



Case Report: Intraoperative Hyperkalemia on Cardiopulmonary Bypass

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Disclosures

- None

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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 $\mu\text{mol/L}$ (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



On CPB

- Equipment used:
 - 3/8-3/8 Circuit
 - Terumo Fx 15-40 oxygenator
 - Sorin S5 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

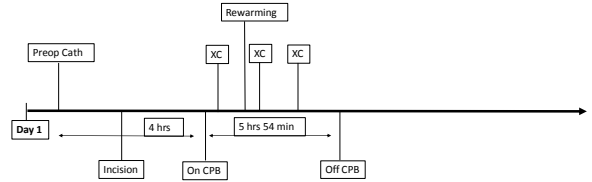
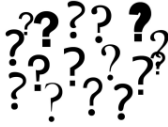
- At 2nd cross clamp noted:
 - ↑ K⁺ (6.5 to as high as 8.1mmol/L)
 - ↑ PaCO₂
 - ↓ PaO₂
- Requirement of:
 - Increased Sweep: 2L to 5L over second half of pump run
 - Increased FiO₂: 60 to 100%
 - Initial Treatment: ZBUF with 0.9% NS (3 liters) + NaHCO₃
 - Followed by insulin, dextrose administration

time	Temp	pH	pCO2 (mmHg)	pO2 (mmHg)	Hb (g/dL)	K (mmol/L)	Lactate (mmol/L)	ABEC (mmol/L)	HCO3- (mmol/L)
Preop	35	7.31	47	338	13.9	6.5	2.6	-3	23
12.10	33.0	7.26	51.5	284	10.8	6.7	3.8	-4.5	20
12.47	32.0	7.24	49.4	234	11.3	5.5	3.6	-6.6	18.7
14.06	32.0	7.27	44.6	266	10.7	5.7	5.2	-5.9	19.2
14.29	34.3	7.29	43	214	10.6	6	4.9	-5.81	19.37
14.42	36.2	7.28	43	205	11.2	5.6	4.7	-6	19.15
15.35	36.8	7.26	44	221	11	6.7	4.2	-6.6	18.7
16.28	36.7	7.27	41	296	11	6	4.5	-7	18
17.21	36.7	7.26	44	241	11.3	6.6	4.5	-7	19.3



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

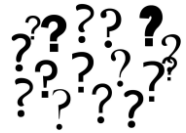
10 minutes later....

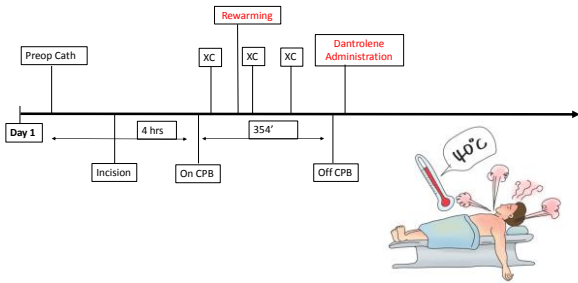
- Tachycardia: 150-160 bpm (recurrent ventricular extrasystoles)
- etCO₂: 60mmHg
- Temperature: 38.9 °C
- ABG pH 7.192 (respiratory & metabolic acidosis)



Differential Diagnosis post CPB

- Sepsis ✗
- Neuroleptic malignant syndrome ✗
- Excessive rewarming post CPB ✗
- MH suspected ✓☐





