Effective Monitoring of Neuromuscular Blockade

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Monitoring basics: proper stimulation of nerve proximal to neuromuscular junction requires supramaximal impulse (to entrain all nerve axons for consistent response across neuromuscular junction with motor unit contraction); stimulus should be as remote as possible from desired muscle response to avoid causing direct muscle response and errors of interpretation; after sedation and analgesia of patient but before muscle relaxation, potentiometer of muscle stimulator should be increased until twitch of muscle observed; maximal impulse — point at which additional increase of stimulus does not further increase muscle twitch; supramaximal impulse — 10% above maximal impulse; current increased above supramaximal impulse level results in direct stimulation of muscle (observable during surgical electrocautery [causes direct muscle stimulation unaffected by maximum neuromuscular blockade])

Testing of neuromuscular blockade: choose nerve and distal motor twitch; gold standard — mechanomyography of ulnar nerve and observed twitch of adductor pollicis muscle

Facial nerve: laparoscopic procedures (which require positioning with arms tucked along sides of patient) increasingly common; such cases limit monitoring to facial nerve and contraction of eye muscles; facial nerve — superficial; has 5 branches; cranial nerve [CN] VII controls muscles of facial expression, with no effect on mandibular or cervical muscles

Differential sensitivity of muscles: diaphragm and laryngeal muscles — show high resistance to neuromuscular blockade; demonstrate early onset and early recovery from neuromuscular blockers; orbicularis oculi and corrugator supercilli — more resistant to neuromuscular blockade; pharyngeal muscles — low levels of blockade produce discoordination, with resulting failure to protect airway and problems with swallowing mechanism; therefore, patients at significant risk for aspiration and respiratory depression; study by Thilen — shows monitoring eye muscles associated with 5 times greater risk for residual paralysis, vs monitoring adductor pollicis; 52% of patients monitored via eye muscles showed residual paralysis in postanesthesia care unit (PACU)

Cranial nerves: facial nerve enervates facial muscles, trigeminal nerve (third branch) enervates muscles of mastication, and spinal accessory nerve enervates sternocleidomastoid muscle; as trigeminal nerve exits at base of skull, placing electrodes proximal to neuromuscular junction to allow proper monitoring of blockade virtually impossible

Stimulation patterns: single twitch — baseline with supramaximal impulse (1 or 0.1 Hz) used to determine dose that produces 95% depression of twitch height (ED95); typical intubating dose of neuromuscular blocking agent 2 times that for ED95; train of 4 (TOF) — 4 impulses (at 2 Hz) causing 4 twitches; ratio of fourth twitch compared to first twitch (T4/T1 [TOFR]); no baseline necessary, but supramaximal impulse should be used; tetanus — 50 or 100 Hz for 5 sec; posttetanic facilitation occurs with residual blockade (to obtain accurate response, waiting period required before repeating tests); double burst — 2 sets of 3 bursts at 50 Hz, with 750 msec between sets; allows easier detection of fade with residual block, but does not meet current criteria for detection of fade; recommendation — maintain 2 twitches (do not abolish all twitches) because inhalational agents potentiate neuromuscular blockade

TOF threshold: early protocols state patients adequately reversed when TOFR 0.7 (ie, vital capacity, inspiratory force, and expiratory force have returned to baseline); recent data suggest continued blockade at TOFR 0.7 places patients at risk

Quantification of motor response: mechanomyography — bulky; requires cooperation of surgeons (access to arm) for use; baseline calibration requires extra time; electromyography (EMG) — smaller device; measures electrical activity across neuromuscular junction; more expensive and electrodes less secure; acceleromyography — smaller, but generates higher TOFR (gold standard remains mechanomyography); more sensitive to small levels of neuromuscular blockade, so if desired TOFR 0.9 on mechanomyography, TOFR of ≥1.0 needed with acceleromyography; clinical signs — visual or palpable subjective assessment

Educational Objectives

The goals of this program are to improve anesthesia outcomes by decreasing the incidence of residual paralysis in postoperative patients and improving electrical safety in the operating room. After hearing and assimilating this program, the clinician will be better able to:

1. Choose appropriate techniques for testing of neuromuscular blockade.
2. Decrease pulmonary complications caused by residual paralysis.
3. Follow evidence-based extubation criteria.
4. Describe the mechanism of injuries caused by electrical shocks.
5. Explain the significance of line isolation monitors in the operating room.

