none	15, 5, 5	apex × 1	apex	8
NI: torn arteries not identified, POD: postoperative day					

Perioperative complications were encountered in some patients. Lung atelectasis accompanied with basal accumulation of effusion was found in Patient 1 but was resolved by placing another chest tube in the base. Patient 3, who had a complete right lung collapse over 2.5 days, and a large amount of total blood loss (2130 cc) experienced severe acute respiratory distress syndrome (ARDS), which started intraoperatively. However, the patient fully recovered following intensive care, including 3 days of mechanical ventilation, administration of methyl prednisolone, vigorous diuresis, and bronchoscopic toileting, and was subsequently discharged on postoperative day 12.

Discussion

Few studies have been reported on the usefulness of IABS in emergency surgery for massive hemothorax [1–3]. Although massive hemothorax with significant blood loss and hemodynamic instability ordinarily requires urgent intervention, including emergency surgery and allogeneic blood transfusions, an innovative IABS technique can reduce the overall blood loss and thereby avoid the need for allogeneic transfusion, which is associated with known adverse clinical outcomes and life-threatening complications. IABS can also save time for the preparation of allogeneic blood. IABS was introduced in the early 1980s and rapidly gained clinical acceptance as a safe alternative to allogeneic transfusion. IABS is now commonly used during surgeries with the potential for massive bleeding, such as cardiac surgery, vascular surgery, spinal surgery, or liver transplant [4, 5]. IABS systems, including Haemonetics Cell Saver 5+, which was used in this study, entail the collection and reinfusion of a patient’s own blood that is lost throughout surgery. First, it collects shed blood from the operative field into a centrifuge. Heparin anticoagulant is added, and the

contents are filtered to remove platelets, white blood cells (WBCs), free hemoglobin, and concomitants such as clots and lipids from the operating field. RBCs are then washed with saline, separated by differential centrifugation, and reinfused. The final blood consists of washed, concentrated RBCs with a hematocrit count of approximately 53.7–60% suspended in normal saline solution. The blood processing speed is 3–5 min. IABS systems have been reported to bring about significant attenuation of the inflammatory response in processed blood, demonstrating the effective elimination of several inflammatory cytokines (TNF- α , IL-2, IL-6, IL-8, etc.), WBCs, and markers of leukocyte activation (myeloperoxidase and elastase) [6, 7]. On the other hand, RBCs salvaged from the operating field in IABS have been suggested to result in bleeding due to dilutional coagulopathy caused by the elimination of platelets and coagulation factors [1, 2]. Recent evidence has, however, demonstrated that no significant coagulopathy is associated with IABS [8]. IABS also carries the risk of bacterial contamination from the operating fields, but none of the patients in our study developed an infection.

Adverse clinical outcomes among recipients of allogeneic blood transfusion have been widely reported, such as higher rates of serious perioperative infections, post-injury multiple-organ failure, pulmonary, renal, and cardiac complications, and higher mortality rate [9]. “Blood storage lesions” and subsequent immune suppression are likely important contributors to these morbidities. Older allogeneic blood is known to increase morbidity and mortality as compared with newer blood [10]. Refrigerated storage of blood results in a “storage lesion,” characterized by rheological changes, metabolic derangements, changes in oxygen affinity and delivery, oxidative injury to lipids and proteins, RBC shape change, loss of membrane carbohydrate, and reduced RBC lifespan. These changes become more pronounced with longer storage, promoting in vivo hemolysis [11, 12]. Other known serious adverse events associated with allogeneic blood transfusion include incompatibility reactions and transfusion-transmitted diseases. Furthermore, many countries often face a shortage of allogeneic blood and issues of increasing cost [13]. Another life-threatening complication of allogeneic transfusion includes transfusion-related acute lung injury (TRALI), which was reported in approximately 2.4% of cardiac surgery patients with 13% mortality in a Dutch-nested, case-control cohort study [14]. TRALI is the acute onset of non-cardiogenic pulmonary edema that occurs within 6 hours of transfusion and is the leading cause of transfusion death. TRALI is thought to be a two-event entity. The first event is the presence of an inflammatory condition in the host that causes endothelial activation, which leads to neutrophil sequestration and priming in the lung. The second event is transfusion of an allogeneic blood product containing either donor leukocyte antibody or bioactive lipids (lysophosphatidylcholines) that accumulate during storage of RBCs or platelets, providing additional signals for neutrophil activation, resulting in the clinical syndrome of pulmonary edema. The onset of TRALI correlates with the total volume of RBC products stored for ≥ 14 days [15, 16]. In the present study, Patient 3, who had 4 U of allogeneic and 1227 cc of IABS transfusions, experienced severe ARDS. While severe ARDS was accompanied by massive, watery intra-airway secretion that started intraoperatively in this case, how much this ARDS is attributable to TRALI by allogeneic blood transfusion rather than by re-expansion lung edema following prolonged lung atelectasis (≥ 2.5 days) or a massive fluid infusion to compensate for hemodynamic instability caused by large blood loss (2130 cc) is unclear. Generally, patients with massive hemothorax, who have undergone a large volume overload with both fluid and blood, and especially with a more prolonged period of lung collapse, seem highly vulnerable to re-

