Original Report

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Projectile Cylinder Accidents Resulting from the Presence of Ferromagnetic Nitrous Oxide or Oxygen Tanks in the MR Suite

OBJECTIVE. The purpose of this study is to alert MR users to the potentially lethal consequences of projectile cylinder accidents in the MR environment.

CONCLUSION. Projectile cylinder tank accidents still occur and may be increasing, despite adherence to screening policies before MR imaging and safety education of hospital personnel. Four of the last five accidents at our institutions occurred within the past 3 years.

MR imaging is generally considered to be a safe imaging modality when appropriate screening of patients and safety education of personnel are carried out [1]. However, numerous accidents and incidents have been described in the literature [2–5]. We present five cases of projectile cylinder tank accidents and incidents that occurred at two academic medical centers and resulted in patient morbidity, machine damage, and loss of imaging time. The purpose of this article is to alert the users of MR that accidents or incidents can occur despite appropriate screening precautions.

Materials and Methods

From 1987 through 1997, 45,865 MR examinations were performed at the first institution on two units, a 0.6-T unit and a 1.5-T unit. From 1985 through 2000, 91,845 MR examinations were performed on two 1.5-T units at the second institution. For our study, we reviewed the accident or incident reports at both institutions to identify those involving tanks used for life support.

Results

Five accidents involving projectile tanks of anesthetic nitrous oxide or oxygen for patient life support occurred from 2–15 years after installation of the MR unit. The impact of these projectile tanks resulted in patient morbidity, machine damage, loss of imaging time, and litigation.

Incident 1

The first MR projectile tank accident occurred in 1987, 2 years after a 0.6-T magnet was installed at the first institution. A 60-year-old patient was receiving oxygen by nasal cannula via extension tubing connected to an H-cylinder tank (the largest tank available, 23.5 cm in diameter and 129.5 cm long) that was placed outside the immediate shielded MR imaging suite. The medical intensive care nurse monitoring the patient noticed that the oxygen cylinder was almost empty and ordered a replacement tank from the respiratory therapy department.

No electronic coded security system was in place. An MR imaging warning sign was attached to the door, but the sign was not visible because the door was propped open while the physicians and technologists were waiting for the tank to be delivered. Unfortunately, no one noticed when the transportation person arrived with the replacement H-cylinder tank, took it into the MR suite on a cart, and placed it beside the unshielded magnet, approximately 20 ft (6 m) away. Instantly, the magnetic force pulled the tank off the cart. The cylinder hit the MR table and then the fiberglass front panels of the magnet, and finally lodged in

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the center of the bore of the magnet. The cylinder was lodged above the patient, with the safety shield portion of the tank against the patient's jaw. The MR technologist attempted to quench the magnet but was unsuccessful because the quenching apparatus failed. Three radiology staff members extracted the patient through the opposite end of the magnet with great difficulty.

The patient sustained facial fractures. The patient and family sued the university for negligence and were awarded $100,000. The magnet sustained $32,000 worth of damage, and 1 week of imaging time was lost. After the accident, an electronic coded security system was added to the facility to limit access by uninformed personnel, and MR imaging safety issues were thoroughly reviewed with the staff.

Incident 2

In 1997, 5 years after installation of a 1.5-T magnet at the same institution, another projectile cylinder tank accident occurred in the MR suite. An 83-year-old woman was undergoing an MR examination of her chest and abdomen to evaluate for a diagnosis of aortic dissection. Because the ECG gating was not functioning properly after the initial pulse sequence, the MR technologist brought the patient out of the magnet bore and attempted to adjust the ECG lead pads.

