CPB FMEA #13: Failure to monitor and maintain the appropriate fluid balance during cardiopulmonary bypass (CPB) and modified ultrafiltration (MUF).

The AmSECT Safety Committee

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Friends- If I had to choose the single, most beneficial, life-saving advance in CPB it wouldn’t be the change from stainless steel and glass oxygenators to disposable oxygenators. Nor would it be the change from bubblers to membrane oxygenators, nor the use of coated circuits. IMHO, the technical advance that has saved the most lives, at least as far as pediatrics is concerned, is the advent of hemoconcentrators.

I remember a time before hemoconcentrators when a 4 kg child would enter the OR for heart surgery and leave looking like the Pillsbury dough boy and weighing 5 kg. Often the first thing the surgeon would do prior to sternotomy was place a temporary peritoneal dialysis catheter so that fluid removal could commence immediately upon arrival in the ICU. Pumping kids without a hemoconcentrator was a nightmare of crystalloid, albumin and RBC administration. To remove extra fluid after giving a unit of RBCs on CPB, I would pump the excess volume in the venous reservoir up into a bag and wait 30 minutes for the RBCs to settle out. When most of the cells had settled to the bottom of the bag, I would drop them in but keep the plasma in the bag. (In the early years we only had glass bottles with air vent tubes in them.) “Why not just pump the extra volume to the cell saver?”, you may ask. Because there were no cell savers then! Remember?

When hollow fiber hemodialyzers became available, I tried those. There were several problems with them. First they were expensive. Many hemodialysis programs could not afford to use them unless they washed and ‘reused’ each dialyzer up to six times (on the same patient of course). Secondly, they were inefficient. The UF rates on them were miserable. Even using the king size units they could not keep up with the UF need. They had large priming volumes to boot. Lastly the blood lines connecting them to the CPB circuit had to be custom made (another expense).

Finally, low volume, high efficiency hemoconcentrators became available in the early 1990s. Many things changed after that. Pediatric cardiac surgery mortality rates started to drop. Length of hospital stay was reduced as well. Blood usage on CPB plummeted and babies would leave the OR the same weight as when they came in. Better control of fluid balance on CPB meant that complex procedures such as atrial switches, aortic switches, Norwoods and Fontans could be successful more often. This was not just at my program, but worldwide survival was up and complications were down. I know that in some emerging countries, simple and complex procedures are still done without the benefit of hemoconcentration, but that is not optimum and the risks are greater for those patients.

My impression is that most adult perfusionists have pretty much ignored the need for detailed monitoring of fluid balance on bypass. Even when adult patients enter the room carrying an extra fluid load from CHF or pre-op resuscitation, not much thought was given to the amount of fluid that should be removed during CPB. I don’t think that the incorporation of a hemoconcentrator into adult circuits is routine like it is in peds, relying instead on diuresis. It is true that, in adults, the problems of fluid imbalance during CPB are not as acute as in peds. But that does not mean they are not important. Many articles have been written about the hazards of fluid overload after major surgery. And recently the importance of proper fluid balance is becoming more recognized among perfusionists. Even the AmSECT meeting in San Antonio this year has the central theme of “Finding Balance: In Search of the Holy Grail of Fluid Management.”

In 2011 I published every thing I knew about fluid balance on CPB. But this is my first attempt at writing a fluid balance FMEA. I am sure that there are things that I haven’t thought of. So please review it and send me your thoughts. As always, thank you for your input.

-Gary

This week’s Failure Mode is below:

I. Failure Mode: Failure to monitor and maintain the appropriate fluid balance during cardiopulmonary bypass (CPB) and modified ultrafiltration (MUF).

II. Potential Effects of Failure:

1. Excessive fluid administration can lead to hemodilution, causing:

a. low hematocrit

b. low albumin

c. low coagulation factor concentration

d. pulmonary edema

e. generalized edema

f. unnecessary RBC transfusion.

2. Excessive fluid removal leading to low pre-load and low cardiac output may make weaning from CPB difficult.

3. If weaning is accomplished, excessive fluid removal may result in post-CPB or post-op hypotension or delay diuresis.

III. Potential Cause of Failure:

1. Patient morbidity and likelihood of transfusion are associated with low plasma protein concentration.

2. Hemorrhage and administered fluids decrease both hematocrit and plasma proteins.

3. Fluid used for CPB prime and anesthesia management represents a significant fraction of total blood volume.

4. Infusion of washed, salvaged blood or donor red blood cells raises hematocrit, but further dilutes clotting factors.

5. If dilution is excessive, coagulopathy may ensue.

6. Patients with the smallest blood volumes are at highest risk.

7. Patients with excessive intraoperative fluid balance have more ICU complications and higher hospital mortality.

8. A positive fluid balance in adults of as little as 500 mls (+7 mls/kg in a 70 kg patient) on CPB is associated with an increased length of stay and the need for blood transfusion in adults (Toraman 2004).

