

**MALIGNANT HYPERTHERMIA:
Keeping Your Cool**

1944



1944
MALIGNANT HYPERTHERMIA:
Keeping Your Cool

AORN INDEPENDENT STUDY ACTIVITY
AORN VIDEO WITH STUDY GUIDE



This publication may be photocopied for noncommercial purposes of scientific use or educational advancement. The following credit line must appear on the front page of the photocopied document:

Reprinted with permission from The Association of periOperative Registered Nurses, Inc.

Copyright 2006 "Malignant Hyperthermia".
Revised 2009 with new title.
All rights reserved by AORN, Inc.
2170 South Parker Road, Suite 400, Denver, CO 80231-5711
(800) 755-2676 • www.aorn.org
Video produced by Cine-Med, Inc.
127 Main Street North, Woodbury, CT 06798
Tel (203) 263-0006 • Fax (203) 263-4839 • www.cine-med.com

TABLE OF CONTENTS

Purpose/Goal	i
Objectives	i
Guide for Study	i
Overview	i
INTRODUCTION	1
Incidence and Mortality	1
Etiology	2
Neuroleptic Malignant Syndrome	2
Pathophysiology	2
Clinical Signs and Symptoms	3
Differential Diagnosis	4
PRECAUTIONARY MEASURES	4
MH Cart	4
Dantrolene	6
Ice Machine	6
Personnel Training	6
Treatment Protocol	6
Preoperative Precautions	6
Intraoperative Precautions	7
Anesthetic Agent	7
Monitoring	7
Postoperative Precautions	7
IF A CRISIS OCCURS	8
Malignant Hyperthermia	8
Acute Phase	8
Post-Acute Phase	10
Masseter Muscle Rigidity	11
Sudden Cardiac Arrest	11
NURSING INTERVENTIONS FOR ALL PATIENTS	11
THE ROLE OF THE PERIOPERATIVE NURSE	12
TESTING FOR MH-SUSCEPTIBLE PATIENTS	13
PATIENT/FAMILY EDUCATION	14
SUMMARY	14
ADDITIONAL RESOURCES	14
GLOSSARY	15
END NOTES	16
SUGGESTED READING	16
POSTTEST	18
Answer Sheet	20

PURPOSE AND GOAL

The purpose and goal of this activity is to provide perioperative nurses with critical information about Malignant Hyperthermia and the potential for a MH crisis during a surgical intervention. Critical thinking, fast action, and teamwork are all necessary to ensure a successful patient outcome.

OBJECTIVES

After viewing the video and completing the study guide, the learner will be able to:

1. List the signs and symptoms of a pending malignant hyperthermia crisis.
2. Describe preoperative assessment guidelines that should be implemented to identify patients at risk for malignant hyperthermia.
3. Identify perioperative precautions necessary for all patients known to be susceptible to malignant hyperthermia.
4. Indicate education needed by the perioperative team to respond appropriately to a MH crisis.

INTENDED AUDIENCE

This independent study activity is intended for perioperative nurses and nurses in post-anesthesia care units (PACUs) who care for patients undergoing surgical procedures involving the use of inhalation anesthetics or the muscle relaxant succinylcholine.

GUIDE FOR STUDY

This study guide is intended to be used in conjunction with the accompanying video, “Malignant Hyperthermia: Keeping Your Cool.” We suggest that you take the following steps to complete this activity:

1. Read the overview and objectives for this educational activity and compare them with your own learning objectives.
2. View the video.
3. Read the study guide, paying particular attention to those areas that reflect the objectives.
4. Consult the glossary or a dictionary for definitions of unfamiliar words.

OVERVIEW

Recognizing and treating a malignant hyperthermia (MH) crisis is one of the greatest challenges facing a surgical team. This study guide reviews the incidence, etiology, and clinical signs of MH. Strategies for preventing and dealing with MH are outlined, including developing and posting a treatment protocol, keeping an MH cart and an ice machine on hand, and providing regular personnel training. Assessment and monitoring considerations for all patients are described, and precautions to be taken for patients who are known to be MH-susceptible are discussed. Steps to be taken in the event of an MH crisis are detailed.

INTRODUCTION

Malignant hyperthermia (MH) is a rare genetic condition characterized by a severe hypermetabolic state and rigidity of the skeletal muscles. MH occurs when susceptible patients are exposed to a triggering agent, such as inhalation anesthetics and succinylcholine, during general anesthesia. Succinylcholine is a depolarizing skeletal muscle relaxant. The syndrome is characterized by a multifaceted chain reaction of symptoms, including greatly increased intracellular calcium ion concentration leading to increased body metabolism, muscle rigidity, and high fever (often a late sign). Unless MH is rapidly identified and treated, death can result from cardiac arrest, brain damage, internal hemorrhaging, or failure of other body systems.

MH was first described, and the term “malignant hyperthermia” first used, in the 1960s by Denborough and Lovell of Australia.¹ At the time, “malignant” referred to the high mortality rates associated with the syndrome, and “hyperthermia” referred to the high body temperature that developed. After their initial report, awareness of MH among anesthesiologists began to increase. Despite this increased awareness, however, the mortality rate for patients experiencing MH in the 1960s was still reported to be as high as 80%.

Subsequently, research in susceptible swine determined that the antidote drug dantrolene sodium could be used safely and effectively to treat MH in humans. Since the US Food and Drug Administration (FDA) approved the use of dantrolene for this purpose in 1979, death and disability related to MH have declined dramatically.

In addition to the availability of dantrolene, greater awareness of the risks and treatment of MH among anesthesia care providers and other health care professionals has resulted in earlier diagnosis and treatment of this life-threatening syndrome. This increased awareness is fostered by the Malignant Hyperthermia Association of the United States (MHAUS). MHAUS was founded in 1981 by a small group of concerned individuals with the objective of reducing the morbidity and mortality of MH by improving medical care, providing patient

information, and improving scientific understanding of the syndrome.

Incidence and Mortality

Although the exact incidence of MH is unclear, studies show that in patient populations that have been diagnostically tested there is an incidence of 1:30,000 and 1:37,000². The MHAUS reports that MH occurs as frequently as 1:5,000 patients but also may occur as infrequently as 1:65,000 administrations of general anesthesia³. Due to increased awareness and improved treatment, the mortality rate has been reduced to 5%. The mortality rate had been as high as 70% in the past.

The decrease in mortality rates is attributable to four factors:

- Better screening for MH susceptible individuals.
- Determination of pharmacologic basis for MH so that triggering agents are avoided.
- Improved monitoring techniques that allow for earlier detection.
- The identification and use of dantrolene sodium to treat MH.

MH is considered the leading cause of anesthetic deaths in healthy young adults. In severe cases, survivors may be left with brain damage, kidney failure, or impaired function of other major organs.

MH occurs worldwide, but its incidence is higher in geographic areas that have high concentrations of MH-susceptible families. In the United States, high incidences of MH occur in Nebraska, Wisconsin, West Virginia, and Michigan, possibly because of the presence of consanguineous populations in which an unusually high number of individuals carry the gene or genes responsible for MH.

MH affects both sexes, but occurs more frequently in males, accounting for 66% of the cases reported in the United States. People under the age of 18 have the highest incidence of MH. In the United States, Caucasians of northern European heritage are most often affected, but MH also occurs in Asian and Black populations.

