Malignant Hyperthermia
Diagnosis, Treatment, and Prevention

INTRODUCTION

Malignant hyperthermia (MH) is a serious and potentially life-threatening hypermetabolic skeletal muscle disorder induced in response to certain anesthetics in genetically susceptible individuals.1,2 Because the condition is relatively uncommon, most clinicians may not have extensive firsthand experience with its diagnosis and clinical management and thus may not be prepared to act quickly and appropriately in an MH crisis. Indeed, a recent study reported that operating room personnel are not prepared to detect and manage episodes of MH sufficiently.3 These limitations may be magnified in ambulatory surgery settings, which have relatively fewer resources for the management of complex patients.3,4

This activity provides an overview of the pathophysiology, epidemiology, clinical presentation, diagnosis, management, and prevention of MH. It also discusses recent changes in the formulation of the major treatment agent, dantrolene, as well as evolving guidelines for the transfer of affected patients to appropriate treatment facilities.

LEARNING OBJECTIVES

At the completion of this activity, participants should be able to:

1. Discuss the pathophysiology of MH.
2. Describe the characteristic clinical findings that identify an MH crisis.
3. Identify all supplies required to manage an MH crisis.
4. Discuss, in order, the appropriate steps that must be taken to manage an MH crisis.
5. Discuss preventive measures required to provide safe care to patients who are susceptible to MH.

INTENDED AUDIENCE

This activity is intended for physicians, perioperative nurses, and other health care professionals responsible for managing MH.

STATEMENT OF NEED

Malignant hyperthermia (MH) is a life-threatening pharmacogenetic disorder triggered by the administration of volatile anesthetics, succinylcholine, or both. It manifests in a hypermetabolic crisis that is likely to be fatal if left untreated. Because MH is rare, clinicians may lack awareness of it, may not recognize it, and may not be prepared to treat it. Important steps in the treatment protocol may be omitted, with potentially lethal results, when clinicians rely on unaided memory alone to treat MH. In addition, stocks of dantrolene or other supplies may be inadequate or not readily accessible in the event of an MH crisis, particularly in non-hospital surgical settings. Finally, preoperative and post-episode evaluation of patients often is inadequate. Clinical education is necessary to close these practice gaps.

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FINANCIAL DISCLOSURES

Cynthia A. Wong, MD: Nothing to disclose
Bonnie Denholm, MS, BSN, RN, CNOR: Nothing to disclose
Oren Traub, MD, PhD (medical writer): Nothing to disclose
AKH planners and reviewers: Nothing to disclose

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ESTIMATED TIME OF COMPLETION

60 minutes

METHOD OF PARTICIPATION

There are no fees for participating in and receiving credit for this activity. The participant should, in order, read the objectives and monograph and complete the multiple-choice post-test.

Participation is available online at CMEZone.com. Enter IP112 in the keyword field to access this activity directly. Or, complete the answer sheet with registration and evaluation on page 22 and mail to AKH Inc., PO Box 2187, Orange Park, FL 32067-2187; or fax to (904) 683-3803. Statements of participation will be mailed/emailed approximately 6 to 8 weeks after receipt of mailed or faxed submissions. A score of at least 70% is required to complete this program successfully. One retake is allowed. Credit is available through December 1, 2013. For questions regarding this CME/CE activity, please contact AKH Inc. at trish@akhealthcare.com.

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Pathophysiology and Epidemiology

The level of calcium in the cytoplasm of skeletal muscle cells is the primary determinant of muscular contraction. In the baseline relaxed state, intracellular calcium is sequestered within a specialized organelle, the sarcoplasmic reticulum (SR). Upon stimulation of skeletal muscle at the neuromuscular junction, membrane depolarization leads to activation of dihydropyridine receptors on the skeletal muscle cell membrane, which subsequently activate ryanodine-sensitive calcium channels on the SR. This results in the release of calcium from the SR into the intracellular cytoplasm, thereby activating actin and myosin and producing skeletal muscle cell contraction. When the neuromuscular stimulus is terminated, the ryanodine-sensitive calcium channel closes, and calcium is resorbed into the SR via specialized calcium pumps, resulting in cession of muscular contraction.2-4

