Monitoring Body Temperature During MRI

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Introduction

Magnetic resonance imaging (MRI) has been an important diagnostic imaging modality for almost 30 years. Advancements in technology and imaging protocols have contributed to the growth of MRI applications and expanded the demographic of patient populations from neonates to high-risk patients. The use of sedation or anesthesia is necessary for certain MRI examinations, especially for pediatric or critically-ill patients (1). Importantly, the volume of pediatric patients undergoing MRI or computed tomography (CT) procedures under sedation or anesthesia has grown at an annual rate of 8% - 9% (2).

This monograph focuses on the need to monitor body temperature in patients during MRI and discusses the sites to record temperature based on efficacy and stability of the measurement, as well as the response time (i.e., the temporal resolution) during temperature fluctuations.

Monitoring Patients in the MRI Environment

Conventional monitoring equipment and accessories were not designed to operate in the harsh MRI environment that utilizes electromagnetic fields that can adversely affect or alter the operation of these devices (3). Fortunately, various monitors and other patient support devices have been developed to perform properly during MRI procedures.

MRI healthcare professionals must consider the ethical and medico-legal ramifications of providing proper patient care that includes identifying patients that require monitoring in the MRI setting and following a proper protocol to ensure their safety by using appropriate equipment, devices, and accessories (3). The early detection and treatment of complications that may occur in high-risk, critically-ill, sedated, or anesthetized patients undergoing MRI examinations can prevent relatively minor issues from becoming life-threatening situations.

General Policies and Procedures

Monitoring during an MRI procedure is indicated whenever a patient requires observations of vital physiologic parameters due to an underlying health problem or is unable to respond or alert the MRI technologist or other healthcare professional regarding pain, respiratory problem, cardiac distress, or difficulty that might arise during the examination (3, 4). In addition, a patient should be monitored if there is a greater potential for a change in physiologic status during the MRI procedure.

Table 1 summarizes the patients that require monitoring and support during MRI procedures. Besides patient monitoring, various support devices and accessories may be needed for use in high-risk patients to ensure safety (3, 4).

Table 1. Patients that require monitoring and support during MRI procedures.

-Physically or mentally unstable patients.
-Patients with compromised physiologic functions.
-Patients who are unable to communicate.
-Neonatal and pediatric patients.
-Sedated or anesthetized patients.
-Patients undergoing MR-guided interventional procedures.
-Patients who may have a reaction to an MRI contrast agent or medication.
-Critically-ill or high-risk patients.

Patients undergoing MRI examinations while under sedation or general anesthesia require the same standard of care as provided in operating rooms and intensive care units (ICU)(5). This includes monitoring vital physiological parameters including the electrocardiogram (ECG), oxygen saturation, blood pressure, end tidal carbon dioxide (CO_2), and body temperature (6, 7). The use of sedation or anesthesia is necessary for certain MRI examinations, especially for pediatric or critically-ill patients (3, 8). Importantly, children represent the largest group requiring sedation for MRI exams (3, 8). Sedation is used on children to minimize discomfort, motion and anxiety during the procedure (8, 9). The American Academy of Pediatrics and the American College of Radiology have published guidelines for monitoring children and adults during sedation (8, 10). The vital signs that must be monitored include the heart rate, blood pressure, respiratory rate, oxygen saturation, and temperature (8).

Because of the widespread use of MRI contrast agents and the potential for adverse effects or idiosyncratic reactions to occur, it is prudent to have appropriate monitoring equipment and accessories readily available for the proper management and support of patients who may experience side-effects. This is emphasized because adverse events, while extremely rare, may be serious or life threatening. In addition, patients may have adverse reactions to other medications while undergoing MRI procedures.

In 1992, the Safety Committee of the Society for Magnetic Resonance Imaging published guidelines and recommendations concerning the monitoring of patients during MRI procedures (11). This information indicates that all patients undergoing MRI examinations should be visually (e.g., using a camera system) and/or verbally (e.g., intercom system) monitored, and that patients who are sedated, anesthetized, or are unable to communicate should be physiologically monitored and supported by the appropriate means.

Injuries and fatalities have occurred in association with MRI examinations. These may have been prevented with the proper use of monitoring equipment and devices (3, 4, 11). Notably, guidelines issued by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) indicate that patients receiving sedatives or anesthetics require monitoring during administration and recovery from these medications (12). Other professional organizations similarly recommend the need to monitor certain patients using proper equipment and techniques (5, 6, 8, 9, 13).

Why Monitor Body Temperature?

In human subjects, “deep” body or core temperature is regulated between 36^{o}C and 38^{o}C by the hypothalamus and continuously fluctuates due to diurnal, internal, as well as external factors (14). Importantly, the regulation of body temperature is suppressed by anesthesia and generally results in the patients becoming hypothermic (15, 16). Side-effects of a decrease in body temperature can range from hypovolemia, myocardial ischemia, cardiac arrhythmia, pulmonary edema, decreased cerebral blood flow in cases of mild hypothermia, to mortality related to extreme hypothermia (17).

Additionally, some patients may experience malignant hyperthermia, which is a rare life-threatening condition that is usually triggered by exposure to certain drugs used for general anesthesia. In susceptible individuals, these drugs can induce a drastic and uncontrolled increase in skeletal muscle oxidative metabolism, which overwhelms the body's capacity to supply oxygen, remove carbon dioxide, and regulate body temperature. Malignant hyperthermia can eventually lead to circulatory collapse and death if not quickly identified and treated.

The anesthesiologist or nurse anesthetist may not be able to clearly see or have close access to the patient during the MRI procedure due to the design of the MR system. Therefore, it is imperative to continuously monitor the body temperature and provide real time information to the anesthesia healthcare professional. It is also important that the measurement site has clinical relevance and a relatively “fast” response time to any fluctuation in body temperature because the anesthesiologist or nurse anesthetist is unable to see the discoloration of the patient’s skin in cases of sudden temperature changes.

