PACEMAKERS: A PRIMER FOR ANESTHESIOLOGISTS
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Definitions: P acemaker—sends current (measured in milliamperes [mA]) to pace heart and measures voltage (measured in millivolts [mV]) heart produces; electric current—flow of electrons; pacemaker acts as “drug” (ie, electrons) delivery device, with current (dose) measured in electrons per sec, voltage—electric potential; ground—reference point (ie, earth) dissipates excess electrons; electrons measured with potential relative to ground; Ohm’s law—voltage (V) equals current (I) multiplied by resistance (R); violation of physical laws results in severe penalties; ground loop—violation of Ohm’s law; variations in ground voltage cause high current and can result in fire, burns, and (in operating room) ventricular tachycardia

Electricity in operating room: electrical equipment in operating room designed for prevention of ground loops; bioengineering tests all equipment for leakage current; protection from microshocks eliminated when pacemaker wires exit skin; multiple grounding sources built into operating rooms to ground anesthesiologist, anesthesia machinery, and other personnel, and thereby avoid sparks and explosions in oxygen-rich environment; electrocardiography (ECG) wires optically isolated from monitor (ie, monitor not physically connected to patient [relies on photodiodes that transmit light rather than current]), monitor isolated from power supply for operating room by isolation transformer, and room isolated from main power supply; no such isolation exists in “normal” world outside operating room

Electrocardiography: plot of voltage (1 mV) vs time; humans unable to sense voltage until it reaches 20 to 30 V, so ECG imperceptible; timing—for heart rate (HR) of 60 bpm, R-R interval 1 sec (1000 msec); PR interval ≤200 msec (PR interval >200 msec indicates first-degree heart block); QRS complex 80 to 120 msec (>120 msec indicates bundle branch block); QT interval 400 to 450 msec

Detection of R wave: detected by pacemaker when voltage exceeds set level above baseline (referred to as sensitivity [measured in mV] rather than threshold; threshold defined as minimum current necessary to pace ventricle); to increase sensitivity (and allow detection of R waves), lower mV setting for sensitivity Detection of P wave: after R wave detection, ECG allows “refractory period” of 400 to 450 msec, during which no voltage measured; next impulse detected read as P wave

Effect of electrocautery: appears as “smudge” on QRS complex; generates large signal that “confuses” device and inhibits pacing; example—patient with third-degree heart block has pacemaker with DDD setting; continuous cautery inhibits pacemaker; to prevent severe bradycardia or asystole, set pacemaker to DOO (ie, setting for dual pacing [D] with no sensing [O] and no inhibition [O]); pacemaker ignores intrinsic beats and may generate pacing impulse on T wave (R-on-T phenomenon), which may cause ventricular tachycardia (VT) or ventricular fibrillation (VF); warning—never leave pacemaker in DOO or VOO mode when not operating with electrocautery; anesthesiologist responsible for detecting intrinsic beats when pacemaker in DOO or VOO mode, and must convert setting to DDD or disable pacemaker when extra beats noted

Inhibition: pacemaker senses voltage coming from heart and monitors P waves and QRS waves; clock counts 1000 msec, and if no impulse detected, pacing impulse sent; every P wave resets clock to zero and counts 200 msec (waiting for QRS); QRS resets clock to zero and cycle begins again; pacemaker unable to inhibit heart; heart inhibits pacemaker and resets counter to zero

Magnets: often associated with erroneous “magical thinking” (ie, believed to solve all pacemaker problems); affect pacemaker by activating programmable switch in device; effect produced depends on, eg, brand and type of device, specific mode to which magnet is set, level of battery charge in device; possible effects—deactivation of pacemaker; activation of “listening” for information from radio-frequency controller; change of functions; result of applying magnet not always desired effect, so effect must be known before activation of switch; often deactivates sensors for VT and VF without changing pacing mode (DDD) for implantable cardiac defibrillators (ICD); pacemakers frequently convert to DOO

Educational Objectives
The goal of this program is improve the intraoperative management of patients with pacemakers. After hearing and assimilating this program, the clinician will be better able to:

1. Describe a ground loop and safety precautions used in the operating room.
2. Explain how a pacemaker detects the various electric impulses generated by the heart.
3. Follow appropriate procedures before applying a magnet to a pacemaker.
4. Demonstrate the proper use of an external pacemaker.
5. Select the most appropriate pacemaker mode for specific dysrhythmias.