9. A positive fluid balance from excessive crystalloid may mask acute kidney injury (AKI) by diluting creatinine/BUN values after cardiac surgery. However, AKI is not consistently associated with fluid overload.

10. In adults, a positive fluid balance after CPB is associated with higher hospital mortality and is independent of diuretic administration, diuretic response, and type of surgery.

11. Early postoperative fluid overload is independently associated with worse outcomes in pediatric cardiac surgery patients who are 2 weeks to 18 years old.

IV. Interventions to Prevent or Negate the Failure:

PRE-EMPTIVE MANAGEMENT:

1. Monitor I&O during CPB to measure the net fluid balance. (\* If there is no accurate I&O monitoring, the detectability value would be 5, resulting in a RPN of 225.)

2. A computerized spreadsheet with the necessary categories and calculations can be used real-time during CPB and MUF and to give situational awareness to fluid balance (Grist 2011).

3. The fluid balance can be adjusted by adding or removing fluid to achieve a specific goal at the end of CPB/MUF.

MANAGEMENT:

1. A CPB/MUF fluid balance goal of negative 20 ml/kg should be achievable for most patients. This does not include fluid given by anesthesia pre-CPB.

2. Negative fluid balances can be achieved with slow, continuous ultrafiltration during the CPB time span.

3. Patients with excessive fluid accumulation in the pre-CPB period from CHF, resuscitation or liberal anesthesia rehydration may require additional fluid removal.

4. The need for excessive fluid administration during weaning resulting in a positive fluid balance may indicate myocardial failure in varying degrees or a detrimental change in pulmonary or systemic vascular resistance (McKiernan, 2005).

5. Patients with stiff, hypertrophied ventricles, as seen in Tetralogy of Fallot or left ventricular outflow tract obstruction, may require a positive fluid balance to enhance ventricular preload (Krayenbuehl, 1988, Romand 1995).

6. A zero or negative fluid balance is associated with decreased mortality and implies that there was no need for fluid resuscitation at the termination of CPB/MUF with the exceptions listed in #5.

7. Excess fluid removal (balances of negative 40 mls/kg or greater), even with uncomplicated weaning from CPB, may trigger a hypotensive episode in the post-CPB or post-op period (Grist 2011).

V. Risk Priority Number (RPN): (select the number from each category that you feel best categorizes the risk).

A. Severity (Harmfulness) Rating Scale: how detrimental can the failure be:

1) Slight, 2) Low, 3) Moderate, 4) High, 5) Critical

(The problems that this failure causes are 3, moderate.)

B. Occurrence Rating Scale: how frequently does the failure occur:

1) Remote, 2) Low, 3) Moderate, 4) Frequent, 5) Very High

(This occurs very commonly because many perfusionists do not place a high priority on maintaining fluid balance. So occurrence should be 5, very high.)

C. Detection Rating Scale: how easily the potential failure can be detected before it occurs:

1) Very High, 2) High, 3) Moderate, 4) Low, 5) Uncertain

(This problem can be easily detected with computer spread sheet program to monitor I&O during CPB/MUF. So the detection RPN should be 1, very high. However, if there is no accurate I&O monitoring, the detectability value would be 5.)

D. Patient Frequency Scale:

1) Only a small number of patients would be susceptible to this failure, 2) Many patients but not all would be susceptible to this failure, 3) All patients would be susceptible to this failure.

(All patients undergoing CPB with or without MUF are at risk. So the Patient Frequency RPN should be a 3.)

Multiply A\*B\*C\*D = RPN. The higher the RPN the more dangerous the Failure Mode.

The lowest risk would be 1\*1\*1\*1\* = 1. The highest risk would be 5\*5\*5\*3 = 375. RPNs allow the perfusionist to prioritize the risk. Resources should be used to reduce the RPNs of higher risk failures first, if possible.

(The total RPN for this failure is 3\*5\*1\*3 = 45. Without monitoring I&O the RPN would be 3\*5\*5\*3 = 225.)