Etiology

The cause of MH susceptibility is believed to be an inherited genetic defect. Research conducted in swine pointed to a defect in the gene coding for the ryanodine receptor (RYR1) that could be correlated with porcine MH, also known as porcine stress syndrome or PSS. The RYR1 controls the part of the muscle cell involved in the movement of calcium into the cell, and this mutation causes it to function abnormally.

Identification of a corresponding single-gene mutation in humans would facilitate the development of a sensitive, noninvasive diagnostic test for MH. Unfortunately, research suggests that MH is more likely heterogeneous, with a variety of defects in one or a number of genes (including the RYR1 gene on chromosome 19) responsible for its expression. Data from large family-based studies suggest three modes of inheritance: autosomal dominant (approximately 50% of cases); autosomal recessive or polygenic (approximately 20% of cases); and sporadic (approximately 30% of cases).

An association has been noted between MH and certain muscular disorders, such as

- Central core disease (CCD) - a rare congenital myopathy,
- Duchenne muscular dystrophy,
- King-Denborough syndrome, and
- Becker muscular dystrophy.

Central core disease has a particularly strong correlation with MH. Patients with central core disease frequently have abnormal *in vitro* contracture tests and, like MH, the disease has been mapped to abnormalities in the RYR1 gene. Patients with certain forms of muscular dystrophy may develop life-threatening cardiac arrhythmias and rhabdomyolysis on exposure to MH-triggering agents. Although these reactions resemble MH in many ways, they do not progress to hypermetabolism and hyperthermia, and it is not clear if they represent “true” MH.

Some experts believe that heat stroke may occur more often in MH-susceptible individuals. A research report from France found that 17% of those who suffered from heat stroke tested positive for anesthesia-related MH, suggesting the existence of some form of cross-susceptibility.

It also has been suggested that non-pharmacological factors, such as strenuous exercise, infection, trauma, emotional stress, and pain, could trigger MH in susceptible individuals, but the majority of experts do not believe that such factors precipitate MH. MH-susceptible individuals should be able to lead normal lives, except when general anesthesia is administered.

Neuroleptic Malignant Syndrome

Phenothiazine, haloperidol, and drugs used to treat schizophrenia are some of the medications that may stimulate a condition known as neuroleptic malignant syndrome. Signs and symptoms include muscle rigidity, elevated body temperature, elevated creatine phosphokinase (CPK), rhabdomyolysis, and myoglobinuria.

Pathophysiology

MH is triggered in susceptible individuals by certain potent inhalation anesthetic agents and by the depolarizing muscle relaxant succinylcholine. Triggering inhalation anesthetics include the following agents:

- Halothane
- Enflurane
- Isoflurane
- Desflurane
- Sevoflurane
- Methoxyflurane

Alternative anesthetic agents that can be safely used include:

- Barbituates
- Propofol
- Local and regional anesthetics, Benzodiazepines
- Opioids
- Ketamine
- Nitrous Oxide
- Etomidate

In MH-susceptible patients, exposure to a triggering agent causes a hypermetabolic chain reaction of events, which proceeds as follows:

1. Exposure to the triggering agent causes excessive amounts of **calcium** to be released from the sarcoplasmic reticulum (the organelle primarily responsible for control of intracellular calcium movement) in striated muscle cells, causing an increase in the concentration of calcium in the cytosol.
2. The excess calcium causes **sustained muscle contraction**.
3. Because the muscle cells of susceptible individuals are incapable of reprocessing the calcium and returning it to the storage areas within the cell, skeletal muscles remain contracted, resulting in **muscle rigidity**.
4. As the muscle ineffectively uses its adenosine triphosphate (ATP) stores to attempt to reprocess the calcium and terminate the muscle contraction, excess heat is generated, causing **hyperthermia**.
5. Excess carbon dioxide (CO₂) is produced, leading to **respiratory acidosis**.
6. As ATP stores are depleted, anaerobic metabolism increases. Accumulation of lactic acid results in **metabolic acidosis**.
7. Cellular function is compromised and cell damage occurs. Striated muscle cells ultimately disrupt rhabdomyolysis releasing myoglobin and potassium into the bloodstream (**myoglobinemia** and **hyperkalemia**).
8. The release of myoglobin can result in damage to the renal tubules and ultimately to **renal failure**.
9. The hyperkalemia can cause **cardiac dysrhythmias**.
10. If MH is not treated immediately and correctly, the hypermetabolic state progresses, causing irreversible **organ damage** or **death** from cardiac arrest, brain damage, internal hemorrhaging, or failure of other body systems.

Clinical Signs and Symptoms

Clinical signs and symptoms of MH include the following:

- The earliest and most sensitive indicator of an acute MH crisis is an unanticipated increase (eg, a doubling or tripling) of end-tidal CO₂ (ET CO₂) on a capnograph. Excess CO₂ production may cause the soda lime canister in the anesthesia machine to discolor rapidly and become hot to the touch.
- If ET CO₂ is not being monitored, the first presenting sign of MH is often unexplained ventricular dysrhythmia, mainly tachycardia or premature ventricular contractions. Tachycardia occurs in 96% of patients with MH and generally occurs within 30 minutes of induction of anesthesia. It can lead to arrhythmias (such as ventricular fibrillation) and to unstable blood pressure. Tachycardia may be mistakenly attributed to “light anesthesia,” with the unfortunate result that additional anesthesia is administered.
- Masseter muscle rigidity (MMR), which is a sustained contracture of the jaw muscles following the use of succinylcholine, occurs more frequently in children. As tension in the masseter muscle (the muscle used to close the mouth) increases, progressive difficulty opening the mouth occurs.
- Generalized muscle rigidity is the most specific sign of MH, but it is absent in 20% of MH episodes. Muscle rigidity may spread to the chest, extremities, and the rest of the patient’s body.
- Any rise in temperature greater than one-half degree per hour should raise suspicion of MH, but elevated temperature may be a late sign or may be absent entirely. Fever, hot skin or tissues, and diaphoresis are symptoms of heat buildup. If MH is untreated, the patient’s body temperature can rapidly rise at a rate of 1.8° F (1° C) every 5 minutes. A temperature as high as 117° F has been recorded, but 111.2° F is probably the highest recorded with survival.
- Rhabdomyolysis, the disintegration of striated muscle fiber, with excretion of free myoglobin in the urine (myoglobinuria) may occur as part of the MH episode, resulting in cola-colored urine. Patients who have brown or cola-colored urine in the PACU may have experienced an abortive MH episode with rhabdomyolysis.

- General erythematous flushing, peripheral mottling, cyanosis in the extremities, and diaphoresis may develop.
- Laboratory test abnormalities may occur, including increases in creatine phosphokinase (CPK), lactate dehydrogenase (LDH), myoglobin, and CO₂. Also seen are decreases in pH, abnormal coagulation studies, and imbalances in magnesium, calcium, phosphate, and potassium levels.

Not all signs are present in every episode. Additional clinical findings may include:

- Hyperkalemia
- Acute renal failure (even with identification of MH and successful treatment)
- Left-sided heart failure
- Disseminated intravascular coagulopathy (DIC)
- Skeletal muscle swelling or necrosis from hypoxia and acidosis
- Pulmonary edema
- Neurologic sequelae, including paraplegia and decerebration
- Coma from ischemia secondary to hypoxia

Differential Diagnosis

Intraoperative hyperthermia can be the result of many factors other than MH, including increased ambient temperature and equipment malfunction or misuse (use of external warmers, plugged probes, or airway warmers being set too high). In small children, intraoperative elevation of body temperature is sometimes a result of attempts to prevent heat loss by excessive covering, which can prevent dissipation of endogenous heat.

