Smart suction device for less blood trauma: a comparison with Cell Saver

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Received 12 October 2000; received in revised form 25 January 2001; accepted 16 February 2001

Abstract

Objective: The major source of hemolysis during cardiopulmonary bypass remains the cardiotomy suction and is primarily due to the interaction between air and blood. The Smart suction system involves an automatically controlled aspiration designed to avoid the mixture of blood with air. This study was set-up to compare this recently designed suction system to a Cell Saver system in order to investigate their effects on blood elements during prolonged intrathoracic aspiration. Methods: In a calf model (n = 10; mean weight, 69.3 ± 4.5 kg), a standardized hole was created in the right atrium allowing a blood loss of 100 ml/min, with a suction cannula placed into the chest cavity into a fixed position during 6 h. The blood was continuously aspirated either with the Smart suction system (five animals) or the Cell Saver system (five animals). Blood samples were taken hourly for blood cell counts and biochemistry. Results: In the Smart suction group, red cell count, plasma protein and free hemoglobin levels remained stable, while platelet count exhibited a significant drop from the fifth hour onwards (prebypass: 683 ± 201*10^9/l, 5 h: 280 ± 142*10^9/l, P = 0.046). In the Cell Saver group, there was a significant drop of the red cell count from the third hour onwards (prebypass: 8.6 ± 0.9*10^12/l, 6 h: 6.3 ± 0.4*10^12/l, P = 0.02), of the platelet count from the first hour onwards (prebypass: 630 ± 97*10^9/l, 1 h: 224 ± 75*10^9/l, P < 0.01), and of the plasma protein level from the first hour onwards (prebypass: 61.7 ± 0.6 g/l, 1 h: 29.3 ± 9.1 g/l, P < 0.01). Conclusions: In this experimental set-up, the Smart suction system avoids damage to red cells and affects platelet count less than the Cell Saver system which induces important blood cell destruction, as any suction device mixing air and blood, as well as severe hyproproteinemia with its metabolic, clotting and hemodynamic consequences. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Cardiopulmonary bypass; Hemolysis; Blood; Suction

1. Introduction

Cardiac procedures are a major source of the total amount of blood used for transfusion purposes in the western world. However, there exists increasing pressure to reduce or eliminate the exposure of patients to blood and blood products because of the widespread recognition of the multiple dangers associated with homologous blood transfusion: infection transmission, incompatibility reactions, febrile reactions, blood elements deficiencies and immunomodulatory effects.

Hemolysis during cardiopulmonary bypass has been commonly associated with shear stresses [1,2] induced by flow through roller of centrifugal pump, oxygenator, and cannulae [3]. However, the major source remains cardiotomy suction system whose design and concept have not fundamentally changed in common practice since the introduction of cardiopulmonary bypass [4–6]. These conventional systems generate a continuous negative pressure at the tip of the suction cannula, which is not selective and may aspirate either blood or air or both. The blood damage that occurs during aspiration is primarily due to the interaction between the air and the blood and/or the turbulent shear stress generated by their interaction as shown by in vitro and in vivo studies [7–9]. These alterations of corpuscular and plasmatic blood elements can lead to an activation of leukocytes and cytokine release as well as to an activation of platelets. Therefore, improvement of cardiotomy suction system remains a crucial challenge in blood preservation policy. Two alternatives, whether the cause or the consequence of blood suction trauma is targeted, appear to offer a potential for improvement of blood preservation. The first one involves an automatically controlled aspiration designed to avoid the mixing of blood with air. The second one uses a suction device with the possibility of processing the collected blood, thereby clearing the blood from plasmatic components, the Cell Saver device.

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This study compares a recently designed suction system with automatically controlled aspiration, the Smart suction system, to a Cell Saver system in order to investigate their effects on blood elements during prolonged intrathoracic aspiration.

2. Methods

The protocol described herein were reviewed and approved by the Committee on Animal Care, Office Vétérinaire Cantonal, Lausanne. All animals received care in compliance with the European Convention on Animal Care.

2.1. Suction devices

The Smart suction system (Cardio Smart, Fribourg, Switzerland) is composed of a ‘sensitive’ suction cannula, a reservoir with automatically controlled constant negative pressure, a servo-controlled roller pump and a computer. The suction cannula is coupled to an optic fiber which transmits an on/off signal to the computer whether its end is in contact or not with blood. The pressure into the reservoir is maintained at an adjustable constant negative level. When the tip of the suction cannula is in contact with blood (Fig. 1a), the sensor will automatically open a clamp located at the entrance of the reservoir. Blood will thus immediately be aspirated. When contact is lost (Fig. 1b), the clamp closes immediately. Emptying of the reservoir starts when a defined high level has been detected by another sensor (Fig. 1b). A second clamp placed at the exit port of the reservoir automatically opens and the roller pump simultaneously runs on and pushes the collected blood into the cardiopulmonary bypass circuit. In the same way, a low-level sensor automatically closes the exit clamp and stops the roller pump (Fig. 1a). The reservoir is thus kept isolated and the negative pressure can easily be adjusted.