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 following has been disclosed: Dr. Wallace is a consultant and designer for ConMed Corporation, and an investigator for NIHON KOHDON. The planning committee reported nothing to disclose. In his lecture, Dr. Wallace presents information that is related to the off-label or investigational use of a therapy, product, or device.
Critical device information: type of device; brand and manufacturer and provide appropriate contact information

End-of-life mode: end of battery life; when battery runs low, power conservation alters magnet mode in some devices (e.g., DOO rate of 50 bpm; if underlying rate 70 bpm, asynchronous pacing may trigger VT or VF)

Examples: if intrinsic rate 80 bpm, pacemaker rate 50 bpm, and mode DDD, actual rate 80 bpm (pacemaker inhibited); if intrinsic rate 50 bpm, pacemaker rate 80 bpm, and mode DOO, actual rate 80 bpm (paced rate faster than intrinsic rate); if intrinsic rate 80 bpm, pacemaker rate 50 bpm, and mode DOO, VF likely (probability of R-on-T phenomenon high); intrinsic patient rate should not be higher than pacemaker rate in DOO mode

Pacemakers and tachycardia: DDD — dual pacing, dual sensing, and dual inhibition; DVI — dual pacing, ventricular sensing, and ventricular inhibition (atrium ignored); R-R interval 200 msec; if patient converts from paced mode to atrial flutter at 300 bpm, pacemaker senses P wave, waits 200 msec, and fires QRS; repeating with each P wave leads to paced rate of 300 bpm; maximum rate setting — prevents 1:1 conduction of supraventricular tachycardia (SVT); DVI or VVI appropriate for patients with atrial fibrillation, atrial flutter, or frequent VT; case example — pacemaker in DDD mode with rate of 50 bpm, but patient pulse 110 bpm, with pacing spikes on every QRS complex (pacing rate appears to be 110 bpm); pacemaker working properly, but detecting P waves caused by sinus tachycardia; treat source of tachycardia (e.g., admininister fluids, analgesia, or β-blockers) to slow rate; “show pacemaker spikes” setting — option available on monitor; monitors filter ECG signal to eliminate electrical noise; ECG signal 0.05 to 20 Hz; in United States, electricity in walls causes high level of background noise at 60 Hz (50 Hz in Europe); pacemaker spike 1 msec (1000 Hz); if filter on monitor set to 0.05 to 20 Hz, pacing spikes not shown; monitors have band-pass filter at 20 Hz (to eliminate background noise), and another at 1000 Hz to allow pacing to be shown (second filter activated when “show pacemaker spikes” mode selected)

Most efficient pacing mode: efficiency defined as maximum cardiac output in patient with intact conduction system; AAI mode (atrial pacing, atrial sensing, and atrial inhibition) avoids risk of R-on-T phenomenon from ventricular pacing; intact conduction system allows Purkinje fibers to synchronously contract ventricle; pacemaker-induced QRS complex wider than normally conducted complex (i.e., tissue conduction not fully synchronous); efficient contraction requires 2 leads in ventricle or use of Purkinje system; therefore, AAI most efficient pacing mode in patient with intact conduction system (improves cardiac output by ≈10%)

Case example: patient in asystole after sternotomy; 4 wires protrude from patient’s skin lateral to inferior edge of sternotomy wound (2 on each side); after beginning cardiopulmonary resuscitation, ventilating, oxygenating, administering epinephrine and atropine, and intubating, attach pacing wires to external pacing box and activate pacing (patient wires go directly into box without extension wires); wires on right side pace right atrium, and wires on left side pace ventricle; wires from right side should be placed in port on pacing box marked “A,” and wires from left side in port marked “V” (however, contraction of some type [preferable to asystole] produced if box turned on with wires reversed)

Bipolar vs unipolar: bipolar cautery — often used in neurosurgery; 2 tongs (one for source and one for ground) control current; saline around tips keeps current localized; unipolar cautery — spinal cord and brainstem become grounding tissue if used in neurosurgery; sends current from stylus, through body, to grounding pad; burns at grounding sites avoided when current density decreased by spreading over large area (source must be much smaller than grounding pad); electrocautery and heart — heart unaffected because frequency of Bovie 1 million Hz (1 MHz; too fast for heart to track); reducing frequency to 1000 Hz would result in AF and death

Examples of bipolar and unipolar systems: rubber tires on electric bus isolate it from ground, and require 2 wires for complete circuit (bipolar); electric train grounds through steel wheels and tracks, and needs only single wire for complete circuit (unipolar); bird on wire has no ground to complete circuit, and therefore remains unaffected