In some individuals, inherited or spontaneous mutations of genes associated with the dihydropyridine receptor, ryanodine-sensitive channel receptor (RYR1), or other proteins lead to excessive calcium release from the SR, resulting in sustained skeletal muscle contraction.2-4 The sustained contraction leads to a hypermetabolic state represented by excess production of lactate, carbon dioxide (CO₂), and heat, as well as excess consumption of adenosine triphosphate (ATP) and oxygen. Ultimately, ATP depletion causes the failure of cellular homeostatic mechanisms and the release of potassium, creatine kinase (CK), and myoglobin from skeletal muscle cells into the bloodstream, resulting in hyperkalemia, rhabdomyolysis, arrhythmias, end-organ damage, and death.2-4 Individuals who possess these genetic mutations are designated as "at risk" (in humans, stressors such as vigorous exercise and heat (Table 1).2-4 Very little is known about the specific mechanisms by which anesthetics interact with these abnormal receptors to trigger an MH crisis.

An episode of MH typically requires underlying MH genetic susceptibility and the presence of a triggering agent, the most common being volatile inhalational anesthetic agents (e.g., halothane, sevoflurane, or desflurane), the depolarizing muscle relaxant succinylcholine, and the nondepolarizing agent, the most important indicator of MH is the presence of a triggering agent.2-4 The incidence of MH episodes is lower (between 1 in 5,000 and 1 in 50,000 anesthetics), due to the variable penetrance of genetic abnormalities and the requirement for a triggering factor.3,6 Further, an MH crisis may develop at first exposure to anesthesia with triggering agents or patients may experience multiple uneventful anesthetic episodes before having an episode.5 Reactions occur more commonly in younger patients and in males, but there is no ethnic or geographic predominance.2-5

Clinical Presentation and Consequences

Clinical manifestations of MH may vary, and not all of the classic symptoms associated with MH may occur. The most reliable initial clinical sign heralding the development of acute MH is an increase in end-tidal CO₂ (ETCO₂) that is resistant to increasing the patient’s minute ventilation.2 The increase in exhaled CO₂ may heat the CO₂ absorbent in the circle system and exhaust the absorbent rapidly.11 Other early signs may include sinus tachycardia, respiratory distress, and muscle spasm (or tension) and/or generalized muscle rigidity.1-5

Contrary to its nomenclature, hyperthermia often is a later sign of MH and may be absent when the diagnosis is suspected initially.12 Sustained muscle contraction from unregulated calcium release generates more heat than the body is able to dissipate. The resulting hyperthermia can occur minutes to hours following the initial onset of symptoms.13,14 Severe hyperthermia is associated with development of disseminated intravascular coagulation (DIC), a poor prognostic indicator and often terminal event.13 The severity and timing of other signs of MH can vary and depend on the degree of muscle mass.1,14 They include electrocardiographic (ECG) changes and arrhythmias (e.g., peaked T-waves, premature ventricular contractions, ventricular tachycardia, ventricular fibrillation) caused by elevated potassium levels from muscle breakdown. Rhabdomyolysis also can occur, with plasma CK and urine myoglobin levels peaking hours to days after an acute MH episode.14 In muscular patients, plasma CK levels may exceed 100,000 units/L.15 Brownish or tea-colored urine may indicate the presence of myoglobinuria.16

Time of initial symptom onset can vary as well. Most cases occur intraoperatively, within 1 hour of anesthetic induction.14-16 Following successful treatment, approximately 20% of patients can experience recurrence, usually within the first 24 hours, which are more common in those with greater muscle mass.16

MH crisis is likely to be fatal if left untreated. Even in nonfatal cases, morbidity can be serious; a North American MH Registry study of reports from 1987 to 2006 showed that nonfatal complications occurred in 35% of patients.12 These complications may include cardiac, respiratory, renal, or hepatic dysfunction; coma or change in consciousness level; pulmonary edema; and DIC. In recent years, the MH-related mortality rate has decreased from an estimated 70% to less than 10% as a result of the availability of an effective treatment and an improved understanding of the clinical manifestation and pathophysiology of the condition.17 One study found that the nationwide mortality rate from MH had fallen further, “MH susceptibility” or “having the MH effect” or “awake” MH events have been confirmed in individuals found to have mutations in the RYR1 gene.18,19

