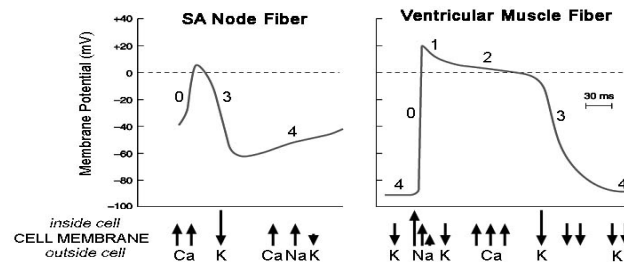


Electrolyte Abnormalities

Cardiac Action Potentials



Phase	Phase Name	SA Node Fiber	Ventricular Muscle Fiber
0	Rapid Upstroke	Slow inward I_{Ca}	Fast inward I_{Na}
1	Early Rapid Repolarization	-	Inactivation of I_{Na} Start outward I_K
2	Plateau	-	Slow inward I_{Ca} = Outward I_K
3	Final Rapid Repolarization	Outward I_K	Inward I_{Ca} < Outward I_K
4	Diastolic Depolarization/ Resting Potential	Slow inward I_{Ca} Slow inward I_{Na} Outward I_K (minimal)	Outward I_K

Hyperkalemia

Definition

- Mild $K^+ = 5.5-6.5$ mEq/L
- Moderate $K^+ = 6.5-8$ mEq/L
- Severe $K^+ > 8$ mEq/L

Contributing Factors

Preoperative

- Renal disease
- Drugs (ACEI, NSAIDs, spironolactone, Digoxin, β -blockers)

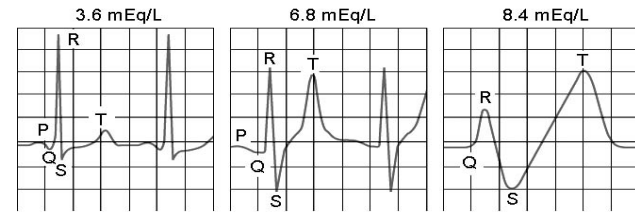
Intraoperative

- Succinylcholine: acute increase of 0.5-1 mEq/L
- Acidosis
- Transfusions
- Hemolysis
- Rhabdomyolysis (tourniquet), trauma

Hyperkalemia

Signs & Symptoms

- EKG changes (usually appear at $K^+ > 6.5$ mEq/L)
 1. Peaked T waves
 2. Flattened P waves & prolonged PRI
 3. Widened QRS \rightarrow sinusoidal QRS
 4. ST elevation
 5. VF arrest & asystole
- Weakness



Hyperkalemia

Treatment

- Calcium
 - Ca gluconate (peripheral)
 - Ca chloride (central)
- Bicarbonate (NaHCO_3)
- Insulin (10-15 Units)
- Glucose (25 g)
- Kayexalate (PO/PR)
- Dialysis

Mnemonic: C BIG K

Hyperkalemia

Anesthetic Considerations

- Consider cancelling elective cases if $\text{K}^+ > 5.5$
- Consider alternative to succinylcholine
- EKG monitoring
- Avoid hypoventilation (respiratory acidosis)
- Treat acidosis
- Use NS instead of LR
- Monitor for increased sensitivity to muscle relaxants.

Hypokalemia

Definition

- Mild $\text{K}^+ = 3.1-3.5 \text{ mEq/L}$
- Moderate $\text{K}^+ \leq 3 \text{ mEq/L}$ with PACs
- Severe $\text{K}^+ < 3 \text{ mEq/L}$ with PVCs

Contributing Factors

Preoperative

- GI losses (NGT, N/V, Diarrhea)
- Lasix, RTA
- Magnesium deficiency

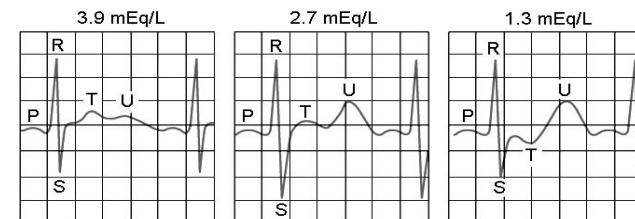
Intraoperative

- Alkalosis (both metabolic and respiratory)
- Insulin therapy
- Hypothermia

Hypokalemia

Signs & Symptoms

- EKG changes
 1. Flattened/inverted T wave
 2. U waves
 3. ST depression
- Arrhythmias
 1. PACs, PVCs
 2. SVTs (esp. A Fib/A flutter)
- Metabolic alkalosis
- Autonomic lability
- Enhanced response to muscle relaxants
- Weakness, ↓DTRs
- Ileus
- Digoxin toxicity