The differential diagnosis of intraoperative fever, tachycardia, tachypnea, and muscle rigidity includes conditions such as sepsis, thyrotoxicosis, pheochromocytoma, hypoxic brain damage, infection, transfusion reactions, central nervous system (CNS) injury, and drug reactions.

PRECAUTIONARY MEASURES

Precautionary measures against MH should be in place in every facility in which general anesthesia is administered. Such measures include:

- providing a cart with drugs and supplies that will be needed in an MH episode,
- having an ice machine available,
- providing regular training for OR and PACU personnel, and
- developing and posting a written MH treatment protocol.

MH Cart

An MH cart should be assembled and kept in a central location in the surgical suite. Policies for checking the cart should be implemented. It may be helpful to keep a modified MH cart in the PACU as well. There are specially made MH carts available for this purpose, but any cart with adequate space may be used as an MH cart. Table 1 lists appropriate medications, equipment, and supplies for an MH cart as suggested in the Malignant Hyperthermia Guideline included in the 2009 Perioperative Standards and Recommended Practices of the Association of periOperative Registered Nurses (AORN).

Table 1. Suggested contents for a malignant hyperthermia cart

Suggested medication and equipment		
Qty	Size	Item
36	Ampules 20-mg vials	dantrolene sodium (ie, Dantrium) IV
4	500-ml bottles	sterile water (preservative-free)
6	50-mEq syringes	50% sodium bicarbonate
2	50-ml syringes	50% dextrose
2	4-ml vials	furosemide
2	100mg in 10 ml pre-loaded syringes OR 100mg in 5 ml pre-loaded syringes	lidocaine
2	150mg/3ml OR 450/9ml	amiodarone

2	10mg vials	calcium chloride 10% (or calcium gluconate)
3	10-ml vials	heparin (1000 U), for use if DIC develops
2		semiautomatic dispensing syringes
2		stopcocks (3-way)
4	60-ml	syringes

Other equipment

Qty	Size	Item
6	10-ml	syringes
6	18-gauge	needles
6		alcohol prep pads
1	4-oz bottle	povidone-iodine paint
2	10-each boxes 4X4	sterile gauze
2		tourniquets
2		radial artery catheters
1		arterial line monitoring kit
1		central venous pressure line kit
2	Sets	cassette tubing for IV pumps
2	Sets (1 pediatric/1 adult)	IV tubing
2	Sets	extension tubing
10		medication labels
2	1 pediatric/1 adult	wrist splints

Tubes for laboratory tests

Qty	Size	Item
6	5-ml	heparinized blood gas syringes for ABG kits
1		urine specimen container
1	bottle	urine test strips for myoglobin
6	pediatric and adult sizes	light blue tubes
6	pediatric and adult sizes	lavender tubes
10		gold tubes with gel
10		red stopper tubes

Cooling equipment		
Qty	Size	Item
2	pediatric and adult	nasogastric tubes
2	30-ml (several pediatric and adult sizes)	balloon 3-way Foley catheters
2		closed-system Foley catheter tray
2		peritoneal lavage trays
2		sets cystoscopy tubing
2	60-ml	catheter tip syringes
2		5-in-1 connectors
2		Y-connectors
2		plastic buckets to hold ice
10	Medium- and large-size	plastic bags

Anesthesia equipment (Have on cart or immediately available)

Qty	Size	Item
2	pediatric and adult	breathing circuits
2		breathing circuit adapters
2		pressure bags
2		soda lime canisters

Miscellaneous

Qty	Size	Item
1		sharps container
2	pediatric and adult	Ambu bags
1		MH cart medications/supplies checklist
1		label on front of cart listing MHAUS hotline number

At the time cart is requested, add:

Qty	Size	Item
3-6	1000-ml bags	Refrigerated IV normal saline solution
6	1000-ml bags	Refrigerated normal saline for irrigation
6	3000-ml bags	Refrigerated normal saline for irrigation
1		Refrigerated regular insulin
		Ice

Dantrolene

Dantrolene is the only known therapeutic agent that counteracts the effects of MH. It acts by blocking the release of calcium by the sarcoplasmic reticulum of skeletal muscle cells. Dantrolene is a lipid-soluble hydantoin that was initially introduced as a skeletal muscle relaxant for use in chronic disorders of muscle spasticity. It acts specifically on skeletal muscle without any appreciable effect on cardiac or smooth muscle.

Dantrolene should be available for the treatment of MH crises anywhere general anesthesia is administered. Because of the need for continued treatment for at least 24 hours after MH at a dose of about 1 mg/kg every 6 hours, a total of 36 vials should be stocked in the MH cart. The cart should be kept in, or very close to, the OR so that it is available immediately if MH occurs.

Dantrolene has a shelf life of 3 years from the date of manufacture. Even though it is expensive to purchase, it is recommended that a minimum of 36 vials be stocked at all times. Although dantrolene has a long shelf life, the relative rarity of an MH crisis causes the drug to become outdated far more often than it is used. The cost of replacing outdated dantrolene is borne by the hospital. It is not advisable for institutions to share a supply of dantrolene because every minute counts in an MH emergency.

Possible adverse reactions to dantrolene include pulmonary edema, thrombophlebitis, urticaria, erythema, and anaphylaxis. It has the potential to produce serious side effects (eg, hepatotoxicity) with prolonged use. The most common side effect of dantrolene is skeletal muscle weakness. Central nervous system side effects include drowsiness, dizziness, blurred vision, and generalized weakness. Gastrointestinal side effects include nausea, vomiting, and diarrhea (more often associated with oral administration for MH prophylaxis or treatment of spasticity). Dantrolene and verapamil, when given in combination, have been shown to cause hyperkalemia and cardiovascular collapse in swine. Until the relevance of these findings for humans has been established, the combination of dantrolene sodium and calcium channel blockers should be avoided.

Ice Machine

A refrigerator containing at least 3000 ml of cold intravenous and irrigation solutions should be readily available to the OR. If an ice machine is not readily accessible, the freezer compartment of the refrigerator should contain bags of ice.

A hypothermia blanket should also be available in the department to treat hyperthermia.

Personnel Training

A prompt response to an MH crisis requires that the responding individuals act in an organized and coherent fashion. All OR and PACU personnel should be trained in the recognition of MH, the contents of the MH cart, and the MH treatment protocol. MHAUS recommends that two drills be conducted each year. Drills should include the staff members from the OR and PACU, as well as care providers. The drill should include a mock preoperative interview and assessment, simulations of the acute and post-acute phases of treatment, and a post-drill evaluation to help identify any necessary protocol modifications. For the drill, outdated bottles of dantrolene may be obtained from the pharmacy to allow staff to practice mixing the drug.

Treatment Protocol

An MH treatment protocol and nursing care plan should be developed and posted, along with the telephone number for the MH hotline for healthcare personnel (1-800-MH HYPHER, or 1-800-644-9737). The protocol should include specific therapies and treatments for MH. The protocol recommended by MHAUS is available in both poster and wallet card form. It can be used as a guide for developing facility-specific protocols.

