Equipment

Successful use of a Fortec II vaporizer in the MRI suite: a case report with observations regarding magnetic field-induced vaporizer aberrancy

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Conducting a general anaesthetic within a magnetic resonance imaging (MRI) suite poses many problems for the anaesthetist. Ferromagnetic substances are contained in most anaesthetic and monitoring equipment. Their presence within the magnetic field may cause hazards and artifacts during imaging. This report describes the testing and use of a free-standing Fortec II vaporizer within an MRI suite. The Fortec II vaporizer's function was altered depending upon its distance from and orientation to the magnetic field. The MRI images were not affected by this vaporizer's presence within the MRI suite. We conclude that an inhalational anaesthetic can be administered, using a pretested free-standing anaesthetic vaporizer and a Bain circuit, within the magnetic field of a magnetic resonance imager.

L'administration de l'anesthésie générale à la salle de résonance magnétique (MRI) pose plusieurs problèmes à l'anesthésiste.

Key words

ANAESTHESIA: general, inhalational;

EQUIPMENT: vaporizers;

MEASUREMENT TECHNIQUES: nuclear magnetic resonance.

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Les substances ferromagnétiques sont contenues dans plusieurs équipements anesthésiques et du monitoring. Leur présence dans un champ magnétique peut provoquer des risques et des artefacts durant l'imagerie. Ce rapport décrit l'étude et l'utilisation d'un vaporisateur Fortec II hors circuit à l'intérieur d'une salle de MRI. La fonction du vaporisateur Fortec II fut altérée selon sa distance et son orientation dans le champ magnétique. Les images obtenues par MRI n'étaient pas affectées par la présence de vaporisateurs. On conclut que l'anesthésie par inhalation peut-être administrée utilisant un vaporisateur d'anesthésie hors circuit testé au préalable et un circuit de Bain, à l'intérieur d'un champ magnétique.

The hazards and artifacts caused by ferromagnetic substances have imposed numerous limitations on anaesthetic management in the magnetic resonance imaging (MRI) suite.¹⁻⁵ Intravenous techniques combined with spontaneous ventilation via the unprotected airway have been widely and satisfactorily employed.⁶ However, the unsecured airway and the inability to control carbon dioxide tension mean that these techniques may not be appropriate in all clinical situations, e.g., obesity, history of gastro-oesophageal reflux, elevated intracranial pressure.

General anaesthesia with tracheal intubation has been performed in the MRI suite.⁷ This can be accomplished with intravenous techniques, although anaesthesia with inhaled agents offers the potential advantage of more rapid emergence and in addition is more conducive to spontaneous ventilation with its inherent safety. However, there has been a general conviction that large metallic objects, i.e., vaporizers, should not be introduced into the immediate vicinity of the magnet because

of concerns over both safety and image degradation. Anaesthesia with inhaled agents has been maintained from outside the MRI suite using a long extension of the anaesthetic circuit.⁸ However, this approach may prove cumbersome and impractical in many situations. An MRI-compatible anaesthetic apparatus is available.⁹ However, the considerable expense may be difficult to justify when the need for the apparatus will arise infrequently. The authors, faced with institutional reluctance to make a substantial outlay for the acquisition of a dedicated anaesthetic apparatus, sought to determine whether a standard volatile agent anaesthesia vaporizer could be used safely and efficiently in the MRI suite. A Fortec II (Fraser Harlake; Orchard Park, N.Y.) was available.

Methods of vaporizer evaluation

Before bringing the Fortec II into the vicinity of the 1.5 tesla General Electric Magnetic Resonance Imager (General Electric, Milwaukee, WI), an identical Fortec II was dismantled to permit identification (using a magnet) of its ferromagnetic components. The majority of its components are non-ferromagnetic, largely aluminium. However, there are eight stainless steel screws that secure the outer housing, and one that secures the spring within the vaporizer output dial. In addition, a bimetallic (brass and stainless steel) component of the temperature compensator is ferromagnetic. Because of the limited mass of these components, it appeared unlikely that the vaporizer could become a projectile in the magnetic field.