The Cell Saver device is a centrifuge that, when simultaneously spinning and washing its contents with saline solution, leaves in its bowl the heavy elements of the blood suctioned from the field (i.e. the cells). The Cell Saver device removes the lighter elements, the proteins, and the saline washings, transferring all of the latter to a waste bag. With continuing centrifugation, the red cells gradually fill the bowl. When it is filled, the cells are washed with saline solution and transferred to a reinfusion bag for return to the patient.

2.2. Animals

This study was conducted on ten calves with a mean bodyweight of 69.3 ± 4.5 kg (standard deviation). All the animals were premedicated with xylazine (0.15 mg/kg, given intramuscularly). General anesthesia was started with thiopentone sodium (10 mg/kg, given intravenously) and maintained thereafter with volatile anesthetic (N₂O and Halothane) mixed with oxygen-enriched air. The animals were equipped with a jugular central venous catheter and a femoral arterial catheter for hemodynamic monitoring.

2.3. Suction protocol

Heparin (Liquemin, 300 U/kg body weight, F. Hoffmann-La Roche & Co., Basle, Switzerland), was given systemically and the activated clotting time (ACT, Hemochron, International Technidyne corp., Edison NJ, USA) was kept above 400 s throughout the experiment. A 24 French venous cannula was then introduced into the jugular vein.
through a short cervicotomy. A mini-anterior right thoracotomy was performed and the pericardium was opened to approach the right atrium. A segment of perfusion tube was introduced across a purse string placed on the atrial wall to create a standardized hemorrhage of about 100 ml/min during 6 h. The blood was continuously aspirated either with the Smart suction system (five animals) or the Cell Saver system (five animals).

In both groups the suction cannula was placed into the thoracic cavity in a fixed position so that its tip could not be in contact with anything else that the accumulated blood.

The vacuum pressure was adjusted to 60 mmHg in both groups.

Crystalloid solution (NaCl 104 mmol/l, KCl 5.4 mmol/l, CaCl2 1.6 mmol/l, MgCl2 1 mmol/l, NaLactate 27 mmol/l, NaBicarbonate 50 mmol/l) was infused as required in order to maintain the mean arterial pressure above 60 mmHg. No vasoactive drug was used.

2.4. Measurements

A standard battery of blood samples was taken for blood gas, hematology (hematocrit, red cells and platelets) and chemistry (LDH, free plasma hemoglobin, total protein and fibrinogen), before suction, after 10 min, and then hourly for the 6 h of the protocol. Notably, the lowest measurable protein level was 10 g/l (Hoffmann-La Roche & Co., Basle, Switzerland) and the lowest measurable fibrinogen level was 0.3 g/l (Dade Behring Marburg GmbH, Marburg, Germany).

2.5. Data analysis

Mean and standard deviation were derived for each parameter analyzed. Student’s t-test and analysis of variance for repeated measures were used for determination of statistical significance (P < 0.05).

3. Results

The complete 6 h protocol could be performed in all the animals. Because of the targeted mean arterial pressure of 60 mmHg, the Cell Saver group required massive volume infusion of crystalloid solution in comparison with the Smart suction group as shown on Table 1: the total amount of volume infusion was 39 ± 1.7 l and 5.2 ± 1.1 l, respectively. Despite this amount of volume infusion in the Cell Saver group, the targeted mean arterial blood pressure could not be maintained from the third hour onwards (Table 1) with values of 50 ± 11 mmHg at 3 h and 47 ± 7 mmHg at 6 h. The total amount of collected blood in the Smart suction and the Cell Saver group was 36.5 ± 0.2 l and 36.4 ± 0.5 l, respectively.

The absolute values of the hematological and chemical parameters are shown on Table 2.

Hematocrit and red cell profiles of values normalized for prebypass values are found on Table 3. For both parameters, the values of the Smart suction group remained stable, while those of the Cell Saver group exhibited a clear decreasing tendency (P < 0.001). When compared with baseline absolute values (Table 2), the drop was significantly different from the third hour onwards in the Cell Saver group (hematocrit, P < 0.01; red cell, P = 0.02).