Faculty Disclosure

In adherence to ACCME Standards of Commercial Support, Audio-Digest requires all faculty and members of the planning committee to disclose relevant financial relationships within the past 12 months that might create any personal conflicts of interest. Any identified conflicts were resolved to ensure that this educational activity promotes quality in health care and not a proprietary business or commercial interest. For this program, the faculty and planning committee reported nothing to disclose.
Lessons learned:

Electrical principles:
- Electricity — electron flow; conductor — any substance that permits flow of electrons or current (eg, copper); insulator — any substance interrupting flow of electrons or current (eg, air, ceramic, rubber); direct current (DC) — electron flow in single direction; alternating current (AC) — electron flow switches directions at regular intervals (eg, 120 times/sec for 60-Hz wall current); electrons flow from negative terminal to positive terminal in batteries, but conventional current moves from positive terminal to negative terminal; electrical current (I) moves through resistor (R) generating voltage (V) and producing heat (watts); Ohm’s law — V = I x R (ohms); physiologic application of Ohm’s law to fluids (pressure = flow multiplied by resistance) includes blood pressure (BP), where BP = cardiac output (CO) multiplied by systemic vascular resistance (SVR); electrical power — measured in watts (V x I); electrical energy — watt-second (joule) designation for electrical energy expended during work; defibrillator output measured in joules, and larger quantities of energy measured in kilo-watt-hours; capacitor — stores electrical charge (electrons); any 2 parallel conductors separated by insulator; permits AC flow but not DC; capacitance (C) = charge on plates (Q)/V; stray capacitance — causes capacitive coupling (inherent in all electrical equipment and generally undesirable [creates safety risk]); develops when 2 wires in close proximity
Exhution criteria: TOFR of 0.7 considered adequate in 1970, but later determined to be insufficient; tongue depressor test then recommended (accurate to ±0.8); head-lift test not sufficient, and TOFR ≥0.9 recommended; evidence indicates even experienced clinicians cannot discern fade with TOFR >4.0; fade with 100 Hz tetanus discernable with TOFR >0.85, but test painful (should be limited to anesthetized patients); retesting required to reach full ratio of 0.9, but must be delayed 10 to 20 min to avoid posttetanic facilitation; no qualitative test available for evaluation of TOFR ≥0.9; quantitative tests include acceleromyography with TOFR set ≥1.0; meta-analysis — 40% of patients admitted to PACU show TOFR <0.9; Debaene study (2003) — patients given single-dose neuromuscular blockade and no reversal showed TOFR <0.9 2 hr after administration; Murphy study (2005) — 88% of patients extubated after reversal of neuromuscular blockade and no clinical fade with tetanus showed TOFR <0.9
Effects of residual paralysis: impaired pharyngeal function, with increased risk for aspiration; decrease in hypoxic ventilatory drive by 30% (interrelated with chemoreceptors); significant risk for hypoxemia, atelectasis, acute respiratory failure, permanent brain damage, or death
Safety issues: numbers of obese patients (often with obstructive sleep apnea) steadily increasing; Anesthesia Patient Safety Foundation published report warning against opioid-induced respiratory depression, and the Joint Commission issued Sentinel Event Alert; one-third of “code blue” arrests in hospitals associated with respiratory depression, and residual paralysis adds to “perfect storm” for increasing risk; conclusion — use of acceleromyography should be considered for detection of residual paralysis despite increased time and cost
Lessons learned: clinical estimates of neuromuscular blockade not adequate; many patients extubated too early; reversal agents often administered when level of blockade too deep and patient too close to extubation; waiting until all 4 twitches return and delaying extubation for 15 to 20 min after administration of reversal agent recommended, unless quantitative measure of blockade used; virtually all patients should receive reversal agent for prevention of residual blockade; many patients experience residual paralysis in PACU; discontinuation of use of pancuronium should be considered (increases risk for residual paralysis); not all cases require neuromuscular blockade; threshold for defining residual paralysis increased from TOFR >7.0 to ≥9.0; residual neuromuscular blockade increases risks
Final recommendation: routinely checking quantitative TOFR of adductor pollicis muscle before extubation should be considered to avoid residual paralysis