Preoperative Precautions

To prepare the anesthesia machine for use with an MH-susceptible patient:

- Drain vaporizers and tape closed or remove.
- Use a new or disposable breathing circuit.
- Flush 10L/m oxygen (O₂) through the anesthesia circuit for at least 20 minutes. (If the fresh gas hose is replaced, MHAUS suggests that flushing oxygen

through the anesthesia circuit for 10 minutes is adequate.) During flushing time, attach a disposable, unused, breathing bag to the Y-piece of the circle system and cycle the ventilator.

- Place a cooling blanket on the operating table.

Pretreatment with dantrolene is not recommended for most MH-susceptible patients. It does not influence the likelihood of an MH crisis when proper precautions (eg, non-triggering anesthetic agents) are used. Furthermore, dantrolene pretreatment can cause significant muscle weakness in patients with muscle disease; even patients without pre-existing muscle disease may experience mild muscle weakness after dantrolene pretreatment. If the physician chooses to administer dantrolene prophylaxis on an individual patient basis, the dosage is 2.5 mg/kg IV, starting 30 minutes before anesthesia.

Intraoperative Precautions

When surgery is to be performed on a patient who is known to be MH-susceptible, special intraoperative precautions include selecting a non-triggering anesthetic agent and using additional monitoring measures.

Anesthetic Agent

Depending upon the surgical procedure, a regional block (eg, a spinal, epidural, or axillary block) is considered safe for MH-susceptible patients. The use of local anesthetics is also considered safe. Agents considered safe for use with MH-susceptible patients are listed in Table 2.

Table 2. Agents considered safe for MH-susceptible patients

Non-depolarizing muscle					
Relaxants	Narcotics	Barbituates	IV Anesthetics	Benzodiazepines	Local Anesthetics
pancuronium	morphine	methohexital	propofol	diazepam	lidocaine
pipecuronium	meperidine	thiopental	ketamine	lorazepam	chloroprocaine
doxacurium	hydromorphone	thiamylal	etomidate	midazolam	prilocaine
vecuronium	alfentanil				mepivacaine
rocuronium	sulfentanil				procaine
mivacurium	fentanyl				etidocaine
atracurium					tetracaine
tubocurarium					bupivacaine

Monitoring

Whenever a patient known or suspected to be MH-susceptible undergoes a surgical procedure, essential monitoring includes:

- Electrocardiogram (ECG)
- Blood pressure
- Central temperature
- Pulse oximetry
- Capnography (ET CO₂ levels)

If a general anesthetic is used, monitoring of respiratory rate and volume is strongly suggested. Use an arterial line, central venous pressure (CVP) monitoring, or other invasive monitors when appropriate for the procedure and the patient's underlying medical condition.

Postoperative Precautions

While most MH episodes occur during general anesthesia, delayed onset of MH may manifest initially in the PACU or after the patient has returned to his or her room. If the anesthetic course of an MH-susceptible patient has been uneventful, continue to monitor his or her temperature, respiratory rate, pulse rate, and ECG for 1 to 2 hours.

Ambulatory Note: Following ambulatory surgery, observe the patient for 4 hours before discharge. On discharge, provide outpatients and their families with an emergency telephone number to contact if the patient experiences rapid breathing, an elevated heart rate, dark-colored urine (indicative of rhabdomyolysis), or a temperature in excess of 101° F.

IF A CRISIS OCCURS

In addition to a true MH crisis, a number of related events can occur intraoperatively, including masseter muscle rigidity or sudden cardiac arrest. These conditions are discussed later in this study guide.

Malignant Hyperthermia

If an MH crisis occurs, everyone must act quickly. A direct correlation exists between the severity of an MH episode and the timeliness of treatment. Any delay in the early recognition and prompt treatment of an MH episode can result in a sudden and unexpected patient death.

In the event of an MH crisis, the anesthesia care provider is in charge. He or she tells the surgeon to close the surgical site quickly and notifies the other surgical team members that the patient is experiencing an MH crisis. Perioperative nursing interventions are directed against alterations in temperature regulation, acid-base balance, cardiac output, and fluid volume. Nurses must follow the MH treatment protocol as described below:

Acute Phase

1. **Get help.** The care provider immediately ceases the administration of all triggering agents and uses non-triggering agents to maintain the patient under general anesthesia until the surgeon closes the surgical wound. (If wound closure is not possible, the wound should be packed with saline-soaked towels or laparotomy sponges.) The care provider hyperventilates the patient with 100% oxygen at high gas flows - at least 10 L/min. (The circuit system and CO₂ absorbent need not be changed.) The circulating nurse summons additional help and also notifies the PACU to arrange for a ventilator for the patient in the PACU. Other staff members bring the MH cart and at least 4 bags of ice to the OR.

2. **Get dantrolene. Administer 2.5 mg/kg IV rapidly through a large bore if possible.** *Reconstituting dantrolene during an MH crisis can be very labor-intensive.* The mixing process can take several minutes. Several individuals are needed to mix and administer the medication IV push. Dantrolene is supplied in ampules containing 20 mg of lyophilized dantrolene sodium powder, with 3 g of 20% mannitol, and sufficient sodium hydroxide to yield a pH of 9.0 when reconstituted. Each vial of dantrolene must be dissolved in 60 ml of sterile, preservative-free water for injection USP (without a bacteriostatic agent). (Do not use any other diluent. For a 70-kg patient requiring 10 mg/kg of dantrolene, approximately 2100 ml of diluent will be required. If a bacteriostatic agent were present, it could reach hazardous levels at this volume.) After 2 to 3 minutes of vigorous shaking, the reconstituted dantrolene is yellow to yellow/orange. It must be protected from light and used within 6 hours of reconstitution. If the dantrolene precipitates, the vials can be run under warm water to re-dissolve the crystals before the drug is infused. There are new multi-fluid dispensing systems available for rapid mixing. Consult with the clinical pharmacist in your facility to determine availability and feasibility of this technology.

Most patients experiencing an MH crisis respond to 2-3 mg/kg of dantrolene initially, but some patients need significantly more to bring the episode under control. For example, a 70-kg (154-lb) patient who is treated with 2.5 mg/kg of dantrolene will require that 9 vials of dantrolene be reconstituted, assuming that the patient responds favorably to this initial dose and does not need an increased dose of dantrolene. In some cases, a total dose exceeding 10 mg/kg may be required. The amount of dantrolene administered should be recorded after each injection, so that an accurate record is maintained of the amount the patient has received.