The vaporizer was then carried into the MRI suite. A barely perceptible "tug" was felt when the vaporizer was in the orifice of the scanner, and it was determined that the vaporizer remained immobile at all locations in the scanner suite.

There remained concern that the vaporizer's ferromagnetic components would cause degradation of the images obtained. To evaluate this possibility a chemical shift imaging shim test was performed using a Daily Quality Assurance "phantom" (General Electric, Milwaukee, WI) (composed of 35% glycine, 65% deionized water, 9 ppm sodium hyperchloride, and 0.1 M sodium chloride with three sets of three bottles containing 0.01 M copper sulfate, 0.005 M copper sulfate, and 0.001 M copper sulfate, arranged along the axial sagittal, and horizontal planes). The phantom was imaged (T1 relaxation time) with the Fortec II vaporizer at various locations in the MRI suite. No instability suggestive of ferromagnetic artifact was noted unless the vaporizer was placed within the orifice of the scanner.

The final concern was that the Fortec II's output would be influenced by the magnetic field. Vaporizer output was first evaluated at a location remote from the MRI suite.

TABLE 1 Vaporizer output at three dial settings outside the MRI suite (no MRI) and in the MRI scanner orifice at different orientations (in degrees) to the long axis of the bore of the magnet

Setting (%)	No MRI	0	90	180	270
1.0	0.80	0.85	0.50	0.85	1.10
2.0	1.65	1.65	1.10	1.60	2.10
3.0	2.40	2.50	2.10	2.40	3.20

Eight metres of 6.0 mm ID Argyle polyvinyl chloride tubing (Sherwood Medical; St. Louis, MO) was used to connect the O₂ source to the vaporizer. Vaporizer outflow was directed through four metres of polyvinyl chloride tubing. The sample port was placed one metre downstream from the vaporizer. Oxygen flow was maintained at 10 L·min⁻¹. Using a Puritan-Bennett Anaesthetic Analyzer (Datex; Helsinki, Finland) vaporizer output was sampled at dial settings of 0.5, 1.0, 2.0, and 3.0% through six metre long 1.5 mm ID polyvinyl chloride teflon-coated tubing. The analyzer was recalibrated after each sampling series. Outputs were measured for three minutes at each dial setting. The vaporizer was then taken to the MRI suite. With the analyzer in an adjacent room shielded from the magnetic field, an assessment of the magnetic field's influence on vaporizer output was performed. Constant temperature and an oxygen flow of 10 L·min⁻¹ were maintained.

In the first evaluation, the vaporizer was placed in the patient access orifice of the scanner with the dial facing outward. Measurements of vaporizer output (Table I) were made at dial settings of 1.0, 2.0, and 3.0% as the vaporizer was rotated in 90 degree increments through 360 degrees. Rotation altered vaporizer output by as much as 91% (see 2.0% setting in Table I).

In the second evaluation, the vaporizer was moved to three additional locations in the MRI suite. These locations were selected as being practical for the anaesthesia care provider attending a patient within the bore of the magnet. The three locations were (A) at floor level adjacent to the left-hand side of the patient table and approximately 0.25 metres from the front surface of the scanner; (B) at the foot of the patient access table, i.e., five metres from the front surface of the scanner at the level of the orifice; and (C) at the side of the scanner at the midpoint of the bore of the magnet at the level of the orifice. At each location, the vaporizer was rotated in 45° increments through 360°. Table II presents the vaporizer output data vaporizer dial settings of 0.5%, 1.0% and 2.0%. As in the first evaluation performed with the vaporizer within the orifice of the magnet, rotation resulted in an alteration of output. In addition, both the absolute output and the percentage change in output

TABLE II Vaporizer output (%) at various dial settings at different orientations (in degrees) to the long axis of the bore of the magnet in three locations* in the MRI suite