Electrical Safety in the Operating Room

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Electrical principles: electricity — electron flow; conductor — any substance that permits flow of electrons or current (eg, copper); insulator — any substance interrupting flow of electrons or current (eg, air, ceramic, rubber); direct current (DC) — electron flow in single direction; alternating current (AC) — electron flow switches directions at regular intervals (eg, 120 times/sec for 60-Hz wall current); electrons flow from negative terminal to positive terminal in batteries, but conventional current moves from positive terminal to negative terminal; electrical current (I) moves through resistor (R) generating voltage (V) and producing heat (watts); Ohm’s law — V = I x R (ohms); physiologic application of Ohm’s law to fluids (pressure = flow multiplied by resistance) includes blood pressure (BP), where BP = cardiac output (CO) multiplied by systemic vascular resistance (SVR); electrical power — measured in watts (V x I); electrical energy — watt-second (joule) designation for electrical energy expended during work; defibrillator output measured in joules, and larger quantities of energy measured in kilo-watt-hours; capacitor — stores electrical charge (electrons); any 2 parallel conductors separated by insulator; permits AC flow but not DC; capacitance (C) = charge on plates (Q)/V; stray capacitance — causes capacitive coupling (inherent in all electrical equipment and generally undesirable [creates safety risk]); develops when 2 wires in close proximity
Electrical shock hazards: injury or death results when voltage pushes electrons through body (causing, eg, electrical burns, ventricular fibrillation [VF]); risk for injury greater with AC than with DC current; high-frequency current has low tissue penetration from and does not excite contractile cells (but still causes burns); electricity flows from “hot” to neutral points through impedance (eg, light bulb, radio, computer); burn or VF experienced when human body completes circuit
Mechanisms of electrical injury: 1) disruption of normal electrical function of cells, causing contraction of muscles, paralysis of respiration, or cardiac arrest (VF); 2) dissipation of electrical energy through body (“cooking” of flesh); microshock — large amounts of current flow; macroshock — small amount of current; can cause VF when directed through heart of susceptible patient (with, eg, pacing wires, central venous line); physiologic effect of 1-sec exposure to 20 μA sufficient for VF in microshock situation; 1 to 5 mA creates tingling sensation; 10 to 20 mA causes sustained muscular contraction; 100 to 300 mA causes VF in macroshock setting
Summary: <1 mA imperceptible; 10 mA causes skeletal muscle effect (with retained ability to let go); VF can be induced with 100 mA of macroshock or 100 μA of microshock in susceptible patient; 10 μA maximum leakage current (from stray capacitance) allowed for operating room (OR) equipment
Electrical grounding: 3-prong (neutral, hot, and ground) grounded system in modern homes reduces chance of macroshock when stray or frayed wires contact equipment case; also prevents problems due to capacitive coupling caused by stray capacitance; stray current exits through ground plug, not person touching unit, thereby preventing shock; amount of shock (current passed through body) depends on resistance of body
Ground-fault circuit interrupter (GFCI): required by electrical codes in potentially hazardous (wet) areas (eg, bathroom, kitchen, outdoor electrical outlets); monitor both sides (hot and neutral) of circuit for equal flow, and interrupt circuit if difference detected; disadvantage — interrupts power supply without warning and blocks use of defective equipment; can be problematic in OR environments, where, eg, life-support equipment may be affected; line-isolation monitors (LIM) sound alarms but permit continued use of equipment
Line isolation and LIMs: in OR, isolation transformer separates circuit with hot, neutral, and ground lines from secondary circuit (labelled line 1 and line 2) that has no connection with ground, and thereby prevents macroshock injury from contact with lines (unless leakage current...
Suggested Reading


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Estimated time to complete the educational process:

- Review Educational Objectives on page 1: 5 minutes
- Take pretest: 10 minutes
- Listen to audio program: 60 minutes
- Review written summary and suggested readings: 35 minutes
- Take posttest: 10 minutes
1. Choose the correct definition for a supramaximal impulse.
   (A) Point at which further increase of stimulus does not further increase muscle twitch
   (B) Impulse generated when the potentiometer of the muscle stimulator is set at 10
   (C) Stimulus 10% greater than the maximal impulse
   (D) Impulse that causes direct stimulation of muscle

2. The diaphragm and laryngeal muscles show ______ resistance to neuromuscular blockade and demonstrate ______ onset and recovery from neuromuscular blockade agents.
   (A) Low; late
   (B) Low; early
   (C) High; late
   (D) High; early

3. Which of the following methods of measurement is the most sensitive for quantification of the motor response?
   (A) Clinical assessment
   (B) Mechanomyography
   (C) Electromyography
   (D) Acceleromyography

4. Which of the following is an adequate “train of four” threshold when using acceleromyography to monitor neuromuscular blockade?
   (A) ≥ 0.4
   (B) ≥ 0.7
   (C) ≥ 0.9
   (D) ≥ 1.0

5. A study demonstrated that, despite administration of a reversal agent and no clinical fade with tetanus, the majority of patients show TOFR < 0.9 at the time of extubation.
   (A) True
   (B) False

6. What is the correct term for a substance that interrupts the flow of electrons?
   (A) Conductor
   (B) Insulator
   (C) Resistor
   (D) Capacitor

7. High-frequency current has ______ tissue penetration; it ______ burns.
   (A) Low; does not
   (B) Low; does
   (C) High; does not
   (D) High; does

8. How much voltage is required to induce ventricular fibrillation in a patient susceptible to injury from microshock?
   (A) 20 μA
   (B) 100 μA
   (C) 2 mA
   (D) 100 mA

9. A ground-fault circuit interrupter (GFCI) is a preferred electrical safety feature in operating rooms.
   (A) True
   (B) False

10. A burn injury from the use of surgical electrocautery is most likely in which of the following situations?
    (A) No return plate is placed on the patient
    (B) A large return plate is used
    (C) Saline is spilled and contacts the return plate
    (D) Only a small point of contact is created with the return plate

Answers to Audio-Digest Anesthesiology Volume 55, Issue 37: 1-C, 2-A, 3-B, 4-D, 5-B, 6-C, 7-A, 8-D, 9-C, 10-B

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