expansion lung edema. Tension thorax, which is prone to accompany hemopneumothorax rather than simple hemothorax, may partially contributed to re-expansion edema.

Owing to such adverse clinical outcomes and life-threatening complications, allogeneic blood transfusion should be avoided as much as possible. From this standpoint, IABS is an effective blood conservation strategy in surgeries with massive bleeding.

Strong clinical and economic evidence supports the use of IABS in surgeries with massive bleeding, as IABS results in a significant reduction in allogeneic RBC and coagulant product transfusions [4], earlier discharge from the intensive care unit, and a lower incidence of myocardial infarction in cardiac [5, 8] and pediatric cardiac surgery patients [17]. On the other hand, IABS is believed to be cost-effective only when large blood loss equivalent to 1–2 units of RBCs can be salvaged during surgery [13]. While a minimum of 600–800 ml of intraoperative bloodshed is required for the Cell Saver devices to process, only one-third of this amount is returned. In cases where the system is set up and fails to collect enough volume to process, a considerable cost is incurred for zero benefit [18].

As the blood drained through the chest tube cannot be processed for reinfusion because of its considerable risk of contamination, the greater the preoperative chest tube drainage of intrathoracic shed blood, the less the amount of blood available for IABS, thereby increasing the likelihood of a subsequent allogeneic transfusion in surgery for massive hemothorax. Among the 7 IABS patients in the present study, 3 who did not undergo preoperative chest tube drainage (patients 5, 6, and 8) and/or one who had a chest tube drainage of < 150 cc (Patient 3) showed a trend toward receiving more IABS transfusions (mean, 1162 ± 414 cc), than the 3 patients who had preoperative chest tube drainage of ≥ 150 cc (patients 4, 7, and 9; mean, 666.7 ± 150 cc; $P = 0.0574$); that is, the amount of IABS transfusion was inversely proportional to the amount of preoperative chest tube drainage and allogeneic transfusion, which means that the lower the amount of chest tube drainage, the larger the amount of IABS autotransfusion, and the fewer units of allogeneic transfusion were required irrespective of the total amount of shed blood. Thus, from the standpoint of promoting maximal IABS utilization and limiting allogeneic blood transfusion, preoperative chest tube drainage should be spared to the maximum possible extent as long as hemodynamics remain stable.

