Screening Test for Detection of Metallic Foreign Objects in the Orbit before Magnetic Resonance Imaging

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RATIONALE AND OBJECTIVES. **A study was designed to determine whether plain films, used as a screening modality for magnetic resonance imaging (MRI), could reliably detect intraorbital metallic foreign objects.**

METHODS. **In the first experiment, 20 metal particles were placed in five human cadaver orbits. Routine orbital plain film series and computed tomography (CT) were obtained, randomized, and interpreted blinded by three experienced radiologists.**

RESULTS. **The threshold size of particle detection for CT (0.07 mm^3) was lower than for plain films (0.12 mm^3). Placing metal particles in artificial and true vitreous demonstrated that all particles moved under a magnetic field at 1.5 T. When human globes were exposed to industrial tools (grinder, bandsaw, air hose, etc.), no metal objects penetrated the sclera.**

CONCLUSIONS. **Plain films can be used as a low-cost, low-radiation screening procedure for high-risk patients with occupations involving metal work. CT should be used for patients with a history of eye trauma from other causes.**

KEY WORDS: **computed tomography; magnetic resonance imaging; orbit; orbital foreign body; screening procedure.**

THE POTENTIAL FOR significant ocular injury exists in patients with intraocular and intraorbital ferromagnetic foreign bodies undergoing magnetic resonance imaging (MRI). High-risk patients are those involved with metal work, such as steel workers, welders, and pipe fitters. The records of 2,000 patients at the University of Florida who underwent MRI were reviewed. Of these patients, 4% had occupations involving metal work and required an orbital computed tomographic (CT) scan before MRI. Currently, CT is considered the test of choice for the detection of intraorbital and intraocular metallic particles; however, as a screening method before MRI, it is very costly. A CT of the orbits costs approximately $300 and delivers approximately 5 rad to the lens. Ideally, a screening examination should be both highly sensitive and cost effective. The purpose of this three-phased experiment is to determine what constitutes the best screening method for high-risk patients before MRI.

Materials and Methods

Experiment 1: Computed Tomography and Plain Film Threshold Detection

Two steel wires (consisting of 97% iron and 2.8% carbon; Bulldog Home and Hardware, Newell Group, Memphis, TN) of multiple sizes (ranging in size from 0.3 × 0.5 mm to 0.9 × 2.0 mm) were implanted into various positions (superior fornix, inferior fornix, cornea, vitreous, sclera, posterior orbit, superior orbit, and inferior orbit) within each orbit of five cadaver heads. A plain film series which included Waters and Caldwell views and a lateral view coned to the orbits was taken before the implantation of any steel wires, after two steel wires were placed in the right orbit and after two steel wires were placed in the left orbit of each cadaver. These 15 films were then marked by one of the authors (PMO) and randomized and interpreted by three experienced radiologists (KCPL, JVK, EVS), given the history of "rule out intraorbital metallic foreign body." To reduce bias, the readers were not informed of the experimental design.

The same cadaver heads (after the placement of two metal objects in each orbit) were scanned on a Picker 1200 CT scanner (Picker International Inc., Cleveland, OH). We performed 3-mm

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sections every 3 mm in axial and coronal projections. These were then marked, randomized, and given to the same three radiologists with the same instructions.

Experiment II: Movement of Metal Objects in a (1.5-T) Magnetic Field

Three small steel wires of varying sizes (0.3 × 0.5, 0.5 × 1.0, and 0.9 × 1.0 mm) were placed separately in three beakers of sodium hylauronate, a synthetic vitreous humor (Healon, Pharmacia Ophthalmics, Pasadena, CA). Each beaker was placed on the scan table at the bore aperture of a whole body 1.5-T magnet and visually observed by the investigators (PMO, CV, SMF). The bed was then moved into the bore of the magnet along with an observer with a flashlight (PMO), who carefully observed the movement of the metal particle in the synthetic vitreous humor. To further substantiate the movement of metal particles, five cadaver eyes were bisected horizontally. Metal particles were placed in human vitreous, and the same experiment was conducted. Great care was exercised in the dissection to ensure that no retinal detachment occurred.

