Case Report: Intraoperative Hyperkalemia on Cardiopulmonary Bypass

Molly Oldeen CCP FPP LP
Ann & Robert H Lurie Children’s Hospital of Chicago

Disclosures

• None

Our patient

• 16 yo Caucasian male, 52kg
• Hx: infective endocarditis in presence of VSD
• s/p mechanical AVR, VSD closure at 10yo
  – Surgery complicated by renal impairment secondary to embolic glomerulonephritis, requiring 3 days PD
• Presented with LVOTO, preop creatinine 200 µmol/L (normal 60-110)
• Rx: ramipril, warfarin
• No significant family hx
• Planned Surgery: Ross Konno

Preop Diagnostic Cath

• Uneventful angiogram
• Transfer to Operating Room
Intraoperative

- Redosternotomy
- CPB established 4 hours after induction

Preop Cath Induction

Day 1

Induction On CPB

On CPB

- Equipment used:
  - 3/8-3/8 Circuit
  - Terumo FX 15-40 oxygenator
  - Sorin SS HLM, 3T HC
- Cooled to 32 degrees C
- Cardioplegia - High K+ induction – Buckberg solution
- Total CPB Time: 354 minutes
- Total XC Time: 221 minutes
  - x3 due to new RV outflow obstruction requiring intervention

Issues on CPB

- At 2\textsuperscript{nd} cross clamp noted:
  - ↑ K+ (6.5 to as high as 8.1mmol/L)
  - ↓ PaCO\_2
  - ↓ PaO\_2
- Requirement of:
  - Increased Sweep: 2L to 5L over second half of pump run
  - Increased FiO\_2: 60 to 100%
  - Initial Treatment: ZBUF with 0.9% NS (3 liters) + NaHCO\_3
  - Followed by insulin, dextrose administration

<table>
<thead>
<tr>
<th>Time</th>
<th>Temp</th>
<th>pH</th>
<th>pCO_2 (mmHg)</th>
<th>pO_2 (mmHg)</th>
<th>Hb (g/dL)</th>
<th>K (mmol/L)</th>
<th>Lactate (mmol/L)</th>
<th>AB Ec (mmol/L)</th>
<th>HCO_3 (mmol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/07</td>
<td>33</td>
<td>7.51</td>
<td>47</td>
<td>208</td>
<td>11.9</td>
<td>6.5</td>
<td>2.6</td>
<td>-3</td>
<td>23</td>
</tr>
<tr>
<td>52.18</td>
<td>33</td>
<td>7.26</td>
<td>51.5</td>
<td>266</td>
<td>10.2</td>
<td>6.7</td>
<td>3.8</td>
<td>-4.5</td>
<td>20</td>
</tr>
<tr>
<td>52.67</td>
<td>32</td>
<td>7.24</td>
<td>48.4</td>
<td>254</td>
<td>11.3</td>
<td>5.5</td>
<td>3.6</td>
<td>-6.6</td>
<td>10.7</td>
</tr>
<tr>
<td>54.06</td>
<td>32</td>
<td>7.27</td>
<td>48.6</td>
<td>266</td>
<td>10.7</td>
<td>5.7</td>
<td>5.2</td>
<td>-5.9</td>
<td>10.2</td>
</tr>
<tr>
<td>54.28</td>
<td>32.2</td>
<td>7.29</td>
<td>43</td>
<td>215</td>
<td>10.6</td>
<td>4</td>
<td>0.9</td>
<td>-5.81</td>
<td>18.37</td>
</tr>
<tr>
<td>54.52</td>
<td>32.2</td>
<td>7.28</td>
<td>43</td>
<td>215</td>
<td>11.2</td>
<td>5.6</td>
<td>4.7</td>
<td>-6</td>
<td>19.15</td>
</tr>
<tr>
<td>55.16</td>
<td>36.8</td>
<td>7.26</td>
<td>44</td>
<td>231</td>
<td>11</td>
<td>6.7</td>
<td>4.2</td>
<td>-6.4</td>
<td>18.7</td>
</tr>
<tr>
<td>56.28</td>
<td>36.7</td>
<td>7.27</td>
<td>41</td>
<td>206</td>
<td>11</td>
<td>6.5</td>
<td>7</td>
<td>-5</td>
<td>18</td>
</tr>
<tr>
<td>57.01</td>
<td>36.7</td>
<td>7.26</td>
<td>44</td>
<td>281</td>
<td>11.3</td>
<td>6.6</td>
<td>4.5</td>
<td>-7</td>
<td>19.3</td>
</tr>
</tbody>
</table>
Differential Diagnosis on CPB

- Hyperkalemia
  - Multiple doses of High K+ Cardioplegia
  - Preop chronic renal dysfunction
  - Heat exchanger leak in the oxygenator
- Hypercarbia & Hypoxia
  - Failing oxygenator
  - Patient was warm → hypermetabolic

Post CPB

- Mild tachycardia: 110 bpm
- etCO₂ 40 mmHg
- Temperature 36.7 °C

10 minutes later....