Hemodynamic status at the first hospital visit varied in each patient; some patients who had continuous or vigorous bleeding from the onset of hemothorax might appear with relatively unstable conditions, whereas others who had substantial initial bleeding with the subsequent hemostasis caused by the spasm of torn arteries, or by compression of the intrathoracic clot might show more stable hemodynamic conditions. In the present study, 3 patients who had an onset-to-surgery time of < 10 hours (patient 2, 7, and 9) simultaneously had a mean bleeding rate of ≥ 400 cc/hour and further had a larger total blood loss exceeding 2800 cc. These three patient had a significantly higher mean bleeding rate (mean, 438 ± 21.7 cc/hour; range, 424.0–463.0 cc/hour; $P = 0.006$; Fig. 2), significantly greater total blood loss (mean, 3533 ± 690 cc; range, 2800–4170 cc; $P = 0.0246$; Fig. 3), and further significantly shorter onset-to-surgery time (mean, 8.03 ± 1.27 hours; range, 6.6–9.0 hours; $P = 0.0091$), than the other 6 patients. These results suggest that more vigorous arterial bleeding probably started concurrently with the onset and continued

until surgery in these 3 patients. This high mean bleeding rate (mean, 438 ± 21.7 cc/hour, range, 424.0–463.0 cc/hour) could have led to hemodynamic instability sooner, promoting surgical intervention at an earlier timing (Online Resource 1).

As for surgical approaches, all patients in this study were treated with complete thoracoscopic surgery, which is less invasive and can provide far superior vision as compared with thoracotomy alone. It is well-suited for observing the entire pleural cavity following evacuation of shed blood and clot, and for searching and clipping the bleeding torn arteries. The thoracoscopic procedures have been refined over the years, and the incision sizes have decreased. This is partially because it has turned out that the evacuation of massive blood and coagula is feasible even through smaller-sized ports in most cases.

In the present study, the chest radiographs taken at the initial visit to the hospital demonstrated a significant mediastinal shift in all the patients except for Patient 6, who had the lowest net blood loss. Once tension thorax with some hemodynamic instability is demonstrated in patients with hemothorax or hemopneumothorax, immediate chest tube placement is usually required. All the patients in this study except for Patient 8 had spontaneous hemopneumothorax that tended to accompany tension thorax more easily than simple hemothorax, with chest tube placement required more frequently. In these cases, the best practice might be to place the chest tube first and then clamp it when the hemodynamics is stabilized with the relief of the mediastinal shift by the evacuation of air and blood. This can minimize unnecessary blood loss and allow for scheduling of early emergency surgery. On the basis of the results of this study, we propose the following algorithm for treating hemothorax with hemodynamic instability: 1) stabilization of hemodynamics on arrival by fluid infusion, 2) radiological diagnosis (chest radiography and/or computed tomography scan), 3) chest tube placement for the relief of tension thorax as required, 4) preparation of allogeneic blood as needed, and 5) scheduling early emergency thoracoscopic surgery in combination with IABS when ≥ 800 cc of intrathoracic blood is suspected.

In conclusion, utilizing the Cell Saver IABS with the sparing of preoperative chest tube drainage to the maximum possible extent is an efficient strategy to reduce both overall blood loss and subsequent allogeneic blood transfusion in emergency thoracoscopic surgery for massive hemothorax.

Declarations

Ethics approval and consent to participate

The present study was ethically approved by Institutional Review Boards in Uji Tokushu-kai Hospital (#2016-10- \square). Informed consent was obtained from all patients.

Consent for publication

Informed consent for publication was obtained from the patients.

Competing interests

The authors have no relevant competing interests.

Funding

The authors have no relevant funding.

Authors' contribution

HI designed the study, performed surgery, and analyzed the data. TT participated in the care of the patients. HN, TK and JH participated in surgery, the care of the patients, and the data collection.