Experiment III: Threshold Scleral Penetration by Metal Particles

Three fresh cadaver eyeballs were exposed for 5 minutes to metal particles emitted from a Johnson bandsaw (Johnson Co., Inc., Albion, MI) while cutting a steel pipe at 1,725 rpm. The eyeballs were held 6 cm from the cutting surface. The same eyeballs were exposed in a similar fashion to a Black and Decker industrial grinder (Black and Decker, Inc., Hunt Valley, MD) at 5,000 rpm, 5 cm from the grinding surface. Both tools produced waste metal particles with size variation within our experimental design, as determined by sampling of the metallic waste products in the area. The metallic waste particles measured in size from dust-sized particles to 3 × 1 × 1.5 mm. CT scans were then performed with contiguous 2 mm sections. Three more fresh cadaver eyeballs were exposed to a high-pressure air hose operating at 100 psi. Metal wires (0.4 × 0.5, 0.5 × 1.0, and 0.5 × 1.5 mm) with sharp ends were shot five times at each eyeball. Subsequent CT scans were performed as above.

Results

Experiment I

Table 1 shows the plain film and CT readings of three observers for 20 metal particles. The filings were too small to measure accurately. Volumetric calculations were performed using the formula for calculating the volume of a cylinder ($v = pi \times r^2 \times 1$). The sensitivity of intraorbital metallic foreign body (IMFB) detection on plain film and CT increases with increasing volume (Table 1). The observer threshold for detecting metal particles is lower for CT (0.07 mm^3) than for plain film (0.12 mm^3). Specificity for CT and plain film was 100%. Interobserver variability for plain film and CT was analyzed with the kappa statistic. This resulted in the following: plain film, 0.929; axial CT, 0.555; and coronal CT, 0.760 (values > 0.5 = good agreement; > 0.75 = excellent agreement). Thus, in general, there was consistent interobserver performance, in particular for plain films.

TABLE 1. Detection Rate of Intra-Orbital Steel Wires by Size

Filings* to 0.04 mm^3	Undetected by coronal and axial CT; undetected by plain film
0.07 to 0.11 mm^3	Detected by axial and coronal CT; undetected by plain film
0.12 mm^3 and larger	Detected by axial and coronal CT; detected by plain film

CT: computed tomography.
*Too small to accurately measure.

Experiment II

All metal particles aligned themselves rapidly in the direction of the magnetic field when placed on the scan table at the bore opening. The particles migrated into the magnet at a velocity dependent on their size. Regardless of the liquid environment (true or artificial vitreous) the velocity for the smallest particles was barely visible, whereas the velocity of the largest particle tested was greater than 1 to 2 cm/second. Movement of the scan table into the magnet helped speed the movement of the smallest particles slightly. The response to the inward movement of the scan table into the magnet for the largest particle was not known, since they rapidly reached the wall of their containment before movement of the bed could be initiated. Three of the five eyeballs were examined pathologically for retinal tears. However, due to the in vitro condition and low retinal impact, differentiation between injury and artifact was impossible.

Experiment III

None of the three common industrial tools (bandsaw, grinder, and pressurized air hose) used in this experiment were able to drive particles through the sclera into the vitreous. CT showed that although the outer surface of the sclera was coated with metal particles, no particle passed through into the inner scleral surface, nor into the vitreous. Results of the air hose experiment showed that most particles tended to bounce off rather than penetrate the sclera.

Discussion

The need to screen patients for MRI with suspected IMFB is predicated on a single-case report. In 1986, Kelly et al[1] reported a 2.0 × 3.5-mm iron particle located in the vitreous of a sheet metal worker-lathe operator. The patient reported a decrease in vision as he was being moved out of the bore of a (0.35-T) magnet. Subsequent investigations (Table 2) attempted to address three main issues: 1) the best screening modality for MRI; 2) whether metal particles would move under the influence of a magnetic field; and 3) whether eye damage could result from movement of these particles. The inherent limitations of these experimental designs which prompted our own are stated in Table 2.