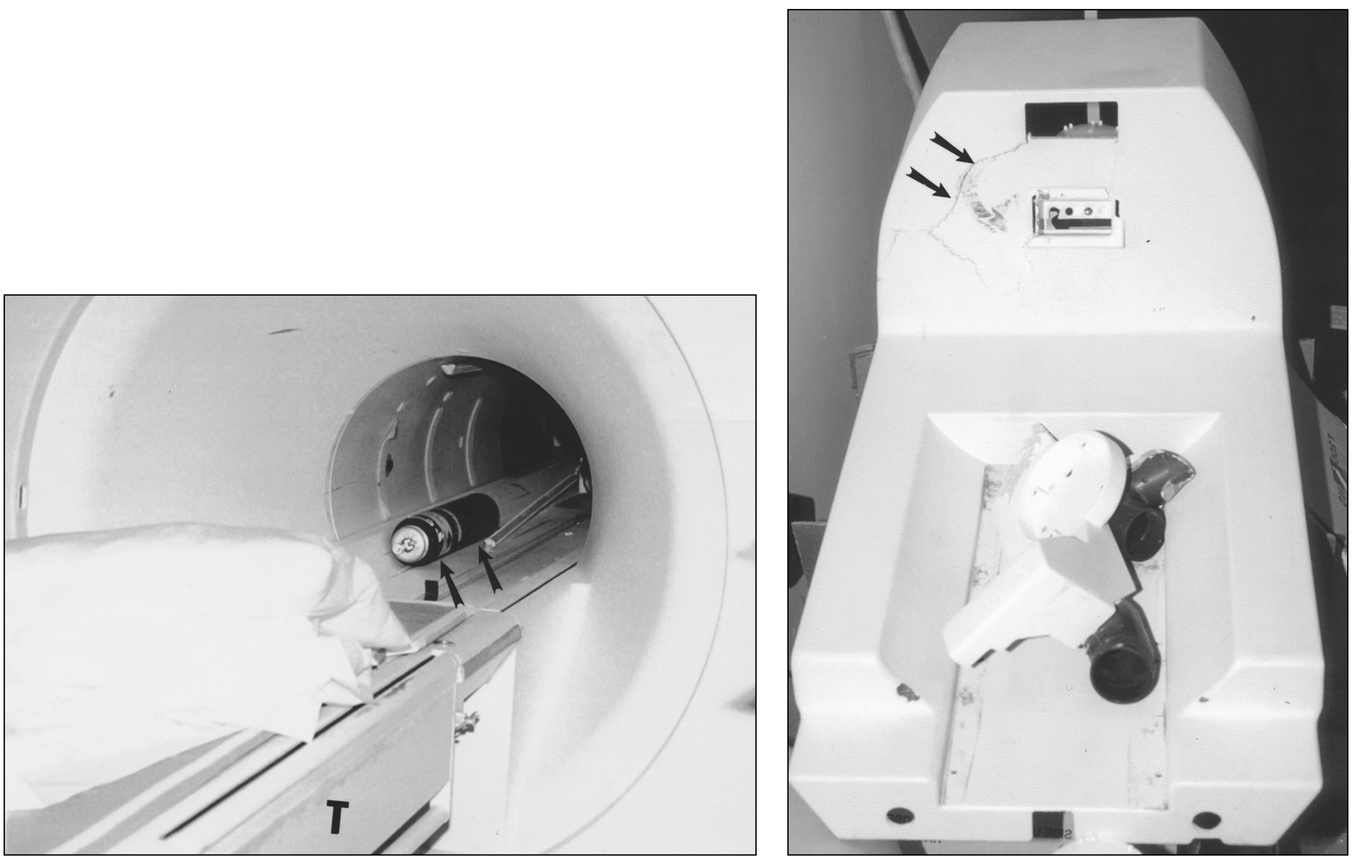
Coincidentally, and unrelated to the clinical activities, preventative maintenance was being performed on the MR imaging–compatible anesthesia machine, which was outside of the immediate magnetic imaging suite. When the work was finished, the serviceman returned the unit to the MR imaging suite. Without thinking, the serviceman had placed a noncompatible ferromagnetic nitrous oxide E-cylinder tank (the most commonly used tank on anesthesia units,10.8 cm in diameter and 66 cm long) on the machine. Realizing his mistake, he disconnected the ferromagnetic nitrous oxide tank from the MR anesthesia cart and attempted to walk out of the magnetic field with the tank under his arm. The magnetic force pulled the cylinder from the serviceman's arm and sent it flying across the room. It narrowly missed the technologist and slammed into the front panel of the magnet (Fig. 1). The patient, MR technologist, and equipment serviceman were not injured, but the projectile collision resulted in $50,000 damage to the magnet and loss of 1 week's imaging time.

The patient's family pursued legal action against the serviceman's company for negligence and won a $35,000 settlement for "mental anguish and suffering."

Incident 3

An MR projectile cylinder tank incident occurred at the second institution in 1998, 10 years after installation of a 1.5-T magnet. At this institution, the MR department maintains a stock of aluminum oxygen tanks for use with MR-compatible anesthesia machines. When exhausted aluminum tanks are sent for recharging, ferromagnetic oxygen tanks are sometimes inadvertently returned, resulting in a mixed supply of oxygen tanks.