Malignant Hyperthermia Emergency

Dantrolene Dosage Chart

Based on recommended loading dose of **2.5 mg per kg**
 Chart calculated using 20 mg Vials of Dantrolene reconstituted with
 60 ml of Sterile Water (without a bacteriostatic agent)

Patient's Weight in Kilograms	Number of 20 mg Vials of Dantrolene to Open	Milligram dosage needed	ML's of reconstituted Dantrolene to administered	Patient's Weight in Pounds
20	3	50 mg	150 ml	44
25	4	62.5 mg	187.5 ml	55
30	4	75 mg	225 ml	66
35	5	87.5 mg	262.5 ml	77
40	5	100 mg	300 ml	88
45	6	112.5 mg	337.5 ml	99
50	7	125 mg	375 ml	110
55	7	137.5 mg	412.5 ml	121
60	8	150 mg	450 ml	132
65	9	162.5 mg	487.5 ml	143
70	9	175 mg	525 ml	154
75	10	187.5 mg	562.5 ml	165
80	10	200 mg	600 ml	176
85	11	212.5 mg	637.5 ml	187
90	12	225 mg	675 ml	198
95	12	237.5 mg	712.5 ml	209
100	13	250 mg	750 ml	220
105	14	262.5 mg	787.5 ml	231
110	14	275 mg	825 ml	242
115	15	287.5 mg	862.5 ml	253
120	15	300 mg	900 ml	264
125	16	312.5 mg	937.5 ml	275
130	17	325 mg	975 ml	286
135	17	337.5 mg	1012.5 ml	297
140	18	350 mg	1050 ml	308
145	19	362.5 mg	1087.5 ml	319
150	19	375 mg	1125 ml	330



3. **Correct metabolic acidosis.** The anesthesiologist will administer or will order the administration of 8.4% intravenous sodium bicarbonate to correct metabolic acidosis. In the absence of arterial blood gas (ABG) analysis, 1-2 mEq/kg should be administered and repeated as indicated. Thereafter, dose should be based on ABG samples taken at 10-minute intervals.

4. **Cool the hyperthermic patient.** Retrieve cooled IV bags and irrigation bottles of normal saline from the refrigerator. Remove any lactated solutions that are infusing and infuse cold saline intravenously (15 ml/kg q 15 min X 3). Use cold saline to lavage the stomach (through a nasogastric tube), the bladder, and the rectum (ie, through a three-way Foley catheter with a 30-ml balloon attached to cystoscopy tubing). Directly lavage the peritoneal and/or thoracic cavity with refrigerated normal saline irrigation fluid if the surgical site is open. Provide external cooling measures (eg, pack bags of ice around the patient's axillae, groin, neck, and head; or place temperature regulating blankets under and over the patient). Monitor the patient's temperature closely, and discontinue all cooling agents and equipment after the patient's core body temperature decreases to 38° C (100.4° F) to avoid inadvertent patient hypothermia.

5. **Monitor the patient.** Assist the anesthesiologist in inserting arterial and pulmonary artery lines. Determine and monitor ET CO₂; arterial, central, or femoral venous blood gases; serum potassium or other electrolytes; urine color and output; prothrombin time/partial thromboplastin time (PT/PTT); and calcium. Repeat these tests as clinically indicated. Monitor heart rate and rhythm.

6. **Treat hyperkalemia.** Hyperkalemia is defined as a serum potassium of >5.5 mEq/L. It is common in an MH crisis and should be treated with hyperventilation, bicarbonate, and 50% intravenous glucose and insulin (adults, 10 units regular insulin in 50 ml 50% glucose titrated to potassium level or children 0.10 units/kg regular insulin in 1 cc/kg 50% glucose). Potassium levels in excess of 7 mEq/L may be treated with administration of 10 mg/kg calcium chloride or calcium gluconate). Check blood glucose hourly if insulin has been given.

7. If dysrhythmias persist after treatment of acidosis and hyperkalemia, or are life-threatening, the anesthesiologist may administer standard **anti-arrhythmic** agents (eg, procainamide, 15 mg/kg IV over 60 minutes lidocaine or amiodarone). Use of calcium channel blockers should be avoided.

8. **Maintain normal fluid volume.** Ensure urine output of >2 ml/kg/hr by hydration and/or administration of furosemide. Dantrolene contains 3 grams of mannitol in each vial and this should be taken into consideration during the treatment of renal complications. Consider central venous or pulmonary artery monitoring because of the possibility of fluid shifts and hemodynamic instability. In addition to the measurement of volume, urine should be analyzed for hemoglobin and myoglobin.

Throughout the acute phase, the circulating nurse is the timekeeper. He or she documents all medications used, including doses, routes, times, and patient responses. Depending on how quickly the surgical team recognizes and responds to an acute MH episode and the severity of the patient's symptoms, dantrolene administration may resolve the acute episode quickly, or it may be 2 or 3 hours before the patient is stable enough for transfer to the ICU.

Post-Acute Phase

When tachycardia, rigidity, acidosis, and temperature elevation are controlled, transfer the patient to the ICU. Give a report to the ICU nurses, which includes medications given and nursing interventions that took place. Observe the patient in an ICU setting for at least 24 hours. Be aware that recurrence of the MH episode occurs in about 25% of all MH patients, 24 to 72 hours after the initial crisis.

The anesthesia care provider should complete an Adverse Metabolic Reaction to Anesthesia (AMRA) form and submit it to the North American MH Registry of MHAUS, preferably within 48 hours of the event. The form can be accessed through <http://www.mhreg.org/Downloads.aspx>.

Routine documentation of an MH incident should include:

- patient responses,
- personnel involved,
- interventions, including medications administered,
- patient outcomes, and
- times.

To determine the likelihood that an episode was a true MH crisis, the anesthesiologist should use the Malignant Hyperthermia Clinical Grading Scale (CGS)—a consensus definition devised in 1994 through the collaboration of 11 international experts on malignant hyperthermia.⁵ With this scale, the qualitative likelihood that an adverse anesthetic event represents MH is based on a point system. Points are assigned to 18 specific abnormal signs and laboratory findings (clinical indicators) within 5 “physiologic processes” that may be observed during an acute anesthetic reaction (ie, rigidity, muscle breakdown, respiratory acidosis, temperature increase, and cardiac involvement). A certain number of points are assigned to each clinical indicator present, and also to 5 indicators representing family history. The sum of these points provides a raw score, which then translates to an MH rank representing the likelihood that an adverse anesthetic event represents a true MH crisis. MH rank scores range from 1 (“almost never”) to 6 (“almost certain”). The MH Clinical Grading Scale is considered a great improvement over personal opinion as to what constitutes an MH episode.

Continue to administer dantrolene 1 mg/kg q 4-6 hours or 0.25 mg/kg/hr by infusion for 24 to 48 hours after an episode of malignant hyperthermia. Further doses may be indicated. If necessary, the patient can be discharged on oral dantrolene.⁶

After the initial episode, the patient may have muscle stiffness, tenderness, leg pain, and edema due to the intense muscle contractions that occurred during the crisis. Take special care when handling the patient.

Follow ABG, CK, potassium, urine and serum myoglobin, clotting studies, and core body temperature until they return to normal values (eg, every 6 hours). Central temperature (eg, rectal, esophageal) should be continuously monitored until it becomes stable.

Muscle breakdown continues 24 hours after an MH episode; therefore, the patient may experience a temporary decrease in handgrip strength and weaknesses in his or her lower extremity muscles, especially when walking

down stairs. These symptoms may persist for up to 48 hours after an MH episode. The patient also may experience dizziness, double vision, difficulty swallowing, and choking. For these reasons, instruct the patient not to operate a motor vehicle or engage in hazardous activities after discharge.

Masseter Muscle Rigidity

Masseter Muscle Rigidity (MMR), sustained contracture of the jaw muscles, occurs in as many as 1 in 100 children anesthetized with inhalation agents and succinylcholine. As many as 20% of those patients will develop clinical signs of MH that require treatment. If MMR occurs following succinylcholine administration, MHAUS recommends one of two courses of action:

- Discontinue the anesthetic and postpone elective surgery. Consider administration of 1 mg/kg dantrolene. Observe for acute MH and rhabdomyolysis.
- OR
- Continue anesthesia with non-triggering agents, following the patient's ET CO₂ concentration and monitoring core temperature. If acute MH occurs, follow the usual treatment regimen.