- Tachycardia: 150-160 bpm (recurrent ventricular extrasystoles)
- etCO₂: 60mmHg
- Temperature: 38.9 °C
- ABG pH 7.192 (respiratory & metabolic acidosis)

Differential Diagnosis post CPB

- Sepsis ❌
- Neuroleptic malignant syndrome ❌
- Excessive rewarming post CPB ❌
- MH suspected ✔️
Post Dantrolene Administration

- $\text{etCO}_2$: 30mmHg
- Temperature: peaked at 39.3°C and declined on cooling
- Repeat ABG: pH 7.46, K 9.1 mmol/L

MH Treatment

- Dantrolene administration
  - Dose: 1mg/kg
- Discontinuation of volatile anesthetic
- Circuit of anesthetic machine changed
- Fluid warming devices turned off
- Ice packs to axillae, head, groin, neck

<table>
<thead>
<tr>
<th>Time</th>
<th>pH</th>
<th>$\text{etCO}_2$</th>
<th>Temperature</th>
<th>$\text{pH}$</th>
<th>$\text{pCO}_2$ (mmHg)</th>
<th>$\text{pO}_2$ (mmHg)</th>
<th>Hb (g/dL)</th>
<th>K (mmol/L)</th>
<th>Na (mmol/L)</th>
<th>Lactate (mmol/L)</th>
<th>$\text{ABE}$ (mmol/L)</th>
<th>$\text{HCO}_3^-$ (mmol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>7.390</td>
<td>34.2</td>
<td>350</td>
<td>12.1</td>
<td>6.7</td>
<td>106</td>
<td>4.2</td>
<td>-0.2</td>
<td>13.1</td>
<td>4.0</td>
<td>-0.9</td>
<td>20.0</td>
</tr>
<tr>
<td>19:00</td>
<td>7.113</td>
<td>36.7</td>
<td>386</td>
<td>13.3</td>
<td>6.3</td>
<td>140</td>
<td>8.2</td>
<td>-15.0</td>
<td>16.7</td>
<td>13.0</td>
<td>16.7</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>7.094</td>
<td>36.7</td>
<td>364</td>
<td>12.2</td>
<td>5.1</td>
<td>145</td>
<td>8.9</td>
<td>7.0</td>
<td>12.9</td>
<td>4.7</td>
<td>-1.0</td>
<td>22.7</td>
</tr>
<tr>
<td>20:00</td>
<td>7.060</td>
<td>31.0</td>
<td>621</td>
<td>11.7</td>
<td>8.0</td>
<td>129</td>
<td>3.8</td>
<td>1.0</td>
<td>21.3</td>
<td>5.0</td>
<td>2.0</td>
<td></td>
</tr>
</tbody>
</table>
Post Op

- ICU
  - CVVHD 3 days in ICU
  - CK peaked at 18,868U/L 15 hrs after MH crisis
    - Indication of rhabdomyolysis
    - No further doses of dantrolene given

Review: What is malignant hyperthermia?

- Autosomal dominant disorder of the skeletal muscle
- Hypermetabolic reaction after administration of volatile anesthetics or succinylcholine
  - Massive release of calcium from the sarcoplasmic reticulum in response to defective ryanodine receptor
  - Intracellular Ca$^{2+}$ activates contractile filaments and stimulates cellular energy turnover
    - Increased oxygen consumption and CO$_2$ production \(\rightarrow\) lactate production
- Incidence: 0.5 to 2 in 100,000 general anesthesia procedures
- Mortality: 5-10% (down from 80% in the 1960s)
- MH & CPB: symptoms may be obscured!

History of MH

- 1960: Royal Melbourne Hospital, Australia
  - Dr. Jim Villiers
- 20 yo patient, broken leg post-MVA
- Refused anesthetic due to family history of death after anesthesia
- Despite careful anaesthetic plan, still developed symptoms, but survived
- Dr. Michael Denborough and Dr. Richard Lovell went on to study this family in detail
  - Autosomal dominant inheritance
- Dantrolene discovered in 1967

Triggering agents

- Inhaled general anesthetics
  - Desflurane
  - Enflurane
  - Ether
  - Halothane
  - Isoflurane
  - Methoxyflurane
  - Sevoflurane
- Succinylcholine

Other triggers:
- Rapid rewarming
- Administration of catecholamine
- Large heparin doses
Malignant Hyperthermia Symptoms

- 6 Phenotypic Variables
  - Muscle rigidity
  - Evidence of muscle breakdown → myoglobin mediated AKI
  - Respiratory & Metabolic acidosis
  - Rapid temperature increase (late sign)
  - Cardiac tachyarrhythmias/hemodynamic instability
  - Family history of MH

Lunach, et al.