Pacing wires: 2 atrial wires and 2 ventricular wires (bipolar); case example — one pacing wire inadvertently pulled out of pacer-dependent patient’s chest (breaking bipolar circuit and causing asystole); to remedy, insert wire into any site on patient’s skin (electrons find wire and complete circuit); pace until internal wire replaced surgically or through cordis in neck

Pacemaker code: first letter signifies area paced; second letter signifies area sensed; O means no sensing, A represents atrium, V represents ventricle, and D means dual (both atrium and ventricle); last letter indicates whether area ignored, inhibited, or dually inhibited

AOO: atrial pacing, no sensing, and no inhibition; used for patient with sick sinus syndrome and intact conduction system, when extensive use of electrocautery planned

AAI: atrial pacing, atrial sensing, and atrial inhibition; used for patient with sick sinus syndrome and intact conduction system

VOO: ventricular pacing, no sensing, and no inhibition; used in operating room for patient with third-degree heart block and AF (cannot pace atrium if fibrillating)
VVI: ventricular pacing, ventricular sensing, and ventricular inhibition; used for patient with third-degree heart block and AF
DOO: dual pacing, no sensing, and no inhibition; used for patient with third-degree heart block undergoing surgery with electrocautery
DVI: dual pacing, ventricular sensing, and ventricular inhibition; used for patient with third-degree heart block and SVT

DDD: dual pacing, dual sensing, and dual inhibition; used for patient with third-degree heart block; standard setting; requires 2 leads

Resources: speaker answers questions sent via email (to art.wallace@va.gov); handout entitled “Pacemakers for Anesthesiologists Made Incredibly Simple” available at www.cardiacengineering.com

Dr. Wallace’s lecture is from our recently published Audio-Digest Anesthesiology Board Review Course. The course is designed to match the defined learning objectives of the American Board of Anesthesiology, and is intended to provide a source of review material for those who are preparing for the ABA’s Maintenance of Competence Assessment or the initial examinations of the Board. For more information, please visit audiodigest.org/anbr. The Audio-Digest Foundation thanks Dr. Wallace for his cooperation in the production of this program.

Suggested Reading


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**Estimated time to complete the educational process:**

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To test online, go to www.audiodigest.org and sign in to online services.
To submit a test form by mail or fax, complete Pretest section before listening and Posttest section after listening.

1. Choose the correct statement about ground loops.
   (A) Ensures the equipment in the operating room operates safely
   (B) Created when the grounding pad is placed on a patient; required for the electrocautery to function
   (C) Intrinsic to pacemaker sensing; allows repeated signals for pacing
   (D) Occur when variations in ground voltage send high current through a circuit; can cause burns or fire

2. In pacemaker nomenclature, the term “threshold” refers to:
   (A) Voltage level above which there is an R wave
   (B) Minimum current necessary to pace the ventricle
   (C) Time delay between reading a P wave and triggering a QRS complex
   (D) Maximum rate generated by a pacemaker

3. The _____ inhibits the ______.
   (A) Heart; pacemaker
   (B) Pacemaker; heart

4. Which of the following statements about the application of a magnet to a pacemaker is true?
   (A) Required for all patients with pacemakers who undergo surgery
   (B) Provides a “boost” and improves the function of a pacemaker near the end of its life
   (C) Ventricular tachycardia may result from magnet-induced asynchronous mode
   (D) The magnet should be left on the patient until discharge from the recovery room

5. A pacemaker-induced QRS complex is wider than one that is naturally conducted.
   (A) True
   (B) False

6. Reversing the wires of an external pacemaker should be avoided at all costs.
   (A) True
   (B) False

7. Choose the correct statement about circuits and electrocautery.
   (A) Pacing wires form a unipolar circuit
   (B) In unipolar cautery, the source must be much smaller than the grounding pad to avoid causing burns
   (C) The heart often tracks the frequency of electrocautery
   (D) Unipolar cautery is preferred for neurosurgery

8. The first letter in the pacemaker code signifies the area ______, and the second letter signifies the area ______.
   (A) Inhibited; sensed
   (B) Paced; inhibited
   (C) Sensed; paced
   (D) Paced; sensed

9. Select the best mode for a patient with sick sinus syndrome and an intact conduction system.
   (A) AAI
   (B) AOO
   (C) DOO
   (D) DDD

10. Choose the best mode for a patient with third-degree heart block and supraventricular tachycardia.
    (A) AAI
    (B) VVI
    (C) DVI
    (D) DDD

Answers to Audio-Digest Anesthesiology Volume 55, Issue 19: 1-B, 2-C, 3-D, 4-A, 5-C, 6-B, 7-D, 8-A, 9-C, 10-A