Dial setting	Location	0	45	90	135	180	225	270	315
0.5%	A	0.40	0.40	0.30	0.35	0.30	0.35	0.35	0.40
	B	0.35	0.35	0.35	0.35	0.35	0.30	0.30	0.30
	C	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
1.0%	A	0.90	0.80	0.70	0.80	0.70	0.80	0.80	0.85
	B	0.75	0.75	0.80	0.80	0.80	0.75	0.75	0.75
	C	0.70	0.70	0.70	0.70	0.70	0.70	0.75	0.70
2.0%	A	1.75	1.75	1.50	1.55	1.45	1.60	1.65	1.75
	B	1.50	1.50	1.55	1.50	1.65	1.50	1.50	1.50
	C	1.45	1.50	1.55	1.50	1.45	1.40	1.55	1.40

*See text for description of locations.

caused by rotation varied with location. In general, both the vaporizer output at a given dial setting and the rotation-related variation in output were greatest at location A (on the floor adjacent to the patient table and approximately 0.25 metres from the front surface of the scanner). However, the rotation-related output variation in all three locations was less than that observed in the first evaluation performed with the vaporizer in the scanner orifice. For instance, the maximum variation at a 2.0% dial setting was 21% (cf. 91% above).

Case report

A four-year-old white girl was scheduled for a cranial MRI scan as part of the evaluation of developmental delay. Past medical history was otherwise unremarkable. Apart from delayed development milestones, the physical examination, including neurological examination, was normal. Anaesthesia was induced in a room adjacent to the MRI scanner room with ketamine, 5 mg · kg⁻¹ *im*. Monitors included an ECG, pulse oximeter, and precordial stethoscope. An intravenous catheter was inserted. Thiamylal, 70 mg, and succinylcholine, 40 mg, were administered and the trachea was intubated with a 5.0 uncuffed tracheal tube. The lungs were ventilated with 100% oxygen using a Mapleson C circuit. The patient was moved into the scanner room. During transport, oxygen was delivered via extension tubing, from a D cylinder placed outside the scan room door. An MRI compatible pulse oximeter (Biochem International Corporation; Waukesha, WI), an automatic blood pressure cuff (Dinamapp, Criticon; Tampa, FA) with extended tubing, were applied. The ECG is built into the 1.5 tesla General Electric MRI (for the purpose of cardiac gating) and has an oscilloscope outside the scanner room that can be viewed via the observation window.

The endotracheal tube was connected to a Mapleson D

circuit through which 100% oxygen was administered at 10 L · min⁻¹ by way of a wall-mounted oxygen flow meter. Flow to the latter was supplied by a G cylinder in the adjacent room. The Fortec II vaporizer was introduced between the oxygen flow meter and the Mapleson D circuit. It was placed on the floor adjacent to the left hand side of the patient table (location A as described above). The vaporizer was initially adjusted to a nominal inspired isoflurane concentration (dial setting) of 1.5%. The patient was allowed to resume spontaneous respiration. Inspired concentration was adjusted in accordance with blood pressure and heart rate changes, and nominal inspired concentrations of 1.0–1.5% were employed throughout the procedure. All personnel were cautioned regarding the critical importance of preventing inversion of the free-standing vaporizer. Exhaled gases were removed from the MRI suite via wall suction.

The patient remained motionless throughout the 30 min scan. Technically satisfactory scans (T1 and T2 weighted images) were obtained. Upon completion of the imaging sequence, isoflurane administration was discontinued. Within three minutes spontaneous movement occurred. The trachea was extubated in the scanner room and the patient was transferred to the recovery area. Within 30 min, the patient was awake, alert, and responding appropriately. She was discharged home without complication.