Treatment

1. Discontinue volatile anesthetics and succinylocholine
   - If surgery must be continued, use nontriggering anesthetics
2. Hyperventilate with 100% oxygen at flows of 10L/min
   - Flush volatile anesthetics, lower etCO2
3. IV Dantrolene 2.5 mg/kg
4. Active cooling**

https://www.mhaus.org/healthcare-professionals/managing-a-crisis/

Dantrolene

- Inhibits Ca²⁺ release from SR
- Decreases free intracellular calcium concentrations

Cardiopulmonary bypass in malignant hyperthermia susceptible patients: A systematic review of published cases

Thomas Mesterhazy, MD,* Wolfgang Zinke, MD,* Emi Krenke, RN,* Assad Hanesy, MD,‡ Renhard Gunz, MD,* MD,* and Peter Krenke, MD

- 24 case reports and series
- 26 patients
- 14 MH crisis occurred during or shortly after CPB
- 14 reports discussed prevention of episode

0 cases before CPB
3 cases during CPB
11 cases after CPB
Since 2011...

| Butala, 2018 |

Suspected Malignant Hyperthermia in the Setting of Hypothermic Circulatory Arrest for Type A Aortic Dissection Repair: A Case Report

Butala, 2018

**Sevoflurane-induced malignant hyperthermia during cardiopulmonary bypass and moderate hypothermia**


Severe sevoflurane-induced malignant hyperthermia during cardiopulmonary bypass and moderate hypothermia

**Diagnosis**

1. Signs of hypovolemia
   - Severe hypovolemia associated with profound hypotension
   - Reduced cardiac output
   - Low MAP
   - Increased ECG changes

2. Signs of hypothermia
   - Tachycardia
   - Bradycardia
   - Hypothermia

**Table 2**

<table>
<thead>
<tr>
<th>Triggers</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>18</td>
</tr>
<tr>
<td>CPB</td>
<td>2</td>
</tr>
<tr>
<td>CPB, MH</td>
<td>1</td>
</tr>
<tr>
<td>CPB, MH</td>
<td>2</td>
</tr>
<tr>
<td>MH</td>
<td>15</td>
</tr>
<tr>
<td>CPB</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 1**

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>27</td>
</tr>
<tr>
<td>CPB</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
</tr>
<tr>
<td>MH</td>
<td>17</td>
</tr>
<tr>
<td>CPB</td>
<td>3</td>
</tr>
</tbody>
</table>

- Case reports from 1982 to 2016
- Total of 30 cases
- 17 patients – newly diagnosed or presumed MH
- Diagnosis made ‘On CPB’ in 2/17
- Most common indicator = elevated pCO$_2$
- Since 2011
- Table 2: Symptoms that occurred during or shortly after cardiopulmonary bypass, as described in 14 published malignant hyperthermia cases
- Table 1: A potential trigger of the MH malignant hyperthermia in 14 published cases

**Butala, 2018**

**Sevoflurane-induced malignant hyperthermia during cardiopulmonary bypass and moderate hypothermia**


Severe sevoflurane-induced malignant hyperthermia during cardiopulmonary bypass and moderate hypothermia

**Diagnosis**

1. Signs of hypovolemia
   - Severe hypovolemia associated with profound hypotension
   - Reduced cardiac output
   - Low MAP
   - Increased ECG changes

2. Signs of hypothermia
   - Tachycardia
   - Bradycardia
   - Hypothermia

**Table 2**

<table>
<thead>
<tr>
<th>Triggers</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>18</td>
</tr>
<tr>
<td>CPB</td>
<td>2</td>
</tr>
<tr>
<td>CPB, MH</td>
<td>1</td>
</tr>
<tr>
<td>CPB, MH</td>
<td>2</td>
</tr>
<tr>
<td>MH</td>
<td>15</td>
</tr>
<tr>
<td>CPB</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 1**

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>No. of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>MH</td>
<td>27</td>
</tr>
<tr>
<td>CPB</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
</tr>
<tr>
<td>MH</td>
<td>17</td>
</tr>
<tr>
<td>CPB</td>
<td>3</td>
</tr>
</tbody>
</table>