In this case, a ferromagnetic oxygen cylinder was placed unrestrained in the cylinder holder of an MR-compatible stretcher. The stretcher was brought to the table to transfer the patient out of the scanner room at the completion of the examination. As the patient was transferring to the stretcher, the technologist noticed the oxygen tank moving out of the cylinder holder beneath the patient. A staff radiologist, fellow, and two other technologists nearby responded to the technologist's calls for help and used a bed sheet to



A B

Fig. 1.—Photographs show aftermath of incident 2, which occurred at first institution.
A, Portable anesthesia tank of nitrous oxide (*arrows*) lies in bore of 1.5-T MR unit. T = table.
B, Head coil carriage and surface coil connection box have been dislodged from table. Note cylinder mark and cracks in plastic (*arrows*).

secure the oxygen tank, which was precariously stuck beneath the scanner table and stretcher. The patient was then safely removed from the scanner room. The rescue team, realizing that they could not move the oxygen tank against the pull of the magnet, decided to guide it in a controlled manner toward the bore of the magnet. This was accomplished after releasing the remaining oxygen in the cylinder and removing the head coil from the bore of the magnet to prevent damage. The posterior edge of the oxygen tank lodged against the head coil cradle and the lateral margin of the cylinder flattened against the opening of the bore (Fig. 2).

Field engineers from the manufacturer, acquainted with the magnet's construction and current safety approaches, responded to the situation with a plan to extract the cylinder without quenching the magnet. A rope was secured around the valve of the oxygen cylinder at one end and to a 2 in × 4 ft (5.08 cm × 1.22 m) wooden stud at the other end. With sufficient slack in the rope, the stud was positioned outside of the scanner door while three engineers combined their pulling strength on the stud. As the oxygen tank hovered outside the bore, a sheet of plywood was placed over the opening of the bore in case the makeshift system failed. The cylinder was then safely removed without quenching the magnet. The scanner was tested and found to function within normal parameters. This incident resulted in a 1-day loss of imaging time.

Incident 4

In 1999, 14 years after installation of a 1.5-T magnet, another MR projectile cylinder tank incident occurred at the second institution. This time, similar to the previous incident, a ferromagnetic oxygen cylinder, instead of an aluminum cylinder, was inadvertently placed in the oxygen tank holder of an MR-compatible anesthesia cart. In this case, the oxygen cylinder was secured by a latch system. When the anesthesia cart was brought into the magnet room in preparation for a procedure, it lurched toward the magnet and became lodged against the patient table and bore opening. Because the cylinder was securely fitted in the holder, the anesthesia machine on the cart restrained the cylinder from entering the magnet bore or directly touching the magnet. The leverage of the anesthesia machine proved sufficient for staff members to remove both the cart and cylinder from the magnet room without further incident.

Incident 5

The last incident we discuss occurred during preparation of this article, at the second institution 15 years after installation of a 1.5-T magnet. While an anesthetized child was being brought out of the MR suite, an experienced respiratory therapist inadvertently brought an E-cylinder oxygen tank into the suite. The magnet pulled the cylinder into the bore and caused damage to the head coil. One day of imaging time was lost while field engineers retracted the cylinder.

Discussion

To our knowledge, these are the first reports of projectile cylinder tank accidents and incidents in MR imaging involving equipment used for life support. Other significant accidents and incidents have been reported, including a death caused by torquing of an aneurysm clip [2], an intraocular metallic foreign body resulting in unilateral blindness [3], severe skin burns caused by pulse oximeters and other monitoring devices [4, 5], and five deaths possibly related to inadvertent scanning of patients with cardiac pacemakers [1].