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Figures

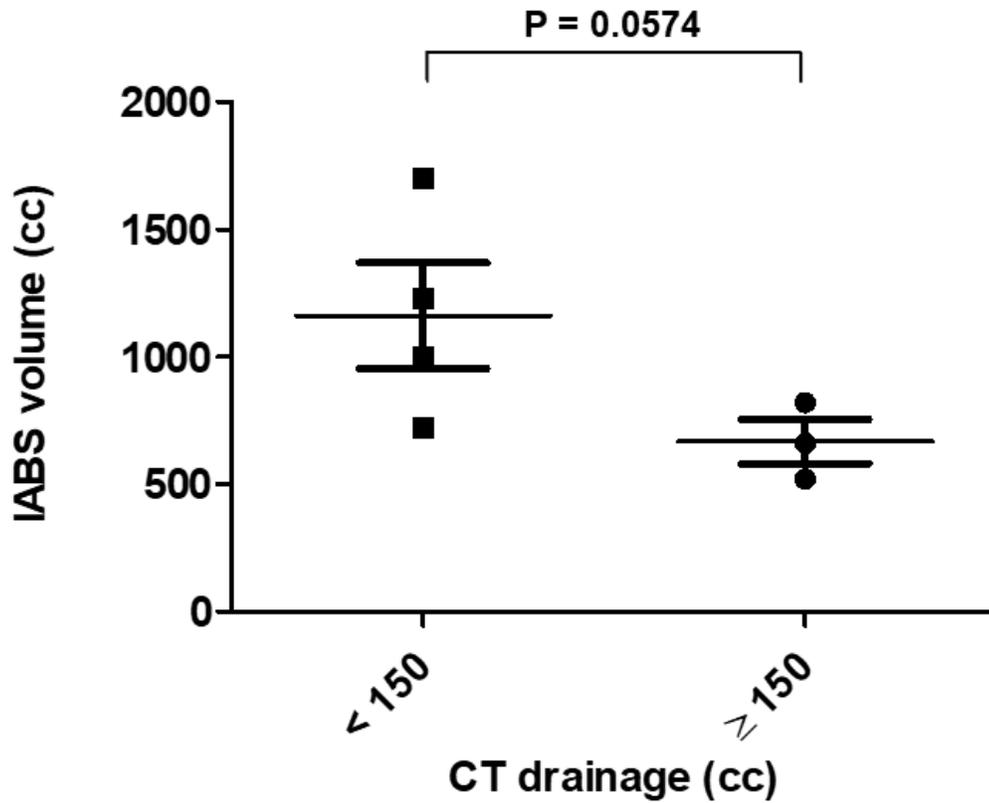


Figure 1

Among the 7 IABS patients, 3 who did not undergo preoperative CT drainage (Patient 5, 6, and 8) and/or one who had a CT drainage of < 150cc (Patient 3) tended to receive greater amounts of IABS transfusion (mean, 1162 ± 414 cc), than the 3 patients who had preoperative CT drainage of ≥ 150 cc (Patient 4, 7, and 9) with a mean IABS transfusion of 666.7 ± 150 cc ($P = 0.0574$).