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

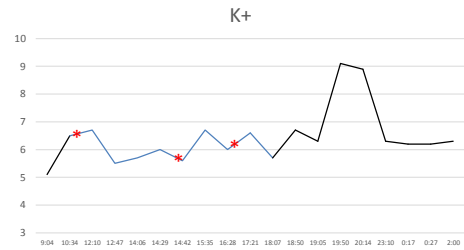


Post Dantrolene Administration

- etCO₂: 30mmHg
- Temperature: peaked at 39.3°C and declined on cooling
- Repeat ABG: pH 7.46, K 9.1 mmol/L

time	pH	pCO ₂ (mmHg)	pO ₂ (mmHg)	Hb (g/dL)	K (mmol/L)	Na (mmol/L)	Lactate (mmol/L)	ABEc (mmol/L)	HCO ₃ ⁻ (mmol/L)
18:50	7.192	54.2	490	13.1	6.7	138	5.5	-8.2	20.0
19:05	7.113	54.7	386	13.5	6.3	142	8.2	-13.0	16.7
19:50	7.463	30.7	414	12.1	9.1	133	4.7	-0.9	21.7
20:14	7.459	31.0	421	11.7	8.9	129	3.9	-1.0	21.7

* = Induction doses CPG



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

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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
 - Δ 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



Dr. Michael Denborough

Triggering agents

- Inhaled general anesthetics
 - Desflurane
 - Enflurane
 - Ether
 - Halothane
 - Isoflurane
 - Methoxyflurane
 - Sevoflurane
 - Succinylcholine
- Other triggers:
- Rapid rewarming
 - Administration of catecholamine
 - Large heparin doses
- OUR PATIENT

Leff et al. 2011

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

Larach, et al.

Treatment

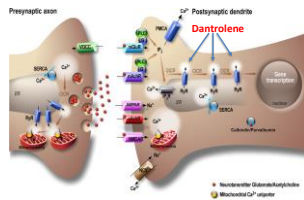


1. Discontinue volatile anesthetics and succinylcholine
 - If surgery must be continued, use nontriggering anesthetics
2. Hyperventilate with 100% oxygen at flows of 10L/min
 - Flush volatile anesthetics, lower etCO₂
3. IV Dantrolene 2.5 mg/kg
4. Active cooling**

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

Dantrolene

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



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

Thomas Metterlein, MD,^a Wolfgang Zink, MD,^a Eva Kranke, RN,^c Assad Haneya, MD,^b Bernhard Graf, MSc, MD,^a and Peter Kranke, MD^d

- 24 case reports and series
 - ↓
 - 26 patients
 - ↓
 - 14 MH crisis occurred during or shortly after CPB
 - 0 cases before CPB
 - 3 cases during CPB
 - 11 cases after CPB
 - 14 reports discussed prevention of episode

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

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TABLE 2. Symptoms that occurred during or shortly after cardiopulmonary bypass, as described in 14 published malignant hyperthermia episodes

Symptom	No. of cases
Total	14
Unexplained increase in arterial P_{CO_2}	14
Metabolic acidosis	9
Unexplained hemodynamic instability	5
Rigor	2
Increased serum creatine kinase and myoglobin levels	7

TABLE 4. Potential triggers of the MH malignant hyperthermia episodes in 14 published cases

Trigger	No. of cases
Total	14
Volatile anesthetics (halothane, enflurane, isoflurane, sevoflurane)	10
Succinylcholine	1
Rapid and exaggerated rewarming alone	2
Unknown (possibly enoximone or rewarming)	2
Sums to 15 because 1 patient received both enflurane and succinylcholine.	

Since 2011....

CASE REPORT

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

Bryant Bunting, DO, Joshua Knight, MD, and Stephen M. McKnight, MD

Suspected Malignant Hyperthermia During Biventricular Assist Device Implantation in a Patient With Left Ventricular Noncompaction Cardiomyopathy

Karim Schmidt, MD^a, Aske Mosler, MD^a, Christoph Lichtenauer, MD^a, Thomas Brenner, MD^a, Bastian Schöneck, MD^a, Agnieszka Polowinski, MD^a, Markus A. Weigand, MD^a, Stefan Höfer, MD^a

^aDepartment of Cardiology, University Hospital Hamburg, Hamburg, Germany; ^bDepartment of Card Surgery, Ulm University Hospital, Hamburg, Germany

Malignant Hyperthermia-Like Manifestations in a Two-Month-Old Child With Holt-Oram Syndrome Undergoing Cardiac Surgery