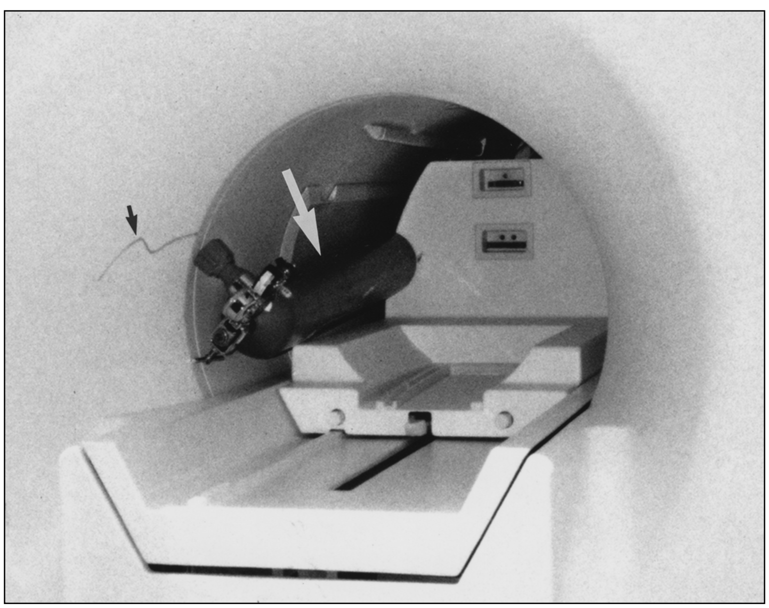


Fig. 2.—Photograph depicts result of incident 3, which occurred at second institution. H-cylinder (*white arrow*) lies within bore of 1.5-T MR magnet lodged against head coil carriage. Note trail of paint along bore opening (*black arrow*), which is only visible damage to scanner.

Prompted by the 1997 incident involving the ferromagnetic nitrous oxide tank (incident 2), members of the first institution designed and sent out 250 questionnaires to MR imaging facilities throughout the country to gather information about accidents and incidents with the goal of increasing MR imaging safety awareness [6]. The questionnaires were sent to the directors of academic MR imaging facilities in the United States and to private MR imaging facilities in our state. Questions focused on the number and types of accidents, injuries, policies, costs, and legal issues. Of the 46 responses, 24 (52%) reported accidents or incidents. Large ferromagnetic objects that were reported as having been drawn into the MR equipment include a defibrillator, a wheelchair, a respirator, ankle weights, an IV pole, a tool box, sand bags containing metal filings, a vacuum cleaner, and mop buckets. In one incident, a member of the cleaning staff sustained a wrist fracture because of torquing of a floor buffer in the vicinity of the MR suite. We believe it likely that accidents and incidents in MR imaging are underreported. Those responding to the questionnaire cited failure to adhere to MR safety policies and human error as the most common causes of the accidents and incidents [6].

Controlled exit and entry sites at MR imaging facilities, perhaps with a keyless electronic coded entry system, could have avoided the first incident we describe. Incident 2, involving the nitrous oxide tank, could have been avoided by adhering to protocols that allow preventive maintenance and housekeeping personnel to enter the MR suite only after proper safety education and when no patient is in the suite. Busy MR imaging schedules, a high volume of patient and personnel traffic, and perhaps a relaxed awareness of safety issues contributed to this accident.

Portable ferromagnetic oxygen cylinders are universal to all hospitals. In addition, metal cylinders are also used to deliver anesthetic gases in specially designed anesthesia carts. The large mass of these cylinders make them potentially lethal missiles in a strong magnetic field. In contrast, nonferromagnetic cylinders, composed of aluminum, are made available in limited quantities to helicopter ambulances to reduce weight on board and to MR departments for use in the presence of strong magnetic fields. Because of the ubiquitous presence of metal cylinders in the hospital and the lack of conspicuous differentiating features between aluminum and ferromagnetic oxygen cylinders, the potential for inadvertent placement of these cylinders near the bore of the magnet remains a constant threat, as seen in incidents 2–5.

To reduce the possibility of projectile missile accidents, the second institution is beginning a pilot project in two phases. In the first phase, all aluminum cylinders will be given an added label. The green color common to oxygen cylinders is used to indicate the oxygen content of the tank, not the composition of the cylinder. The addition of fluorescent orange stripes on the aluminum, nonferromagnetic cylinders will make identification obvious. Only these specifically tagged cylinders should be allowed into the MR suite. The goal of the second phase of the initiative will be to gradually replace all ferromagnetic cylinders in the hospital with aluminum cylinders. We hope that the above initiatives will gain widespread acceptance.

This study is limited because it is not known how many of the total 137,710 MR examinations performed at the two academic medical centers during the period we discuss involved cylinder tanks used for general anesthesia or administration of oxygen, although we estimate that they represent 1–3% of the cases.

The number of cylinder accidents is relatively small, but these incidents highlight the ever-present danger of working in a strong magnetic field. Our experience suggests that, despite MR safety education, projectile cylinder accidents and incidents may be on the increase. More sick patients are undergoing scanning while on life-support equipment, as evidenced by four of the five accidents occurring within the past 3 years at our institutions. Prevention of MR accidents and incidents requires both safety education of hospital personnel [7–12] and adherence to an effective procedural screening policy in preparation for MR examinations [7, 12].

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