After MMR, myoglobinuria usually occurs. Measure creatine kinase (CK) every 6 to 8 hours for 24 hours. Measure urine and blood for myoglobin. Ensure diuresis. If gross myoglobinuria occurs, consider a nephrology consult. Consult the MHAUS hotline.

Hospitalize the patient for at least 24 hours. Follow up on the patient for several days, ensuring that CK has returned to normal. Consult neurology if CK does not normalize or if muscle weakness and pain persist. The patient should consult an MH expert about the advisability of undergoing muscle biopsy testing.

Sudden Cardiac Arrest

Sudden unexpected cardiac arrest has been documented following the administration of succinylcholine in apparently healthy young patients (predominantly males) who are undergoing routine surgery. More than 40 such cases have been described since 1990, with a mortality rate of approximately 50%. It occurs in

patients with an undiagnosed and unrecognized muscle disorder and is secondary to muscle breakdown. The cause of the cardiac arrest is hyperkalemia with an undiagnosed myopathy. Aggressive treatment with glucose, insulin, and bicarbonate is essential. Blood samples for serum potassium should be obtained immediately. Calcium chloride may be necessary to restore a normal heart rhythm. Dantrolene may be administered also, since MH also may cause cardiac arrest, but it is considered a second-line drug in such situations. Presume that children who experience such episodes have subclinical muscular dystrophy and obtain a neurology consult.

NURSING INTERVENTIONS FOR ALL PATIENTS

Twenty-one percent of patients who experience MH episodes have previously undergone general anesthesia uneventfully. Be aware that patients who have previously undergone successful anesthesia with MH triggering agents may still be at risk. Deaths have occurred in patients who have undergone multiple uneventful surgeries.

Preoperative Assessment

The best way to prevent an MH crisis is to identify MH-susceptible patients preoperatively and take appropriate precautions. The preoperative interview is the ideal time to assess MH risk factors. A case has been reported in which an alert perioperative nurse identified an episode of previously undiagnosed MH in an adolescent male during the preoperative history. Appropriate precautions, including use of a non-triggering anesthetic agent during the planned operative procedure, prevented further complications in this patient.

A preoperative history should routinely include questions about:

- Any family or personal history of MH or unexplained death or adverse reaction under general anesthesia, including in a dental office
- Any personal or family history of a high fever associated with an anesthetic
- Any family or personal history of any type of myopathy or acquired muscle disease, such as ptosis, strabismus, an area of muscle weakness or hypertrophy, or muscular dystrophy

Additional questions that might be included in routine preoperative history taking include:

- Any personal history of dark or cola-colored urine following anesthesia
- Any personal history of unexplained high fever after surgery
- Any episodes of heat stroke in the patient or their relatives
- A history of rheumatoid arthritis, particularly in children
- A history of temperature instability with minor illness, such as a sore throat

The preoperative physical assessment should look for any musculoskeletal abnormalities or complaints of muscle weakness or fatigue. An unexplained preoperative elevation of CPK above 280 U/L may be suspicious, although other conditions (eg, alcohol consumption or strenuous exercise) can produce levels above the normal range.

Intraoperative Monitoring

Onset of MH may occur immediately after anesthesia induction, after several hours of general anesthesia, or even in the postoperative recovery period. As a precaution, all patients receiving a general anesthetic for 30 minutes or more, even those with no risk factors for MH, should have their core body temperatures monitored continuously in the intraoperative period. Acceptable monitoring sites (in order of preference) include: pulmonary artery, distal esophagus, nasopharynx, tympanic membrane, rectum, bladder, axilla, and forehead skin.

THE ROLE OF THE PERIOPERATIVE NURSE

Perioperative nurses play a critical role in the early recognition and treatment of MH. AORN specifies perioperative care for MH-susceptible patients in its “AORN Malignant Hyperthermia Guideline”. Responsibilities of the perioperative nurse regarding MH susceptible patients include the following:

Preoperatively

- Assessing patients preoperatively for MH risk factors, documenting those risk factors, and reporting assessment results to the anesthesia care provider and other team members.
- Identifying nursing diagnoses and outcomes related to the care of any patient with a potential or confirmed diagnosis of MH.
- Developing an individualized plan of care for patients identified as being at increased risk of MH.

Intraoperatively

- Keeping operating rooms stocked with appropriate supplies for treatment of an MH crisis wherever MH trigger anesthetics are used intraoperatively.
- Recognizing and evaluating physiologic signs and symptoms of MH intraoperatively.
- Rapidly supplying and reconstituting dantrolene sodium.
- Providing the necessary supplies (eg, ice packs, hyperthermia blankets) without hesitation.
- Assisting the anesthesia care provider with the IV line; drug preparation and administration; drawing blood samples for laboratory testing; and as otherwise directed.
- Cooling the patient, using the appropriate surface, intravenous, and lavage techniques.

Postoperatively

- Observing and managing the patient’s signs and symptoms in the PACU and ICU after an MH crisis has occurred.
- To manage post-crisis problems, care may be transferred from an anesthesia care provider to a pediatric or adult medical or surgical intensivist. Facilitate transfer of care by providing complete information about the MH crisis.

- The perioperative team should complete and submit the Adverse Metabolic Reaction to Anesthesia (AMRA) form (<https://www.mhreg.org/>).
- The perioperative team should conduct post-episode and response to the event analyses to determine how to build on strengths and evaluate procedures for handling malignant hyperthermia emergencies.

TESTING FOR MH-SUSCEPTIBLE PATIENTS *Caffeine-Halothane Contracture Test (CHCT) - Muscle Biopsy*

If it is suspected that a patient is MH-susceptible, elective surgery may be postponed until a skeletal muscle biopsy can be performed. The costly and invasive skeletal muscle biopsy, also known as the caffeine-halothane contracture test (CHCT), is the only definitive test available for identification of MH-susceptible individuals. Due to the invasive nature of a muscle biopsy, it is usually performed only on individuals who have a family member who has experienced an MH crisis.

The procedure for a CHCT involves the following steps:

1. A small strip of skeletal muscle, usually from the vastus medialis or vastus lateralis of the quadriceps, is excised under local anesthesia (usually a femoral nerve block).
2. The muscle specimen is prepared and attached to a force transducer.
3. The transducer is attached to a polygraph.
4. The biopsy specimen is immersed in a special electrolyte solution.
5. Doses of caffeine and then caffeine plus halothane are bubbled across its surface.
6. If the patient is MH-susceptible, the caffeine will induce a greater than normal muscle contracture. When the halothane is added, the muscle contracture increases even more.

After the procedure, the biopsy site and muscle function will return to normal. A CHCT must be performed at a designated muscle biopsy center, a listing of which can be obtained from MHAUS. The patient is required to travel to a designated center for the test, because it must be performed within 5 hours after the muscle is removed

from the patient. This often makes the test both inconvenient and expensive, as the muscle cannot be obtained locally and shipped to these centers for testing. There are approximately 40 muscle biopsy centers worldwide, only six of which are in North America. Charges in the United States are typically more than \$2,500, but most insurance companies cover the cost.