Diagnosis

The signs and symptoms of MH episodes can be variable and nonspecific, making diagnosis difficult.1,10 In addition, risk factors that can predict MH have not been identified. Although specific operative procedures and diseases have been associated with MH, the positive predictive value is extremely low.20 The consequences of difficult diagnosis are magnified by the fact that early detection and treatment of MH are required in order to avoid catastrophic outcomes. Thus, successful diagnosis requires a thorough knowledge of the clinical manifestations and variable time course, in combination with a high degree of clinical suspicion.21

During an acute event, diagnosis of MH is based on clinical signs and symptoms as well as laboratory tests in the appropriate context (i.e., recent administration of a triggering agent). The most important indicator of MH is the presence of respiratory acidosis, manifested as increased ETCO₂. Muscle rigidity, metabolic acidosis, and hyperthermia may be present.21 In a patient anesthetized with volatile agents, MH should be suspected strongly when there is a significant increase (≥55 mm Hg) in ETCO₂ that does not respond readily to large increases in minute ventilation. However, increased ETCO₂ can be caused by technical factors (e.g., malfunction of the circle breathing system, ventilator, moisture removal, or elimination of end-expiratory CO₂), bronchial obstruction, pneumothorax, or increased CO₂ production or retention (e.g., CO₂ insufflation during laparoscopic procedures; reperfusion after prolonged vascular occlusion, thyrotokisis, or pheochromocytoma).1,3 During general anesthesia or sedation, the most common cause of sudden or gradual hypercapnia is hypoventilation. Increasing minute ventilation with supplemental ventilation or correcting ventilator settings should correct the ETCO₂. Ventilating with a bag mask valve attached to a

### Table 1. Anesthetic Drugs and Malignant Hyperthermia Susceptibility

<table>
<thead>
<tr>
<th>Category</th>
<th>Agents</th>
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<tbody>
<tr>
<td><strong>Unsafe for Use in MH-susceptible Patients</strong></td>
<td>Vecuronium, rocuronium, atracurium, sufentanil, naloxone, morphine, methadone, codeine, alfentanil, opioids (all opioids)</td>
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<tr>
<td><strong>Nontriggering Agents</strong></td>
<td>isoflurane, mepivacaine, levobupivacaine, etidocaine, ketamine, midazolam, fentanyl, propofol, thiopental, inhaled volatile general anesthetic, nitrous oxide, diazepam, methohexital, diazepam, ketamine, propofol, thiopental, inhaled volatile general anesthetic, nitrous oxide, diazepam, methohexital, ropivacaine, levobupivacaine, bupivacaine, chloroprocaine, lidocaine, mepivacaine, prilocaine, procaine, ropivacaine, opioids (all opioids), sufentanil, diazepam, codeine, diamorphine, fentanyl, hydromorphone, methadone, morphine, naloxone, oxycodeone, remifentanil, sufentanil, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofol, thiopental, propofo...</td>
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supplemental oxygen source should correct the ETCO2 in the setting of breathing circuit malfunction.

A diagnosis of MH can be supported further by venous or arterial blood gas analysis, which demonstrates a mixed metabolic and respiratory acidosis. In the very early stages of acute MH, the metabolic component of the acidosis may be mild. The presence of hyperkalemia, indicating significant muscle breakdown, further strengthens the diagnosis. Masseter muscle tension normally increases after the administration of succinylcholine, but typically lasts only a few seconds; if it persists, it may indicate MH. Generalized muscle rigidity in the presence of neuromuscular blockade is considered pathognomonic for MH in the presence of other signs of hypermetabolism. The CK level may or may not be elevated in the initial stages of acute MH and, like potassium, increases greatly due to lysis of muscle cell membranes. Detection of urine myoglobin during the clinical course also supports a diagnosis of MH. A rapid test for urine myoglobin is the presence of heme on the dipstick with lack of red blood cells on the urinalysis.

Tachycardia often occurs during the early course of MH but is relatively nonspecific. Other causes of tachycardia that must be distinguished from MH include inadequate depth of anesthesia and sympathomimetic toxicity, among a multitude of others.