In experiment I, the greater sensitivity of CT over plain films for the detection of IMFB is to be expected in view of preceding reports.[2–5] However, interestingly, the difference in threshold volume detection between CT and plain films

TABLE 2. Key Studies Regarding Detection of Metallic Intraocular Foreign Bodies

Reference	Experimental design	Results	Comments
Lagouros et al, 1987[7]	In vitro and in vivo study of migration of ferromagnetic particles in a 2.0-T magnetic field	1. All large metallic particles tested migrated in 1.5-T magnetic field (BB, staple, screw) 2. Ocular trauma secondary to movement of particles	1. Used only large particles
Williams et al, 1988[6]	Placed ferrous particles (0.1 × 0.1 × 0.1 mm to 3.0 × 1.0 × 1.0 mm) in intraocular and intraorbital regions of rabbit eyes	1. All implanted particles detected with plain film 2. Only the largest ferrous particle (3 × 1 × 1 mm) migrated in 2-T field 3. No ocular damage secondary to the movement of ferromagnetic particles	1. Retrospective study without blinded controls 2. Rabbit model 3. Assessed for movement with direct ophthalmologic examination and radiographic methods, which may be inaccurate
Mani (presented at the 1988 Annual Meeting of the American Society of Neuroradiologists)	In vitro migration of submillimetric (0.15–3.0 mm) ferromagnetic particles in bovine eyes and radiographic detection of these particles	1. All submillimetric particles migrated in a 1.5-T magnetic field 2. CT only consistantly accurate and for detection of intraorbital and intraocular ferromagnetic foreign bodies (all sizes)	1. Bovine eyes 2. Unpublished report
Williamson et al, 1989[8]	MRI of several intraorbital and intraocular foreign bodies, some ferromagnetic (up to 20 mm)	1. No ocular injury at 0.08-T magnetic field secondary to the migration of ferrous particles	1. Used 0.08-T magnetic field

CT: computed tomography; MRI: magnetic resonance imaging.

was only 0.05 mm^3. CT could detect IMFB as small as 0.07 mm^3 versus plain film 0.12 mm^3. Among the observers, reader I showed consistency in detecting IMFB at 0.08 mm^3 on CT, and was able to detect one metal wire at this size on plain films. The same observer detected a wire on CT as small as 0.04 mm^3. The overall interobserver variability was good, as shown by a consistency of readings between readers II and III. The kappa statistic was highest for plain film (0.929), indicating consistency in interpretation of plain films by all three observers. Given these results, the next question was whether sub-plain film threshold IMFB would move when placed under a magnetic field and damage the eye.

Based on the results of other investigators it was apparent that extraocular metallic foreign bodies would move very little if at all—presumably tethered by fibrosis.[6] Also, movement in this extraocular location would probably not be as damaging to vision as the intraocular (vitreous) location. In our second experiment, all IMFBs were found to move in vitreous at a velocity dependent on size. The smallest particle tested (0.3 × 0.5 mm, sub-plain film threshold) barely moved under observation as the scan table moved in and out of the magnet. IMFB of different metal composition, ferromagnetic properties, and shape may behave differently. Of interest is the fact that steel wires (cylindrical in shape) aligned themselves rapidly to the flux lines and then moved steadily through the vitreous into the bore of the magnet. In the supine position, this would mean that a wire-shaped IMFB initially located centrally in the vitreous would first impact on the superior retinal surface away from the optic disc. But when a patient is sitting up at the bore aperture, either before or after the scan, serious damage to the sensitive optic disc could occur.

Because we were unaware of any reports concerning what size metallic particles could be expected to penetrate the scleral resistance in occupational settings, we designed experiment III. That such small particles could penetrate the sclera is crucial in deciding whether plain films would be effective screening tools. Intuitively, it appears that scleral penetration would largely depend on scleral resistance and elasticity, as well as momentum and shape of the particle. Theoretical calculations could be performed if the scleral resistance and elasticity could be accurately measured. However, the variation in conditions between in vivo and in vitro environments would invalidate any such experiment.