Andrew D. Franklin, MD, Amanda N. Loring, MD, and Brian S. Donath, MD, PhD

Sevoflurane-induced malignant hyperthermia during cardiopulmonary bypass and moderate hypothermia

A. A. Jovanović, A. J. Pittman, S. Mohr, C. Anderson, J. Scortino, K. Kvernskov, O. G. Pavlov, O. Stokland, and K. A. Karakulski

^aDepartment of Anesthesiology, Section for Cardiothoracic Anesthesiology, ^bDepartment of Anesthesiology, ^cUnit for Experimental Medical Research, ^dDepartment of Thoracic Surgery, and ^eDepartment of Intensive Care Medicine, Ghent University Hospital, Ghent, Belgium

2018

Review Article Malignant Hyperthermia: Review of Diagnosis and Treatment during Cardiac Surgery with Cardiopulmonary Bypass

Brian Butala, DO^a, Michael Busada, DO^b, Daniel Cormican, MD^{a,c}

^aDepartment of Anesthesiology, Michigan Health System, Pittsburgh, PA; ^bDepartment of Critical Care Medicine, Michigan Health System, Pittsburgh, PA

- 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

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Diagnosis

- Signs of hypermetabolism
 - Tachycardia despite adequate anesthesia depth
 - Will not be a sign during cardiac arrest related to cardioplegia administration
 - Hypercarbia despite adequate predicted minute ventilation
 - On cardiopulmonary bypass (CPB), perfusionist controls CO_2 clearance with sweep gas flow. Consideration of MH should be heightened if perfusionist requires escalating sweep gas flows to control hypercarbia
 - Acidosis despite adequate predicted oxygenation and oxygen delivery
 - Arterial blood gas findings:
 - Metabolic acidosis/decreased bicarbonate
 - Respiratory acidosis/elevated P_{aCO_2}
 - Elevated lactate
 - Negative base excess
 - Hyperthermia in absence of iatrogenic overwarming
 - Decreased mixed venous oxygen saturation
 - May be drawn from pulmonary artery catheter if not on CPB
 - On CPB, sample will be "central venous oxygen saturation" (ScvO₂), as blood does not flow through pulmonary artery
- Signs of generalized muscle rigidity/hypocompatibility
 - Palpable rigid skeletal muscle
 - Check masseter and neck muscles, as remainder of body may be inaccessible
 - Dark brown/dark red urine
 - Laboratory Findings:
 - Hypokalemia
 - Elevated creatine phosphokinase with normal CK-MB fraction
 - Home positive urine test in absence of microscopic hematuria/hemolysis
 - Myoglobinuria

Butala, 2018

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 tachyarrhythmias/hemodynamic instability
 - Family history of MH

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time	Temp	pH	pCO2 (mmHg)	pO2 (mmHg)	Hb (g/dl)	K (mmol/L)	Lactate (mmol/L)	ABEc (mmol/L)	HCO3- (mmol/L)
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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

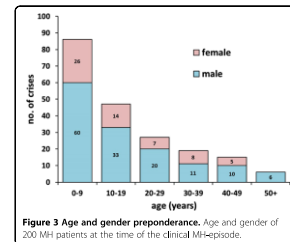
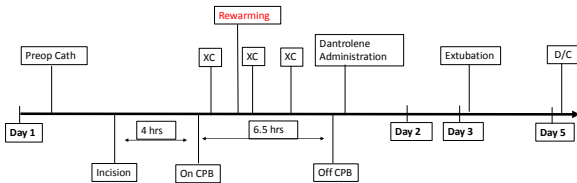


Figure 3 Age and gender preponderance. Age and gender of 200 MH patients at the time of the clinical MH-episode.

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Klingler et al.



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

Note: Patient had subsequent AVR, no MH episode

Conclusions

- Hindsight
- Review symptoms re: MH and CPB



References

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