Muscle biopsy centers in the United States, Canada, and Europe have standardized the contracture test and evaluated its sensitivity and specificity. For diagnostic testing of a potentially lethal condition, a high degree of sensitivity (ie, no false negatives) and an acceptable degree of specificity (ie, few false positives) are desired. In other words, physicians are willing to accept a few false positives to avoid false negatives, because the consequences of a false negative diagnosis might be disastrous. The muscle biopsy is extremely sensitive in detecting MH (ie, there are no false negatives), but specificity is somewhat less accurate. Up to 15% of patients who are diagnosed as MH-positive are not MH-susceptible. However, the CHCT is the most accurate diagnostic test available at this time.

The result of the CHCT will be one of three possible diagnoses:

1. MHS (susceptible), with abnormal results of both halothane and caffeine tests,
2. MHN (normal), with normal results of both tests, or
3. MHE (equivocal), with only one positive result.

Individuals in both the “susceptible” and “equivocal” groups must be considered to be susceptible to MH and should not be exposed to triggering agents.

PATIENT/FAMILY EDUCATION

After any confirmed or suspected MH crisis, the patient's primary physician should be contacted. Once the patient is alert, counsel the patient and family regarding MH and further precautions that should be taken. Explain what happened to the patient while he or she was under general anesthesia. Advise the patient about possible post-dantrolene therapy symptoms (eg, nausea, diarrhea, muscle weakness, double vision, dizziness, or lightheadedness). Answer the patient's questions about the nature of MH and the causes of MH susceptibility. For information about centers where patients and family members can be tested for MH susceptibility, refer the patient to MHAUS.

Advise genetic counseling of known MH-susceptible patients and family members. Whenever an acute MH episode occurs in a family member, all family members, including cousins, should be alerted to their potential risk.

Based on a case report of an MH-susceptible individual who experienced muscle weakness upon occupational exposure to the fire-extinguishing compound bromochlorodifluoromethane, it has been recommended that MH-susceptible individuals avoid occupational exposure to halogenated hydrocarbons, organic solvents, and the solvents used in the dry cleaning industry.

Encourage MH-susceptible patients to wear a medical alert bracelet or tag. MH-susceptible patients should also carry information, such as wallet cards and the MH hotline telephone number, and should notify all health care providers of their susceptibility.

SUMMARY

With careful assessment, planning, and monitoring, MH-susceptible individuals can have a safe surgical and anesthetic experience. Staff education and a preplanned MH protocol and nursing care plan, including the availability of an MH cart, will help ensure that both known MH-susceptible patients and patients who present with a negative history will receive prompt and appropriate interventions.

Goals for future research on MH susceptibility should include:

- Developing a simple, inexpensive test of MH susceptibility, and
- Determining the direct and indirect causes of MH by studying the molecular biology of the syndrome.

ADDITIONAL RESOURCES

For additional information about malignant hyperthermia, contact MHAUS at:

MHAUS
32 South Main Street
P.O. Box 1069
Sherburne, NY 13460-1069
Phone: (800) 98-MHAUS
<http://www.mhaus.org>

GLOSSARY

Abortive. Not reaching completion; said of an attack of a disease subsiding before it has fully developed or completed its course.

Acidosis. Decreased alkali in body fluids in relation to the acid content; pH of body fluids may be normal or decreased, an accumulation of acid metabolites often is present, and tissue function may be disturbed.

Capnograph. An instrument that continuously graphs the CO₂ content of expired air.

Consanguineous. Having a blood relationship or common ancestry.

Diaphoresis. Perspiration.

Diuresis. Excretion of urine.

End tidal. At the end of a normal respiration.

Fulminant. Occurring suddenly and rapidly, with great intensity or severity.

Hyperkalemia. Excess concentration of potassium ions in circulating blood.

Hyperthermia. Hyperpyrexia; extremely high fever.

Masseter muscle. The muscle that closes the jaw.

Myoglobinemia. Presence of myoglobin in the circulating blood.

Myoglobinuria. Excretion of myoglobin in the urine.

Myopathy. Abnormal condition or disease of muscular tissues, usually skeletal muscle.

Polygenic. Related to a hereditary disease, abnormality, or normal characteristic controlled by the interaction of genes at more than one locus.

Recrudescence. Resumption of a morbid process or its symptoms after a period of emission.

Rhabdomyolysis. An acute, fulminating, potentially fatal disease of skeletal muscle with destruction of skeletal muscle, evidenced by myoglobinemia and myoglobinuria.

Sarcoplasmic reticulum. A network of tubules and flattened sacs within skeletal and cardiac muscle cells.

Sensitivity. The ability of a diagnostic test to diagnose disease correctly when disease is known to exist.

Specificity. The ability of a diagnostic test to exclude disease when disease is known to be absent.

END NOTES

1. Denborough MA and Lovell RRH: *Anaesthetic deaths in a family*. *Lancet* 1960; 2:45
2. Rosenberg, H, Davis, M, James, D, Pollock, N, Stowell K. *Malignant hyperthermia*: Orphanet encyclopedia November 2004. http://www.orph.net/data/patho/GB/uk_-malignant-phyerthermia.pdf. Accessed September 7, 2006.
3. Malignant Hyperthermia Association of the United States (MHAUS). *What is malignant hyperthermia?* <http://www.mhaus.org/index.cfm/fuseaction/OnlineBrochures.Display/BrochurePK> . Accessed August 22, 2006.
4. Gronert, DA, Pessah, I N, Muldoon, S M, Tautz T J. Malignant hyperthermia. In: Miller, R D, ed. *Miller's Anesthesia*. 6th ed, vol 1. Philadelphia, Pa: Elsevier, Churchill Livingstone; 2005; 1169-1190.
5. Larach, MG, et al. MH Clinical Grading Scale. *Anesthesiology* 1994; 80:771-9.
6. Malignant Hyperthermia Association of the United States (MHAUS). Online brochure: <http://www.mhaus.org/index.cfm/fuseaction/OnlineBrochures.Display/BrochurePK/B5DBDF12-20C3-4537-948C098DAB0777E3.cfm>. Accessed July 14, 2009.

SUGGESTED READING

1. AORN. Malignant hyperthermia guideline. In: *Perioperative Standards and Recommended Practices*; 2009:127-148.
2. Brandom BW. The genetics of malignant hyperthermia. *Anesthesiol Clin North America*. 2005;23(4):615-9, viii.
3. Denholm B. Clinical issues. Malignant hyperthermia; sterilization monitoring; sterilization indicators; multipack needle counts. *AORN J*. 2007;85(2):403-408, 410-430.
4. Hommertzhaim R, Steinke EE. Malignant hyperthermia—the perioperative nurse's role. *AORN J*. 2006;83(1):151-156, 159-160, 162-164; quiz 167-70.
5. Khan E. Understanding malignant hyperthermia: A discussion paper. *J Adv Perioper Care*. 2007;3(1): 21-25.
6. Larach MG, Brandom BW, Allen GC, Gronert GA, Lehman EB. Cardiac arrests and deaths associated with malignant hyperthermia in North America from 1987 to 2006: A report from the North American malignant hyperthermia registry of the malignant hyperthermia association of the United States. *Anesthesiology*. 2008;108(4):603-611.
7. Litman RS, Rosenberg H. Malignant hyperthermia: Update on susceptibility testing. *JAMA*. 2005; 293(23):2918-2924.
8. Malignant Hyperthermia Association of the United States. Emergency therapy for malignant hyperthermia protocol. <http://medical.mhaus.org/PubData/PDFs/treatmentposter.pdf>. Updated 2008.
9. Malignant Hyperthermia Association of the United States. Anesthetic List for MH-Susceptible Patients. <http://medical.mhaus.org/index.cfm/fuseaction/Content.Display/PagePK/AnestheticList.cfm> Accessed 7/18/200,.