Measuring Body Temperature During an MRI

The accuracy and efficacy of the measurement of body temperature has been a topic of discussion for many years (14, 18, 20). Temperature measurements in human subjects is affected by, the following factors (14, 21):

-The site of measurement (e.g., skin, oral, esophagus, rectal, pulmonary artery, hypothalamus, bladder, tympanic membrane, axillary area).

-Environmental conditions (temperature and humidity).

-The measurement technique (e.g., mercury thermometer, electronic thermometer, thermistor probe or catheter, thermocouple-based probe, infrared radiation readers, fiber optic method).

The most accurate body temperature is measured at the hypothalamus, but this site is not accessible by any practical means. Therefore, a “deep” body site that directly reflects the temperature “sensed” by the hypothalamus will provide clinically relevant information (14). For examples, sites that provide high levels of accuracy and correlation to deep body temperature are pulmonary artery blood, urinary bladder, the esophagus, and rectum (18, 19, 22). However, the temporal resolution for each site varies, which can dramatically impact the ability to recognize clinically important changes that may require prompt patient management (14, 18).

When monitoring temperature during MRI, the decision on which body site to use should be based on accuracy as well as accessibility. There may be limitations on the type of equipment available for temperature measurements in the MR system room (3, 8, 23). For example, hard wire thermistor or thermocouple-based sensors are prone to measurement errors due to electromagnetic interference (EMI) and may introduce artifacts in the MR images (3). Fiber optic sensors (i.e., fluoroptic thermometry) are optimally used to record temperatures in the MRI environment because they are safe and unaffected by EMI (3).

In the MRI setting, anesthesiologists, nurse anesthetists, and clinicians may feel they are limited to measure “surface” temperatures, such as those in the skin, axilla, and groin. However, these temperature measurement sites are very problematic insofar as they do not properly reflect “deep” body temperature. Another option is to use minimially invasive measurement techniques to record temperature in the rectum or esophagus.

While a so-called “surface” temperature site (i.e., skin, axilla, and groin) tends to be used for temperature recordings during MRI mainly because of the ease of obtaining the measurement with currently available equipment, this method does not provide an accurate representation of body temperature and is susceptible to substantial variations and erroneous information relative to the “deep” body temperature due to the specific site selected for temperature probe placement, patient movement, and environmental conditions (14, 19, 20)

Notably, recording skin or surface temperature during MRI can be influenced by the level of the patient’s perspiration due to RF heating and the use of blankets or air circulation from the fan in the bore of the MR system. Additionally, investigations have demonstrated that peripheral vasoconstriction resulting from skin surface cooling decreases the surface temperature measurement without influencing the core or deep body temperature (24).

In contrast, core or “deep” body temperature measurements require additional setup time and are minimally invasive but provide a more accurate representation of the body temperature (14). Two of the most prevalent core temperature measurement sites used during MRI procedures is the rectum and esophagus.

Rectal temperature measurements are highly accurate and within $0.6^{o}C$ of the deep body temperature (14). The main drawback to this temperature measurement site is associated with a lag or delay in the temporal response to changing body temperature due to the presence of thermal inertia from the intervening tissues (i.e., between the rectum and hypothalamus). This temporal delay may also be caused by the presence of feces and poor blood supply in the rectum (14, 25). A clinical investigation reported that the rectal temperature substantially lagged in response to changes in body temperature (25). The lack of temporal resolution can expose the patient to a hypothermic or hyperthermic condition for an extended period without being recognized by the clinician. Also, special care must be taken when placing a rectal temperature probe in neonatal or pediatric patient to prevent perforation and infection (14, 25).

Esophageal temperature measurements provide a high level of accuracy and good temporal correlation to body temperature due to the close proximity to the aorta, a deep body site. (20). In addition to the accuracy, the temperature recorded in the esophagus is responsive to fluctuations in body temperature and readily tracks changes compared to rectal or surface temperature measurement sites (14, 25). The only caveat is that the accuracy of measuring temperature in the esophagus is directly linked to the proper positioning of the probe (14, 19). Air flow in the trachea can impact the measured temperature if the probe is not inserted deep enough into the esophagus. The recommended placement of the sensor is in the lower one-third of the esophagus for an accurate core temperature measurement (14). Table 2 presents a comparison of the measurement sites to monitor during MRI, with the advantages and disadvantages.

Table 2. Comparison of the measurement sites for temperature monitoring during MRI.

Site	Advantages	Disadvantages
Surface/Skin	Non-Invasive Ease of use	Not located near major arteries and will not reflect body temperature fluctuations Accuracy affected by placement and patient movement Affected by environmental conditions
Core/Body - Rectum	Highly accurate Reflects true core temperature	Minimally invasive Response to core temperature change could be up to one hour [3]
Core/Body – Esophagus	Highly accurate Reflects true core or “deep” body temperature Fast response to core temperature changes[2]	Considered invasive Placement can impact accuracy

Monitoring Body Temperature During MRI: Recommendations

In consideration of the available temperature measurement sites that may be monitored during MRI, especially with regard to which site provides the most accurate information along with the best temporal resolution, the temperature of the esophagus will provide the most acceptable and clinically relevant information. Furthermore, esophageal temperature is insensitive to ambient air circulation and patient perspiration during the MRI examination and has the added benefit of fast response time to temperature fluctuations in the body compared to the measurement of temperature in the rectum. The current availability of temperature probes and recording equipment properly designed for use in the MRI setting permits the monitoring of body temperature in the esophagus, which provides physiological information that is vital to patient care.

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