Hypokalemia

Treatment

Chronic hypokalemia = total body K⁺ depletion (1 mEq/L decrease = 300-600 mEq total body deficit)

- Peripheral IV - 10 mEq/hr
- Central IV - 10-20 mEq/hr
- Life-threatening - 5-6 mEq bolus

Acute hypokalemia = likely a redistribution phenomenon

- Reverse underlying cause

Hypokalemia

Anesthetic Considerations

- Consider cancelling elective cases if K⁺ < 3-3.5 mEq/L (based on chronicity of deficit).
- EKG monitoring
- KCl replacement if arrhythmias develop
- Avoid hyperventilation (respiratory alkalosis)
- Consider reducing dose of muscle relaxant 25-50%

Hypercalcemia

Contributing Factors

- Hyperparathyroidism
- Malignancy (especially lung, ENT, GU, GYN, and multiple myeloma)
- Immobilization
- ARF
- Drugs (thiazide diuretics, lithium)

Signs & Symptoms

- EKG changes (short QT)
- Hypertension
- Polyuria

Treatment

- Hydration + Lasix diuresis
- Dialysis

Hypercalcemia

Anesthetic Considerations

- Consider cancelling elective cases
- Avoid acidosis (reduces Ca²⁺-albumin binding)
- Check serial K⁺ and Mg²⁺

Hypocalcemia

Contributing Factors

Preoperative

- Hypoparathyroidism
- Renal failure (decreased Vitamin D)
- Sepsis
- Magnesium deficiency (decreased end-organ response to PTH)

Intraoperative

- Alkalosis (increased Ca^{2+} -albumin binding)
- Massive pRBC transfusion (due to citrate binding)
- Drugs (heparin, protamine, glucagon)

Signs & Symptoms

- EKG (prolonged QT, bradycardia)
- Hemodynamics (vasodilation, hypotension, decreased myocardial contractility, LV failure)
- Respiratory (laryngospasm, stridor, bronchospasm, respiratory arrest)
- Neuro (cramps, tetany, \uparrow DTRs, perioral numbness, seizures, Chvostek's sign, Trousseau's sign)

Hypocalcemia

Treatment

- Calcium gluconate - 1 g = 4.5 mEq elemental Ca^{2+} (give via peripheral or central IV)
- Calcium chloride - 1 g = 13.6 mEq elemental Ca^{2+} (give via central IV)
- Do NOT give Ca^{2+} and NaHCO_3 together in the same IV - it will precipitate!
- Replace magnesium

Anesthetic Considerations

- EKG monitoring
- Avoid alkalosis
- Monitor paralysis with muscle relaxants
- Monitor iCa with transfusions

Hypermagnesemia

Contributing Factors

- Renal failure
- Hypothyroidism
- Iatrogenic (tocolysis)

Signs & Symptoms

- EKG (widened QRS, prolonged PRI, bradycardia)
- Hemodynamics (vasodilation, hypotension, myocardial depression)
- Neuro (\downarrow DTRs, sedation, weakness, enhanced neuromuscular blockade)

Treatment

- Hydration + Lasix diuresis
- Ca^{2+} administration
- Diuresis

Anesthetic Considerations

- EKG monitoring
- Consider reducing dose of muscle relaxants 25-50%

Hypomagnesemia

Contributing Factors

- GI/Renal losses
- β -agonists (cause intracellular shift)
- Drugs (diuretics, theophylline, aminoglycosides, amphotericin B, CSA)

Signs & Symptoms

- Usually asymptomatic alone, but symptomatic in combination with induced hypokalemia, hypocalcemia, and hypophosphatemia
- EKG (prolonged QT, PACs, PVCs, and A Fib)
- Neuro (neuromuscular excitability, AMS, seizures)

Treatment

- Replace with MgSO_4 to $[\text{Mg}^{2+}] > 2 \text{ mg/dl}$
- Watch for hypotension & arrhythmias with rapid administration!

Anesthetic Considerations

- EKG monitoring
- Check for coexistent electrolyte deficiencies.

References

- Kaye AD and Kucera IJ. Intravascular fluid and electrolyte physiology. In Miller RD (ed), *Miller's Anesthesia, 6th ed.* Philadelphia: Elsevier Churchill Livingstone, 2005.
- Morgan GE, Mikhail MS, and Murray MJ. *Clinical Anesthesiology, 4th ed.* New York: McGraw-Hill Companies, Inc., 2006.
- Prough DS, Wolf SW, Funston JS, and Svensén CH. Acid-base, fluids, and electrolytes. In Barash PG, Cullen BF, and Stoelting RK (eds), *Clinical Anesthesia, 5th ed.* Philadelphia: Lippincott Williams & Wilkins, 2006.