Discussion

Administration of anaesthesia in the MRI suite is complicated by the presence of a strong magnetic field. Ferromagnetic objects give rise to three potential hazards: the objects may become dangerous projectiles; image quality may be degraded; and the function of instruments containing ferromagnetic components may be altered. Among the largest of metallic objects is the "anaesthetic machine"

FIGURE Internal components of a Fortec II vaporizer depicting the movements of the bimetallic ferromagnetic temperature compensator in relation to the MRI magnetic field.

with its associated vaporizers and ventilator. It has largely been excluded from the MRI environment. One MRI compatible ventilator, the Monaghan 225/SIMV (Monaghan Medical Corp.; Plattsburg, NY), is available but is not equipped for the administration of volatile anaesthetic agents.¹⁰ MRI compatible anaesthetic machines, e.g., Ohmeda Excel 210 (Ohmeda; Steeton, England), which will deliver volatile anaesthetic agents have been developed recently.¹¹ However, cost may limit their use to centres where there is a more substantial demand than arises in most MRI facilities. Accordingly, techniques for the administration of inhaled anaesthetics without the need for an anaesthesia machine are relevant. Our experience indicates that a free-standing Fortec II vaporizer can be used in close proximity to a 1.5 tesla magnetic resonance imager. It did not interfere with image quality when located at any location outside the scanner orifice.

However, our experience indicates that some caution is required. Considerable differences in vaporizer output were observed with changes in location within the magnetic field. It is probable that this arose because of the presence of a ferromagnetic component in the temperature compensating device that modulates orifice size within the vaporizer (Figure). It might be anticipated that, depending on the orientation of the magnetic field with respect to the bimetallic strip, orifice size (and vaporizer output) could be increased, decreased, or unaffected. Rotation of the vaporizer through the points of the compass in the scanner orifice resulted in observations consistent with this prediction (Table I). At an orientation of 270 degrees to the long axis of the bore of the magnet output was at a maximum; at 90 degrees it was at a

minimum; at 0 and 180 degrees it was intermediate and equal. These differences in output might be a matter of clinical importance. Note that with a dial setting of 2.0% (Table I), a 180 degree rotation of the vaporizer resulted in a 91% increase in vaporizer output. Fortunately, however, when the Fortec II vaporizer was placed at any clinically practical location outside the scanner orifice, the changes in output that occurred with rotation were less likely to have been of major clinical importance.

Subsequently, attempts were made to examine three additional vaporizers: the Ohio Forane (isoflurane) vaporizer (Ohio Medical Products; Madison, WI), the Ohmeda Isotec IV vaporizer (Ohmeda; Steeton, England), and the Forane-Vapor 19.1 isoflurane vaporizer (Drägerwerk AG; Lubeck, Germany). With both the Isotec IV and the Forane-Vapor 19.1 vaporizers a strong pull was evident when the vaporizers were within two metres of the 1.5 tesla General Electric Magnetic Imager. Upon examination, the mass of their ferromagnetic internal components was substantial. No further evaluation of these vaporizers was performed. By contrast, the Ohio Forane (isoflurane) vaporizer had no perceptible "tug" near the magnet and had few ferromagnetic components (four screws and one spring). However, the spring was located within the temperature compensator. Evaluation of this vaporizer's output within the MRI suite revealed that subtle changes in orientation at any location within the MRI's magnetic field could result in variation in output ranging from a maximum concentration corresponding to the dial setting to a minimum of less than 0.1% of that concentration. Given these findings, none of these three vaporizers would be suitable for the application described in this case report.

The constraints of a situation that arose at short notice lead to our using a free-standing vaporizer in the present case. This approach was undertaken cautiously because of the hazards of vaporizer inversion. While our experience demonstrates the feasibility of this approach, we advocate the use of a fixed apparatus for anaesthesia in the MRI suite.

In summary, our experience suggests that a free-standing Fortec II vaporizer can be used to administer general anaesthesia in a General Electric 1.5 tesla MRI suite. Furthermore, the technique is consistent with obtaining high quality MR images. However, our observations indicate that the magnetic field can result in location/orientation-dependent vaporizer aberrancy. Therefore, expired inhalation agent monitoring should be performed when vaporizers are used within the magnetic field of the imager. As a minimum, the performance characteristics of other vaporizers or other vaporizer/scanner combinations should be evaluated before clinical application.

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