- Case reports from 1982 to 2016
- Total of 30 cases
- 17 patients – newly diagnosed or presumed MH
- Diagnosis made ‘On CPB’ in 2/17
- Most common indicator = elevated pCO$_2$
Discussion

- Masked symptoms by CPB
- 6 Phenotypic Variables
  - Muscle rigidity
  - Evidence of muscle breakdown → myoglobin mediated AKI
  - Respiratory & Metabolic acidosis
  - Rapid temperature increase (late sign)
  - Cardiac tacharyrhythmias/hemodynamic instability
  - Family history of MH

Discussion

- Delayed presentation possibly due to hypothermia in cath lab as well as change to propofol infusion for transport
- Possibly experienced MH crisis for several hours on CPB before clinical symptoms were detectable
  - Well controlled with use of continuous blood gas monitoring
  - Triggered on rewarming?
- On average, it takes three anesthetic exposures to trigger MH crisis

<table>
<thead>
<tr>
<th>Time</th>
<th>Temp</th>
<th>pH</th>
<th>pCO2 (mmHg)</th>
<th>pO2 (mmHg)</th>
<th>Hb</th>
<th>K (mmol/L)</th>
<th>Lactate (mmol/L)</th>
<th>ABEc (mmol/L)</th>
<th>HCO3- (mmol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preop</td>
<td>35</td>
<td>7.31</td>
<td>47</td>
<td>338</td>
<td>13.9</td>
<td>6.5</td>
<td>2.6</td>
<td>-3</td>
<td>23</td>
</tr>
<tr>
<td>12:10</td>
<td>32.0</td>
<td>7.26</td>
<td>51.5</td>
<td>294</td>
<td>10.8</td>
<td>6.7</td>
<td>3.8</td>
<td>-4.6</td>
<td>20</td>
</tr>
<tr>
<td>12:40</td>
<td>32.2</td>
<td>7.26</td>
<td>49.4</td>
<td>254</td>
<td>11.3</td>
<td>5.5</td>
<td>3.6</td>
<td>-4.6</td>
<td>18.7</td>
</tr>
<tr>
<td>14:00</td>
<td>31.2</td>
<td>7.27</td>
<td>64.6</td>
<td>266</td>
<td>10.7</td>
<td>5.7</td>
<td>5.2</td>
<td>-5.9</td>
<td>19.2</td>
</tr>
<tr>
<td>14:30</td>
<td>31.6</td>
<td>7.30</td>
<td>43</td>
<td>218</td>
<td>10.6</td>
<td>6.4</td>
<td>6.9</td>
<td>-5.81</td>
<td>18.27</td>
</tr>
<tr>
<td>14:40</td>
<td>31.3</td>
<td>7.29</td>
<td>43</td>
<td>205</td>
<td>11.3</td>
<td>5.6</td>
<td>6.7</td>
<td>-6</td>
<td>19.15</td>
</tr>
<tr>
<td>15:00</td>
<td>31.6</td>
<td>7.26</td>
<td>44</td>
<td>215</td>
<td>11</td>
<td>6.7</td>
<td>6.2</td>
<td>-4.6</td>
<td>18.7</td>
</tr>
<tr>
<td>15:20</td>
<td>31.7</td>
<td>7.27</td>
<td>41</td>
<td>206</td>
<td>11</td>
<td>6</td>
<td>6.5</td>
<td>-7</td>
<td>18</td>
</tr>
<tr>
<td>15:40</td>
<td>31.7</td>
<td>7.26</td>
<td>44</td>
<td>215</td>
<td>11.3</td>
<td>6.6</td>
<td>6.5</td>
<td>-7</td>
<td>19.3</td>
</tr>
</tbody>
</table>
**Post Procedure Testing**

- **Patient tested Positive** at MH muscle biopsy center
- **Muscle Contracture Testing (CHCT)**
  - **Gold Standard**
  - Skeletal Muscle biopsy from thigh to test for contractile properties upon exposure to ryanodine receptor agonists (i.e., caffeine, halothane)
  - Abnormally high levels of contractile force indicate MH susceptibility

**Key Considerations for the Perfusionist**

- Suspected MH? Family History? Patient History?
  - Change oxygen delivery tubing, flush system with 100% FiO2
  - Remove isoflurane from CPB circuit
  - Maintain normothermia if possible to avoid triggering
- Early detection
  - Rule out other possibilities
- Resuscitation with ECMO??
  - Control temperature, O2 and CO2

**Conclusions**

- Hindsight
- Review symptoms re: MH and CPB

---

Note: Patient had subsequent AVR, no MH episode
References