Metal workers comprise the majority of high-risk patients encountered; therefore, we tried to simulate the normal working environment of metal workers by exposing fresh cadaveric eyeballs to common industrial tools, namely a bandsaw, a grinder, and an air compressor hose. Under rigorous conditions, we were unable to penetrate the sclera with submillimetric particles emitted from these common industrial tools. We cannot state definitively that subthreshold-sized metallic particles might not penetrate the sclera under more extreme circumstances, such as explosion or gunshot. However, our preliminary results from experiment III would suggest that submillimetric particles smaller than the detection threshold for plain film would not penetrate the scleral resistance and therefore screening with orbital plain films would represent an adequate screening procedure in the majority of high-risk patients.

In conclusion, our results indicate that screening the majority of high-risk patients before MRI with plain film techniques is probably an adequate screening procedure in light of the evidence that particles smaller than the detection threshold for plain film were unable to penetrate the scleral resistance. Screening with plain film as opposed to CT could represent tremendous saving to the consumer. There also would be significant savings in terms of radiation dose to the lens and MRI scanner time lost secondary to rescheduling of patients, previously sent for CT screening procedures.

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Announcements

Magnetic Resonance Imaging in Spain and Morocco, June 28–July 1, 1992 (Barcelona, Spain), July 3–5, 1992 (Casablanca, Morocco), Hotel Arts a Ritz-Carlton Hotel, Barcelona, Spain, Sheraton Hotel, Casablanca, Morocco. Sponsored by Hoag Memorial Hospital Presbyterian. Credit: 28 Category 1 hours (pending). Fee: $695, complete course; $500, Barcelona only; $500, Casablanca only; residents, fellows, and technologists—$400, complete course; $300, Barcelona only; $300, Casablanca only. Contact: Dawne Ryals, Ryals and Associates, PO Box 1925, Roswell, GA 30077-1925; call 404-641-9773 or fax 404-552-9859.

11th Annual Scientific Meeting and Exhibition of the Society of Magnetic Resonance in Medicine, August 8–14, 1992, Intercontinental Hotel, Berlin, Germany. Sponsored by the Society of Magnetic Resonance in Medicine and the European Society for Magnetic Resonance in Medicine and Biology. Course Directors: Ian C.P. Smith, PhD, and Felix W. Wehrli, PhD. Contact: Jane E. Tiemann, Publications Coordinator, SMRM, 1918 University Avenue, Suite 3C, Berkeley, CA 94704; call 510-841-1899 or fax 510-841-2340.

Diagnostic Imaging Update: Body Imaging, Mammography, MRI and Interventional, July 20–23, 1992, Ritz-Carlton San Francisco, San Francisco, California. Sponsored by the Stanford University Medical Center. Credit: 20. Fee: $450; $300, residents. Contact: Dawne Ryals, Ryals and Associates, P.O. Box 1925, Roswell, GA 30077-1925; 404-641-9773; Fax: 404-552-9859.

Diagnostic Imaging Update: Body Imaging, Mammography, MRI and Interventional, July 23–26, 1992, Quail's Lodge, Carmel, California. Sponsored by the Stanford University Medical Center. Credit: 15. Fee: $400; $300, residents. Contact: Dawne Ryals, Ryals and Associates, P.O. Box 1925, Roswell, GA 30077-1925; 404-641-9773; Fax: 404-552-9859.

Radiology for Non-Radiologists, July 23–26, 1992, Hotel Del Coronado, San Diego, California. Sponsored by the University of California, San Diego. Credit 18.5. Fee: $425; $375, residents. Contact: Dawne Ryals, Ryals and Associates, P.O. Box 1925, Roswell, GA 30077-1925; 404-641-9773; Fax: 404-552-9859.

MRI and Musculoskeletal Imaging, July 27–August 1, 1992, Ritz-Carlton Resort Hotel, Laguna Niguel, California. Sponsored by Hoag Memorial Hospital Presbyterian. Credit: up to 32. Fee: $695; $425, residents. Contact: Dawne Ryals, Ryals and Associates, P.O. Box 1925, Roswell, GA 30077-1925; 404-641-9773; Fax: 404-552-9859.