10. Malignant Hyperthermia Association of the United States. ABCs of Managing Malignant Hyperthermia. <http://medical.mhaus.org/index.cfm/fuseaction/OnlineBrochures.Display/BrochurePK/BCD9151D-3048-709E-5A445BC0808B4767.cfm>. Accessed 7/18/2008,.

11. Malignant Hyperthermia Association of the United States. Malignant hyperthermia: medical professionals' FAQs. <http://medical.mhaus.org/index.cfm/fuseaction/Content.Display/PagePK/MedicalFAQs.cfm> Accessed 7/18/2008,

12. Malignant Hyperthermia Association of the United States. *Malignant Hyperthermia. Ambulatory Surgery Center Procedure Manual*. Sherburne, NY: Malignant Hyperthermia Association of the United States; 2005.

13. Malignant Hyperthermia Association of the United States. *Malignant Hyperthermia. Hospital Procedure Manual*. Sherburne, NY: Malignant Hyperthermia Association of the United States; 2004.

14. Malignant Hyperthermia Association of the United States. Malignant Hyperthermia. *Office-Based Surgery Center Procedure Manual*. Sherburne, NY: Malignant Hyperthermia Association of the United States; 2003.

15. McCarthy EJ. Malignant hyperthermia: Pathophysiology, clinical presentation, and treatment. *AACN: Clin Issues Adv Pract Acute Crit Care*. 2004;15(2):231-237.

16. Neacsu A. Malignant hyperthermia. *Nurs Stand*. 2006;20(28):51-57.

17. Podranski T, Bouillon T, Schumacher PM, Taguchi A, Sessler DI, Kurz A. Compartmental pharmacokinetics of dantrolene in adults: Do malignant hyperthermia association dosing guidelines work? *Anesth Analg*. 2005;101(6):1695-1699.

18. Pollock N, Langton E, McDonnell N, Tiemessen J, Stowell K. Malignant hyperthermia and day stay surgery. *Anaesth Intensive Care*. 2006;34(1):40-45.

19. Pritchard MJ. Malignant hyperthermia: Clinical features and management. *Nurs Times*. 2003;99(23):32-34.

20. Rusyniak DE, Sprague JE. Hyperthermic syndromes induced by toxins. *Clin Lab Med*. 2006;26(1):165-184.

POSTTEST

Multiple Choice: Please choose the one answer that best completes the following statements.

1. Dantrolene sodium counteracts the effects of malignant hyperthermia by:
 - a. Increasing the release of calcium in striated muscle cells.
 - b. Blocking the release of calcium in striated muscle cells.
 - c. Increasing the release of potassium in striated muscle cells.
 - d. Blocking the release of potassium in striated muscle cells.
2. In the United States, malignant hyperthermia occurs more often in:
 - a. Younger patients.
 - b. Males.
 - c. Certain states.
 - d. All of the above.
3. Anesthetic agents that are known to trigger malignant hyperthermia include:
 - a. Halothane.
 - b. Benzodiazepines.
 - c. Nitrous oxide.
 - d. All of the above.
4. The earliest and most sensitive indicator of an acute MH crisis is:
 - a. An increase in end-tidal carbon dioxide.
 - b. A sudden increase in body temperature.
 - c. Masseter muscle rigidity.
 - d. Cola-colored urine.
5. Every facility in which general anesthesia is administered should stock an MH cart with:
 - a. 9 vials of dantrolene.
 - b. 16 vials of dantrolene.
 - c. 30 vials of dantrolene.
 - d. 36 vials of dantrolene.
6. Because of the expense involved in maintaining dantrolene in stock, it is reasonable for nearby institutions to share a supply of dantrolene.
 - a. True.
 - b. False.
7. Patients who report having previously undergone uneventful anesthesia with MH triggering agents may be assumed not to be susceptible to MH.
 - a. True.
 - b. False.
8. Every preoperative history should routinely include questions about:
 - a. Any personal history of MH or adverse reaction to anesthesia.
 - b. Any family history of unexplained death under general anesthesia.
 - c. Any family or personal history of myopathy.
 - d. All of the above.
9. Core body temperature should be monitored in all patients receiving:
 - a. Any anesthetic for 30 minutes or more.
 - b. Any inhalation anesthetic for 30 minutes or more.
 - c. Any general anesthetic for 30 minutes or more.
 - d. Any general anesthetic for 60 minutes or more.
10. The caffeine-halothane contracture test is recommended for:
 - a. All children who will undergo general anesthesia with triggering agents.
 - b. Everyone who will undergo general anesthesia.
 - c. Everyone who will undergo general anesthesia with triggering agents.
 - d. Only individuals with family members who have experienced MH crises.

11. The caffeine-halothane contracture test has:
 - a. A high degree of both sensitivity and specificity.
 - b. A high degree of sensitivity and an acceptable degree of specificity.
 - c. An acceptable degree of sensitivity and a high degree of specificity.
 - d. An average degree of both sensitivity and specificity.
12. Pretreatment of most MH-susceptible patients with dantrolene:
 - a. Is recommended.
 - b. Is not recommended.
13. Which of the following is considered safe for MH-susceptible patients?
 - a. General anesthesia with non-triggering agents.
 - b. Regional anesthesia.
 - c. Local anesthesia.
 - d. All of the above.
14. Following uneventful ambulatory surgery, MH-susceptible patients should be observed for:
 - a. 1 to 2 hours before discharge.
 - b. 4 hours before discharge.
 - c. 12 hours before discharge.
 - d. 24 hours before discharge.
15. If masseter muscle rigidity occurs following succinylcholine administration, the anesthesiologist may:
 - a. Discontinue the anesthetic and postpone elective surgery.
 - b. Continue anesthesia with non-triggering agents, while monitoring ET CO₂ and core temperature.
 - c. A or B.
16. The individual responsible for directing the actions of other members of the surgical team in the event of an MH crisis is the:
 - a. Anesthesia care provider.
 - b. Circulator.
 - c. Surgeon.
 - d. OR manager.
17. Reconstitution and administration of dantrolene sodium is very labor intensive. It requires:
 - a. The efforts of at least two RNs.
 - b. Addition to each vial of 60 ml of sterile preservative-free water for injection USP, without a bacteriostatic agent.
 - c. 2 to 3 minutes of vigorous shaking for each vial.
 - d. All of the above.
18. Dantrolene should not be given in combination with:
 - a. Procainamide.
 - b. Insulin.
 - c. Calcium channel blockers.
 - d. Any of the above.
19. After an MH crisis, the patient should be observed in an ICU setting for:
 - a. 1-2 hours.
 - b. 4 hours.
 - c. 12-24 hours.
 - d. At least 24 hours.
20. Whenever an MH episode occurs in a family member, it is important to notify:
 - a. the patient's primary physician.
 - b. immediate family members.
 - c. aunts, uncles, and cousins.
 - d. all of the above.

Malignant Hypothermia
Answer Sheet

Question	Answer
1	B
2	D
3	A
4	A
5	D
6	B
7	B
8	D
9	C
10	D
11	B
12	B
13	D
14	B
15	C
16	A
17	D
18	C
19	D
20	D