Platelet profiles of values normalized for prebypass values are shown in Table 3. In both groups, the values decreased throughout the protocol. However, while the mean values remained above 250*10⁹/l in the Smart suction group, they reached values lower than 45*10⁹/l in the Cell Saver group.

### Table 1

<table>
<thead>
<tr>
<th>Volume infusion (l)</th>
<th>MAP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Smart suction</td>
</tr>
<tr>
<td>Baseline</td>
<td>77 ± 1</td>
</tr>
<tr>
<td>1 h</td>
<td>1 ± 0</td>
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<tr>
<td>2 h</td>
<td>1 ± 0</td>
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<tr>
<td>3 h</td>
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<tr>
<td>4 h</td>
<td>1 ± 0</td>
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<tr>
<td>5 h</td>
<td>1 ± 0</td>
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<tr>
<td>6 h</td>
<td>1 ± 0</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>Hematocrit</th>
<th>Red cell count (10¹²/l)</th>
<th>Platelet count (10⁹/l)</th>
<th>Protein (g/l)</th>
<th>Fibrinogen (g/l)</th>
<th>Free hemoglobin (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Smart suction</td>
<td>Cell Saver</td>
<td>Smart suction</td>
<td>Cell Saver</td>
<td>Smart suction</td>
</tr>
<tr>
<td>Base</td>
<td>27.7 ± 2.1</td>
<td>28.7 ± 1.5</td>
<td>7.9 ± 1</td>
<td>8.6 ± 0.9</td>
<td>683 ± 201</td>
</tr>
<tr>
<td>10 min</td>
<td>24.7 ± 1.5</td>
<td>27 ± 1.7</td>
<td>7.6 ± 0.7</td>
<td>8.1 ± 1.1</td>
<td>473 ± 131</td>
</tr>
<tr>
<td>1 h</td>
<td>26.3 ± 1.5</td>
<td>25.7 ± 1.5</td>
<td>8.1 ± 0.4</td>
<td>7.6 ± 0.8</td>
<td>514 ± 136</td>
</tr>
<tr>
<td>2 h</td>
<td>26 ± 1</td>
<td>27.3 ± 4.6</td>
<td>8 ± 0.4</td>
<td>8.1 ± 0.7</td>
<td>442 ± 195</td>
</tr>
<tr>
<td>3 h</td>
<td>26.3 ± 2.5</td>
<td>21.3 ± 1.5</td>
<td>8.2 ± 0.1</td>
<td>6.3 ± 0.4</td>
<td>361 ± 160</td>
</tr>
<tr>
<td>4 h</td>
<td>26.7 ± 2.5</td>
<td>23.7 ± 1.5</td>
<td>8.3 ± 0.3</td>
<td>6.8 ± 1</td>
<td>302 ± 144</td>
</tr>
<tr>
<td>5 h</td>
<td>26.3 ± 3.5</td>
<td>23.7 ± 2.1</td>
<td>8.1 ± 0.4</td>
<td>6.9 ± 1.2</td>
<td>280 ± 142</td>
</tr>
<tr>
<td>6 h</td>
<td>26.5 ± 3.2</td>
<td>15.7 ± 1.1</td>
<td>8.1 ± 0.3</td>
<td>4.3 ± 0.3</td>
<td>250 ± 146</td>
</tr>
</tbody>
</table>

* Base, prebypass value.
Saver group from the third hour onward. When compared with baseline absolute values (Table 2), the drop was significant from the fifth hour onwards in the Smart suction group \((P = 0.046)\) and from the first hour onwards in the Cell Saver group \((P < 0.01)\).

Free hemoglobin was lower than 100 mg/l in both groups throughout the experiment and both profiles did not differ significantly (Table 2). Comparison between baseline absolute values and those after 6 h was not significantly different either in the Smart suction group or the Cell Saver group \((P = 0.70\) and 0.14, respectively).

Normalized for prebypass values profiles of total protein and fibrinogen levels are found in Table 3. While both parameters remained stable in the Smart suction group, they dropped dramatically to near zero value in the Cell Saver group. Because of the limit of the measurement methods, values lower than 10 g/l for protein and lower than 0.3 g/l for fibrinogen could not be determined. Therefore, these values were the lowest ones in Table 2. When compared with baseline absolute values (Table 2), the drop in the Cell Saver group was significant from the first hour onwards for both protein and the fibrinogen levels \((P < 0.01\) and 0.03, respectively).

### 4. Discussion

This experimental study compares the effects of prolonged intrathoracic blood aspiration with a Smart suction device vs. a Cell Saver device. In this set-up of massive and prolonged bleeding, the Smart suction system has a weak impact on hemolysis and preserves plasma protein level, while the Cell Saver system has a significant impact on red cells counts and decreases dramatically protein level. Platelets are affected by both devices, however more severely by the Cell Saver system.