Timely detection of an MH event is aided by core temperature monitoring. Skin temperature does not reflect MH adequately in a swine model, therefore, core (esophageal, nasopharyngeal, tympanic, pulmonary artery) or near-core (oral, bladder, axillary) temperature monitoring is recommended. Experts recommend temperature monitoring for general anesthetics longer than 30 minutes in duration. Hyperthermia may be hard to distinguish from causes of perioperative fever, for example, infections, bacteraemia, endothelial cell disruption, and drug effects (recreational drug overdose, serotonin syndrome). Sepsis may be accompanied by fever, metabolic acidosis, and elevated CK, making it difficult to distinguish from MH.

Because of the catastrophic consequences associated with delayed therapy, exploration of the differential diagnosis of a potential MH episode should not delay initiation of therapy if MH cannot be excluded rapidly.

Management

Early identification of MH and initiation of treatment is the main factor determining success in rescue from an MH event (Figure 1). The Malignant Hyperthermia Association of the United States (MHAUS) provides educational materials with emergency consultation to help guide management of an MH episode via a hotline telephone number: (800) 644-9737 (outside the United States: 001-303-389-1647).

Acute Treatment

Once an episode of MH is recognized, anesthetic triggering agents should be discontinued immediately, the patient’s inspired oxygen concentration should be increased to 100%, and ventilation should be increased with high oxygen flows to prevent rebreathing. Surgery should be aborted if the procedure is elective and at a point when it can be stopped. Otherwise, the patient should continue to receive general anesthesia with non-triggering agents (eg, propofol, ketamine, opioids, or benzodiazepines). If the patient’s trachea is not intubated, ETT placement should be performed simultaneously with the remainder of the protocol. Additional personnel should be summoned to assist with drug preparation and administration, as well as other aspects of patient management.

Dantrolene, the only known antidote for MH, should be administered immediately. Dantrolene binds to ryanodine receptors (RYR1) and inhibits SR calcium release, thereby reversing skeletal muscle hypermetabolism.

Dantrolene is administered as a loading bolus of 2.5 mg/kg intravenously via large-bore IV access. If the patient does not respond to the first dose within minutes, subsequent bolus doses of 2.5 mg/kg should be administered until the signs of acute MH have abated. Some patients, especially muscular males, may require initial dantrolene doses approaching 10 mg/kg, and some case reports have described necessary doses of approximately 40 mg/kg. If a response does not occur after repeated dantrolene administration, alternative diagnoses should be considered.

Dantrolene is supplied as a lyophilized powder (20 mg) in a vial that also contains 3 g of mannitol and sodium hydroxide to maintain pH of 9.0 to 10. The powder should be mixed with sterile water. The older formulation of dantrolene did not dissolve readily; a newer, rapidly mixing formulation that solubilizes much more readily (reconstitution time of 20 seconds) is available currently.

Dantrolene generally is safe when administered at recommended dosages. It has no effect on cardiac or smooth muscle. Side effects include nausea, malaise, light-headedness, muscle weakness, and irritation and thrombosis at the IV site due to the high pH of the drug.

Limb muscle weakness usually occurs. Respiratory muscle weakness may occur when large doses are used or when administered to patients with an underlying debility. Pulmonary edema has been described.

Additional Treatment

Simultaneous to dantrolene administration, treatment to address the metabolic effects of MH should be initiated. The patient’s temperature should be monitored, and blood should be collected for assessment of electrolytes, acid–base status, CK, and coagulation parameters. Arterial or venous blood gases should be collected as needed until pH and potassium levels trend toward normal values. An indwelling urinary catheter should be used to monitor urine color and volume.

Hyperkalemia is treated via standard measures (ie, calcium, bicarbonate, and insulin–glucose); lacking laboratory confirmation, treatment should be initiated based on the presence of abnormal ECG waveforms (ie, peaked T-waves) to prevent the development of life-threatening arrhythmias or cardiac arrest. Persistent metabolic acidosis can be treated with repeated doses of sodium bicarbonate, 1 to 2 mEq/kg.

