Foam formation and acute air emboli with the Maquet paediatric Quadrox I: a word of caution

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Abstract

We report 3 cases of significant foam formation in the venous reservoir with the Maquet Quadrox-I oxygenator and VHK 31 000 reservoir system. All the 3 patients required maximal suction return during procedures, causing pressurization of reservoir and foam formation. Two patients experienced systemic air emboli, which were dealt with by means of retrograde cerebral perfusion and hypothermia with no neurological sequela. These events emphasize the importance of device selection in high-risk patients as well as crisis management.

Keywords: Cardiopulmonary bypass • Oxygenator • Air embolism • Accident • Paediatric

INTRODUCTION

Cardiopulmonary bypass (CPB) equipment and techniques have improved dramatically in the last two decades. However, there are still a considerable number of CPB-related incidents in the current era [1]. The Maquet Quadrox-I oxygenator (MQ-I) with integrated arterial line filter (IALF) and the VHK 11 000 and 31 000 reservoir is the new generation of CPB devices, which allow a substantial reduction in prime volume. A recent clinical study identified that there were multiple incidences of foam formation in the cardiectomy when high sucker return was required [2], which poses the risk of air migration to the arterial system. Herein, we report 3 cases of clinically significant foam formation and air embolism related to the MQ-1 system.

CASE REPORT

From September 2011 to November 2012, 215 open-heart surgeries were performed using the MQ-1 system. There were 3 (1.3%) incidences of foam formation. Patient and CPB characteristics are given in Table 1. Vacuum-assisted return was not used. In all cases a level sensor was used, but adequate volume precluded its activation.

In Case 1, the rate of suction return consisting of blood and air needed to be increased up to 3.5 l/min because of significant collateral flow and the presence of a left superior vena cava (SVC). A large amount of foam appeared in the cardiectomy at 31 min after CPB initiation (Fig. 1A). Despite a reduction in the rate of suction return, the foam continued to accumulate on the blood surface within the reservoir and the cardiectomy became pressurized. Three minutes later, the bubble detector was triggered, which automatically shut off the CPB system. A fine stream of micro air was noted at the oxygenator inflow and outflow and foam appeared in the arterial line. The arterial and venous lines were clamped and reconnected in a loop to deair the system. The arterial line was disconnected from the aortic cannula. After deairing the entire arterial line, the arterial line was connected to the SVC cannula and retrograde cerebral perfusion (RCP) through the SVC cannula was performed to remove potential cerebral air embolism. The patient was cooled to 28°C for cerebral protection. The aortic cannula was left open so that blood and bubbles exited through the aorta. After 3 min of RCP, no more macroscopic bubbles were identified. The pump was again stopped and the arterial line connected back to aortic cannula and the venous line was connected back to the venous cannula. Normal CPB was resumed. After the procedure, the patient was rewarmed and weaned from CPB. Postoperative assessment showed no signs of significant neurological injury. Case 2 underwent an extracardiac Fontan operation. During trans-section of the right atrium-inferior vena cava junction, the vascular clamp on the right atrium was dislodged resulting in uncontrollable bleeding. High suction requirement resulted in significant foam formation and subsequent migration of foam in the arterial system. The patient was cooled down and RCP utilizing the SVC cannula was performed, as described in Case 1. For both cases, deep hypothermic circulatory arrest was extremely short, as we only stopped CPB for cannula’s disconnection and reconnection. Postoperative assessment revealed that the patient did not have neurological deficit. In Case 3, the right atrial wall was injured during chest re-entry requiring an excessive suction rate. Foam was formed but did not migrate into the arterial system since early circulatory arrest was employed to control the right atrial injury. The patient was neurologically intact.

DISCUSSION

Figure 1B describes the Maquet VHK 31 000 reservoir. Neonatal and pediatric venous hardshell cardiectomy reservoirs are open
venous reservoirs with integrated cardiotomy filters. Maximum blood rate flow are respectively, 1.5 and 2.8 L/min. Blood is channeled by the venous line into the lower area of the reservoir via a tube. Blood is directed to a concave cup (calotte) at the bottom of the reservoir and is then directed upwards in the venous filter. Once it has passed a venous defoamer, it passes to the outlet via the venous filter. This is done to ensure better bubble separation from the venous blood flow. Suctioned blood is fed through the cardiotomy filter defoaming section. A screen filter (pore size 40 µm, polyester) comprises the lower part of the cardiotomy filter and the upper part is a volume filter. Suctioned blood that is defoamed and filtered is mixed with the venous blood and passes through the venous defoamer and filter as well. Reservoirs are vented to the atmosphere to prevent pressurization; however, the venous reservoir is vented on the outside chamber. The relief valve is located on the reservoir (outer) portion.

When the inner filtering chamber became overwhelmed with the suctioned blood and air, bubbles and foam were visualized within. It was almost immediate that foam broke through and appeared in the outside chamber.

In an attempt to relieve the inner chamber pressurization, two strategies were employed. First, the quick prime line was opened to atmosphere. Secondly, an empty 60 cc syringe was secured via the luer-lock attachment on the reservoir to act as a “chimney”. Immediately, blood and air were being channelled up the quick prime line and the syringe.

Despite using these pressure relief systems, the performance of the venous reservoir was not improved as the bubble/foam formation continued.