Cardiotomy suction has been recognized as the major source of hemolysis during cardiac operations. Moreover, it may play a significant role in major vascular surgery not involving cardiopulmonary bypass. Contact with pericardium, pleura and other tissues have been suggested to be the major determinant of hemolysis by earlier studies \([10,11]\), leading some surgeons to discard pericardial or pleural fluid collections. These findings could not be confirmed \([7]\). A recent report, analyzing the hemolytic effect of the contact of blood with different tissue samples, found that pleura and muscle contributed significantly to the free hemoglobin level, while pericardium, vein and fat did not cause significant elevation when compared with control \([12]\). Some \([13,14]\) have recommended limiting suction vacuum pressure to 150 Torr in order to reduce blood cell destruction, and even to discard the blood, which has been suctioned with high vacuum pressure. Here again, a study \([9]\), which analyzed specifically the amount of hemolysis caused by various vacuum pressures, could not substantiate these recommendations: vacuum pressure of 300 Torr was not found to cause excessive hemolysis. Therefore, it appears that the most important contributor to the hemolytic effect of cardiotomy suction, remains the contact of blood with air \([7\)–9\)]. This is further demonstrated by a previous report \([15]\), comparing the Smart suction device with standard cardiotomy device in a bovine model. At the end of a continuous aspiration of 70 l of blood during 3 h, free hemoglobin, expressed as percent of baseline value, was found to be 94 ± 37% for the Smart suction group vs. 179 ± 42% for the standard group.

In the present study, two different concepts of addressing the problem of contact of air with blood are compared: the Smart suction system is intended to avoid the mixture of air and blood during the suction, while the Cell Saver system does not decrease blood-air contact but separates, after suction, intact blood cells from blood cell debris and serum protein in order to discard the latter at reinfusion. Selective blood aspiration has already been suggested by others \([16]\), who placed electrodes at the tip of the cannula. The current through the electrodes was the signal for regulation of a roller pump speed, which allowed blood suction. The important innovation of the Smart suction system lies in the optical properties of the sensor, which avoids the application of any electrical current to the patient. Moreover,
there is no risk of interaction with electrocautery or other electric devices.

In this experimental set-up, serum protein are literally washed out from the vascular compartment with the Cell Saver device [17], while they are remarkably preserved with the Smart suction device. With the exception of a slight drop of serum protein level at the beginning of the experiment, neither total protein nor fibrinogen level dropped significantly during the 6 h experiment. This is illustrated by the need for volume infusion which was massive in the Cell Saver group, while the Smart suction group required about 1 l/h as expected from the insensible fluid loss of a thoracotomy. Moreover, despite the amount of volume infusion in the Cell Saver group, the target mean arterial pressure of 60 mmHg could not be reached from the third hour onwards. Clearly, this set-up of infusion policy does not reflect the clinical situation. However, it emphasizes the importance of protein preservation in blood processing with its impact on hemodynamics and clotting, as well as the potential of Cell Saver device for important protein loss, as the level of protein was at its lowest after 3 h, which corresponds to a blood loss of 18 l.

The Smart suction system did not have any significant impact on red cells as evidenced by stable hematocrit and red cell count values throughout the 6 h. Moreover, free hemoglobin never exceeded 56 mg/l, further emphasizing the remarkable effect of avoiding the mixture of blood and air during suction on red cell preservation. In the Cell Saver group, there was a significant drop of hematocrit and red cell count values from the third hour onwards. Previous comparisons of red cell survival between Cell Saver system and conventional suction system could not detect any significant difference [18,19], further underlining the main role of air–blood mixture which is common to both types of suction. Free hemoglobin was not significantly elevated, which is likely due to the washing effect of the device, similarly to protein.

Platelet count was affected by both suction devices, emphasizing their fragility. The effect was more pronounced with the Cell Saver device with normalized value below 7%, corresponding to the lowest measurable absolute values, as soon as the third hour, vs. 51% and 34% at the third and sixth hour, respectively with the Smart suction device. Therefore, with massive suction volume, the Smart suction does not obviate platelet damage, however this effect is still far less than with mixed air–blood suction.

In conclusion, in this hard set-up of prolonged blood suction, the Smart suction system avoids damage to red cells and affects platelet count less than the Cell Saver system which produces hemolysis, as any suction device mixing air and blood, as well as severe hypoproteinemia with its metabolic, clotting and hemodynamic consequences.

References