Cooling measures should be instituted to maintain patient temperature at below approximately 38.5°C (101.3°F). This can be achieved by uncovering the patient; decreasing ambient temperature; using cooling blankets, ice packs, IV infusion of cooled saline or ice saline lavage via nasogastric tube; or wound irrigation. Care should be taken not to overcool the patient.

Although cardiac arrhythmia generally abates when acidosis and hyperkalemia are brought under control, it may persist. In such cases, standard antiarrhythmic agents can be used, but calcium channel blockers are contraindicated because they can worsen the hyperkalemic condition and lead to cardiac collapse. Transfer to an acute care facility should be initiated at any point at which these recommended interventions exceed the capacity of the treatment facility (eg, ambulatory surgical center). Patient comfort should be maintained with the administration of sedative–hypnotics.

Ongoing Care

Following initial control of the hypermetabolic event, the patient should be transferred to the intensive care unit (or to an acute care facility if not already done) for ongoing monitoring, mechanical ventilation, and treatment. Because the anesthesiologist may have the most experience and training with the treatment of MH, his or her ongoing participation in the care of the patient is recommended.

CK and renal function (serum creatinine) should be monitored, and urine output maintained at 1 to 2 mL/kg per hour until the urine color returns to normal and CK begins to decrease. Peak CK levels occur 14 to 48 hours after the MH crisis. Diuretics and IV bicarbonate may be used to reduce the risk for myoglobin-induced renal failure; consultation with a nephrologist may be helpful.

Because recurrence occurs in up to 20% of patients after initial treatment, maintenance doses of dantrolene (1 mg/kg every 6 hours) should continue for 24 to 48 hours after the last observed sign of acute MH. If recurrent signs appear despite ongoing treatment, additional dantrolene boluses may be required. Alternatively, a dantrolene infusion (0.25 mg/kg per hour) can be used.

Post-Recovery Management

Following recovery from an acute MH event, patients should be advised to avoid MH-triggering agents and inform future anesthesia providers and emergency response personnel of their susceptibility.

A letter from the anesthesia professional who supervised the initial incident should be sent to the patient, and the patient should be instructed to give a copy to all future anesthesia providers. An additional copy should be placed in the patient’s medical record for future reference. A medical alert bracelet, which can be obtained through MHAUS, also may be indicated. Because MH susceptibility is genetic, health care professionals should inform family members of the event to allow them to seek advice from their personal physicians regarding further evaluation or the potential need to avoid triggering agents.
All patients with a clinical event suspicious for MH should be referred to a Malignant Hyperthermia Testing Center for further evaluation and consult the MHAUS Web site for additional information. The testing center may recommend testing the patient and family members for MH susceptibility. The gold standard is the caffeine-halothane contracture test, which requires a muscle biopsy.2-5 However, in North America, testing is performed only at a few centers and is expensive. In lieu of contracture testing, some patients with suspected MH susceptibility opt for molecular genetic testing or simply consider themselves (and their family members) MH-susceptible. However, because current genetic testing evaluates only a relatively small percentage of possible MH-susceptible. However, because current genetic testing evaluates only a relatively small percentage of possible mutations, its overall sensitivity is low, and a negative genetic test does not rule out underlying MH susceptibility.

Transfer of Care Considerations

MHAUS recently issued recommendations for the transfer of a patient with suspected MH from an ambulatory surgery center (ASC) to an acute care facility (Figure 2).7,8 This is critical for the patient’s well-being. In general, decisions about the timing and mode of transport should be made by ASC clinicians and take into account the patient’s condition, capabilities of the ASC, capabilities of the transport services, and time needed to arrive at an acute care facility.

Because successful treatment for MH requires immediate action, it is preferable that immediate treatment and control of the hypermetabolic event be achieved on site (e.g., ETCO₂: declining or normal, heart rate stable or decreasing, no ominous cardiac dysrythmias, IV dantrolene administration begun, temperature declining, muscular rigidity resolving). However, it will not always be possible for all the indicators of stability to be present before transfer. For the rapidly deteriorating patient, immediate transfer to a sophisticated facility that is prepared to treat MH may be the wisest course of action. The anesthesiologist may have the most experience and training with the treatment of MH and should continue to participate in care of the patient in the ASC, during transport, and/or at the receiving facility. Procedures for transfer should be formulated ahead of time (e.g., admission to the emergency department or direct admission to the ICU); physician-to-physician communication is optimal. The nurse may play an important role by facilitating the transfer and supporting family members.