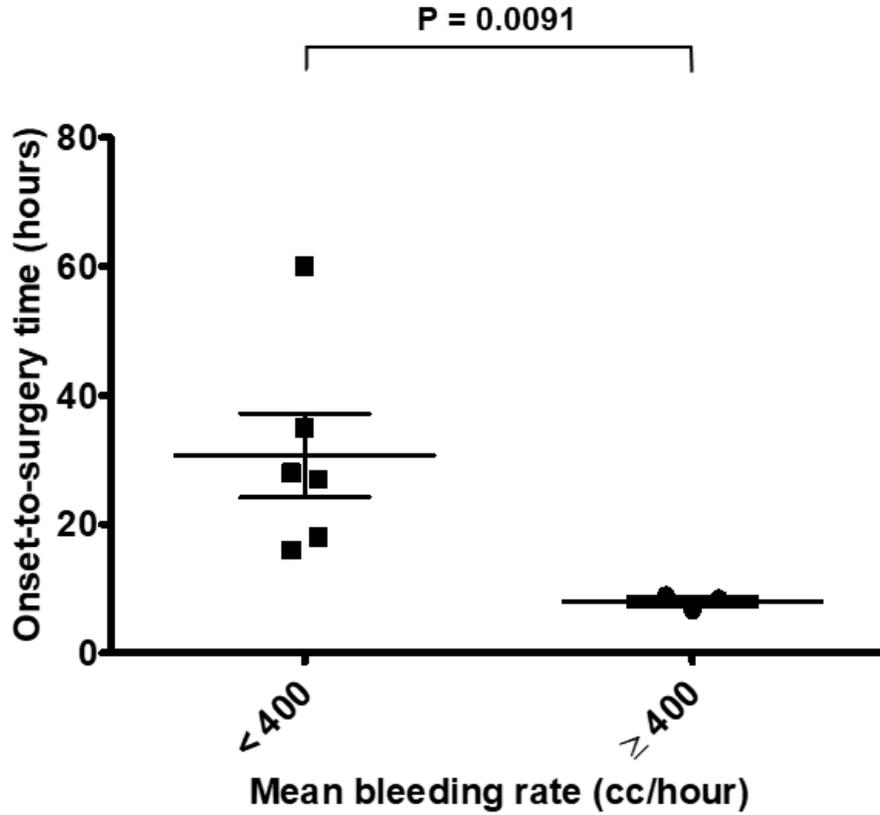


Figure 2

Three patients who had a mean bleeding rate of ≥ 400 cc/hour (Patients 2, 7, and 9) had a significantly shorter onset-to-surgery time (mean, 8.03 ± 1.27 hours, range, 6.6–9.0 hours) than the other 6 patients (mean, 30.7 ± 16.0 hours, range, 16.0–60.0 hours; $P = 0.0091$).

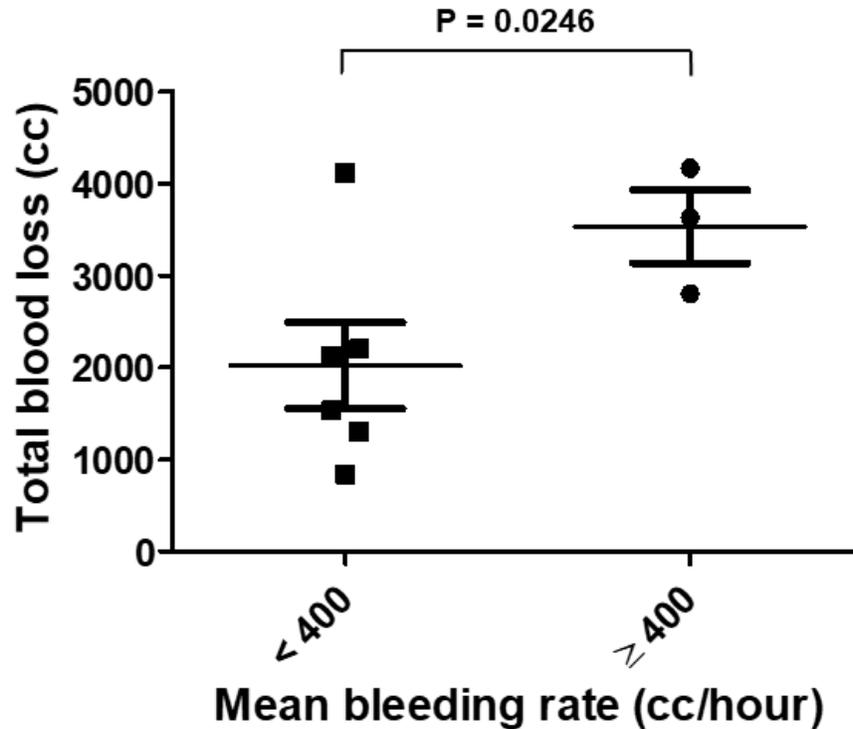


Figure 3

Three patients who had a mean bleeding rate of ≥ 400 cc/hour (Patients 2, 7, and 9) had significantly larger amount of total blood loss (mean, 3533 ± 690 cc, range, 2800–4170 cc) than the other 6 patients (mean, 2020 ± 1149 cc, range, 840–4120 cc; $P = 0.0246$). Online Resource 1: Intraoperative thoracoscopic findings of Patient 2 The preoperative chest radiograph demonstrates a modest mediastinal shift to the right with massive hemothorax on the left chest. A large amount of shed blood (2820cc) was evacuated, and the apical torn

Supplementary Files

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