Foam formation appears to be a unique problem related to the MQ-1 product. Melchior et al. [2] outlined the potential mechanism of foam formation in the MQ-1 venous reservoir, which was the combination of limited venous reservoir capacity and the silicon-free defoamer. The maximal inflow to the cardiotomy portion of the reservoir (VHK 1100, 31 000) is approximately two-thirds of total maximum outflow that can be generated by MQ-1 oxygenators, which explains why the cardiotomy was easily pressurized with maximal suction requirement. The silicon-free defoamer minimizes the risk of silicon emboli but appears to be less effective at removing the foam in comparison with other CPB systems. In fact, the IALF in the MQ-1 system demonstrated a better gaseous micro emboli handling capacity compared with other oxygenators [3]. However, the overwhelming quantity of foam exceeded its capacity of air handling in our 2 cases. It

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Table 1: Patient and cardiopulmonary bypass characteristics

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>2.5</td>
<td>3.1</td>
<td>5</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>0.47</td>
<td>0.56</td>
<td>0.7</td>
</tr>
<tr>
<td>Calculated CPB flow (ml/min)</td>
<td>900–1080</td>
<td>1340–1800</td>
<td>1680–2240</td>
</tr>
<tr>
<td>Diagnosis</td>
<td>TOF/PA, bilateral SVC</td>
<td>DORV, VSD, s/p BCPS</td>
<td>Acute severe mitral regurgitation, s/p heart transplantation</td>
</tr>
<tr>
<td>Procedure</td>
<td>TOF/PA repair</td>
<td>Fontan operation</td>
<td>Mitral valve repair</td>
</tr>
<tr>
<td>Reason for high sucker requirement</td>
<td>Left SVC, collaterals drainage</td>
<td>Atrial clamp dislodgement</td>
<td>Heart injury at re-entry</td>
</tr>
<tr>
<td>Approximate return flow (ml/min)</td>
<td>3500</td>
<td>unknown (suckers all the way up)</td>
<td>unknown (suckers all the way up)</td>
</tr>
<tr>
<td>Time from CPB initiation to critical event (min)</td>
<td>31</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Time from critical event to foam observation (min)</td>
<td>3</td>
<td>1</td>
<td>Not documented</td>
</tr>
</tbody>
</table>

TOF: tetralogy of Fallot; PA: pulmonary atresia; SVC: superior vena cava; DORV: double-outlet right ventricle; BCPS: bidirectional cavopulmonary shunt; s/p: status post; CPB: cardiopulmonary bypass; VSD: ventricular septal defect.

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**Figure 1:** (A) VHK 31 000 reservoir with significant foam formation. (B) Maquet VHK 31 000 reservoir description.
appears that the HSVR (hard shell venous reservoir) was chal-
lobned by the excessive accumulation of blood and air generated
by the overwhelming suction and vent return, within its inner
core. As a result, the defoaming and filtration efficiency may have
been compromised due to a reduced blood residence time in the
defoamer and filtration media of the HSVR.

To prevent excessive pressure conditions, a pressure equaliza-
tion valve and two deairing ports are incorporated into the HSVR.
However, in the case of extreme suction return, these valves and
ports did not provide fail-safe protection. Evidence of reservoir
pressurization was present as described above.

Prevention and management

After those events, our institution now has the neonatal oxygen-
ator HMO 11 000 with the larger capacity VHK 31 000 venous car-
diotomy reservoir.

After foam formation was noticed, the blood level in the reser-
voir was maintained above 150 ml, which is ~5 times more than
the manufacturers’ recommendation, to prevent foam migration to
the oxygenator. Air embolism still occurred despite the measures
employed. It is our institutional bias not to cannulate the left SVC
unless necessary. Cannulation of the left SVC may have decreased
the amount of suction return, thereby preventing foam formation.
If we had known that foam formation was a potential complication
related to the MQ-1 system in patients with high suction require-
ments, we could have chosen an alternative system with a larger
reservoir. Awareness of device limitations is of utmost importance.
Knowing the limitations of the MQ-1 system will prevent its use in
high-risk re-entry cases or patients with significant collateral
flows.

Systemic air emboli in 2 cases were dealt with quick deairing
from the arterial line, followed by hypothermia, RCP [4] and
steroid administration. There was no scientific evidence with
regard to duration of RCP and duration and temperature of hypo-
thermia, but we generally commence RCP for 5–10 min with at
least moderate hypothermia for this particular situation. These
two events emphasize the importance of crisis management con-
sensus and continuing training among the surgical team [5].

Modifications in clinical practice

We have stayed within the flow recommendations of the manu-
facturer. If we do see bubbles forming on the inner chamber of
the cardiotomy, we communicate this occurrence to the surgeon
and suction is reduced (learned through experience). We identify
cases that may have the potential for high suction return and
make the team aware of the limitations of the equipment and we
run the case with a higher-than-normal volume of blood in the
cardiotomy, as a precaution to keep any micro air/foam away
from the outflow if it does appear. Communication and an increased
awareness through experience had been key to prevention.

CONCLUSIONS

Two systemic air embolic events (0.93%) happened purely due to
device-related foam formation associated with high suction re-
quirement. Cautious device selection and perfusion strategy
should be made in high-risk congenital open-heart surgery.

Conflict of interest: none declared.

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