Reporting

All MH events or suspected MH events should be reported to the North American Malignant Hyperthermia Registry (http://www.mhaus.org/malignant-hyperthermia-registry) which was established to acquire, analyze, and disseminate patient-specific clinical and laboratory information to scientific investigators and physicians caring for MH-susceptible patients. Data also are used in research on the epidemiology, diagnosis, and treatment of MH.

Prevention and Preparedness

Any facility that uses MH-triggering agents should be prepared to detect and manage an episode of MH. This includes established protocols for treatment and/or transfer, availability of appropriate drugs and equipment (MH kits, emergency carts), and the presence of personnel who are educated and trained in the detection, treatment, and prevention of MH episodes. MHAUS provides resources for such training, including brochures, posters, and multimedia resources for training and drills (Table 2).31

Prevention of MH episodes also is critical. It is not practical or feasible to screen for MH susceptibility using biopsy or genetic testing in an individual without a personal or family history of MH susceptibility or a previous MH episode, but the preanesthesia evaluation and preoperative nursing assessment should assess for a personal or family history of MH susceptibility.31 Most patients with underlying MH susceptibility will not be aware of it, however, because MH has variable penetrance, previous uneventful anesthesia does not exclude MH susceptibility.

Patients with known or suspected MH should not receive triggering agents but instead should be safely anesthetized using nontriggering agents or local or regional anesthesia.43,51,31 Pretreatment with dantrolene is not recommended. In addition, the anesthesia provider should prepare the anesthesia machine and ensure that the patient will not be exposed to trace anesthetic gases. Measures include flush the anesthesia machine with high-flow oxygen (at least 10 L per minute) for 20 minutes, and removing or placing tape over the vaporizer canisters to avoid accidental administration.55,53 For older machines with copper tubing, the reservoir bag should be attached to the distal end of the ventilator circuit Y-piece with at least 5 ventilator cycles per minute during the 20-minute flushing. Newer anesthesia workstations with plastic components may require more than 60 minutes to purge residual gases.53,52,31 Charcoal filters inserted in the breathing circuit have been shown to reduce the residual anesthetic concentration in the breathing circuit quickly.53 Practitioners should consult manufacturer information in regard to the optimal manner for preparing specific equipment.

All facilities at which general anesthesia is administered should have adequate stocks of dantrolene in the event that MH occurs. Because of the increasing prevalence of obesity and uncertainty regarding the required dosing (actual body weight vs ideal body weight) for effective relief of MH, MHAUS recommends that at least 36 vials be available at all times.21,23 However, it should be noted that 75 vials (20 mg per vial) would be required in the theoretical instance of an obese patient (150 kg) requiring a dantrolene dose of 10 mg/kg.

Conclusions

MH is a serious and potentially life-threatening hypermetabolic condition involving abnormal release of calcium within skeletal muscle cells in response to a
triggering agent. It occurs in genetically susceptible individuals. Successful diagnosis requires recognition of the constellation of symptoms in the right clinical context, and avoidance of catastrophic outcomes requires prompt discontinuation of triggering agents, administration of dantrolene, and therapy directed against the metabolic complications of the disorder. Transfer-of-care protocols are critical for patients who experience an MH episode in an ASC. A rapidly mixing formulation of dantrolene became available in 2009. It is easier to prepare than the older formulation and should facilitate the care of patients with an MH episode.

References

Resources
Association of peri-Operative Nurses: http://www.aorn.org/education/confidencebasedlearning/malignanthyperthermia/
American Society of Anesthesiologists: http://www.asahq.org/education/confidencebasedlearning/malignanthyperthermia/
Knowledge-Base/Diseases-and-Conditions/ASA/Malignant-Hyperthermia-Syndrome-From-Barnyard-to-Molecular-Genetics-Laboratory.aspx

CME Post-Test
1. Which of the following therapeutic agents is contraindicated in the context of an acute episode of malignant hyperthermia (MH)?
   a. Amiodarone
   b. Verapamil
   c. Furosemide
   d. Sodium bicarbonate

2. Which of the following is the earliest and most reliable sign of an acute episode of MH?
   a. Hyperthermia
   b. Elevation in end-tidal CO2 (ETCO2)
   c. Increased serum creatine kinase
   d. Cardiac arrhythmias

3. Which of the following agents represents a potential triggering agent in patients with susceptibility to MH?
   a. Sevoflurane
   b. Midazolam
   c. Fentanyl
   d. Propofol

4. Which of the following tissues is involved in the pathophysiology of MH?
   a. Smooth muscle
   b. Cardiac muscle
   c. Skeletal muscle
   d. Endothelial cells

5. Which of the following is most likely a potential complication of an episode of MH?
   a. Peripheral neuropathy
   b. Central pontine myelinolysis
   c. Penciclovir
   d. Rhabdomyolysis

6. How many vials of dantrolene does the Malignant Hyperthermia Association of the United States recommend should be readily available?
   a. 3
   b. 10
   c. 16
   d. 36

7. Which of the following represents a major advantage of a newer formulation of dantrolene over the previous formulation?
   a. Easier to reconstitute
   b. More potent
   c. Less expensive
   d. Longer shelf-life

8. MH-triggering agents are contraindicated in which of the following patients?
   a. Patients with a personal history of an MH episode
   b. Patients with a history of MH in a first-degree relative
   c. Patients with a positive halothane-caffeine contracture study
   d. All of the above

9. Which of the following preventative measures is recommended in an MH-susceptible patient who requires general anesthesia?
   a. Purging equipment and breathing circuit of volatile anesthetics
   b. Prophylactic dantrolene administration
   c. Induction of intraoperative hypothermia
   d. Prophylactic administration of potassium-binding resins

10. Which of the following is true regarding MH-susceptibility testing?
    a. All patients anticipating surgery with general anesthesia should undergo susceptibility testing
    b. The caffeine-halothane contracture test is expensive and available only at certain centers
    c. Negative genetic testing essentially rules out a diagnosis of MH susceptibility
    d. All of the above
**Answer Sheet and Evaluation Form**

**Malignant Hyperthermia: Diagnosis, Treatment, and Prevention**

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**Post-Test Answer Section**

Please circle the correct answer for each question. (A score of at least 70% is required to receive credit.)

1. a b c d  
2. a b c d  
3. a b c d  
4. a b c d  
5. a b c d  
6. a b c d  
7. a b c d  
8. a b c d  
9. a b c d  
10. a b c d  

**Evaluation Questions**

Please answer the following questions by circling the appropriate rating.

<table>
<thead>
<tr>
<th>Question</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
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<tr>
<td>1. After participating in this activity, I am better prepared to:</td>
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<tr>
<td>a. Discuss the pathophysiology of MH.</td>
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<td>b. Describe the characteristic clinical findings that identify an MH crisis.</td>
<td>4</td>
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<td>c. Identify all supplies required to manage an MH crisis.</td>
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<td>d. Discuss, in order, the appropriate steps that must be taken to manage an MH crisis.</td>
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<td>e. Discuss preventive measures required to provide safe care to patients who are susceptible to MH.</td>
<td>4</td>
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<tr>
<td>2. The activity met my educational needs.</td>
<td>4</td>
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<td>3. The faculty were knowledgeable and effective in the presentation of content.</td>
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<tr>
<td>4. The teaching method and educational materials were effective.</td>
<td>4</td>
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<td>5. The learning activities were effective and incorporated active learning methods.</td>
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<td>6. The post-test accurately assessed learning.</td>
<td>4</td>
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</tbody>
</table>

7. The content was objective, current, scientifically based, and free of commercial bias.
☐ Yes ☐ No (please explain): __________________________

8. Based on the information presented in this activity, I will
   ☐ do nothing, as the content was not convincing.
   ☐ seek additional information on this topic.
   ☐ change my practice.
   ☐ do nothing, as current practice reflects the program’s recommendations.

9. The most important concept learned during this activity that may affect a change in patient care is: __________________________

10. What issue(s) related to the therapeutic area discussed in this activity, or other topics, would you like addressed in future continuing education? __________________________

11. Additional comments: __________________________