Magnetic Resonance Imaging of Intraocular Tamponades

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ABSTRACT
The efficacy of proton magnetic resonance imaging in differentiating vitreous from $C_3F_8$ gas and silicone oil tamponades, and in detecting fresh hemorrhages and condensed vitreous was tested in rabbits in vivo. The results suggest that this imaging method could provide a useful alternative to ultrasonography, especially in eyes with opaque media.

Intravitreous gas\textsuperscript{1,2} and silicone oil\textsuperscript{3,4} injection have been used as intraocular tamponades for the treatment of severe retinal detachment. However, after the gas or silicone oil has been injected, it is difficult to monitor these tamponades with ultrasonography, because significant imaging artifacts arise due to refraction and attenuation of the sound wave by the gas or silicone oil.\textsuperscript{5} Other imaging modalities therefore must be adopted or developed to monitor these procedures. One of the most promising is magnetic resonance imaging (MRI), which has become an important research and diagnostic tool in ophthalmology, since it can provide detailed anatomical, biophysical, and biochemical information about ocular tissues.\textsuperscript{6} Several proton MRI studies have investigated vitreous changes.\textsuperscript{7-11} Recently, Gross et al.\textsuperscript{12} after using MRI to monitor six patients with intravitreal silicone oil, concluded that the technique was promising. To further explore the use of MRI in the evaluation of intraocular tamponades, we tested the capability of proton MRI of rabbit eyes in vivo injected with perfluoropropane gas ($C_3F_8$) or silicone oil to document the presence and the course of disappearance of gas, as well as the location of silicone oil and hemorrhages.

MATERIALS AND METHODS

$C_3F_8$ Injection
Seven New Zealand white rabbits of both sexes (body weight: 2.5 to 3.0 kg) were used. Anesthesia was achieved with an intramuscular injection of ketamine (200 mg/kg), chlorpromazine (25 mg/kg), and 0.5% proparacaine eye drops. Both pupils were dilated with 10% phenylephrine and 1% tropicamide, and the eyes were examined by slit-lamp biomicroscopy and indirect ophthalmoscopy to ensure the absence of abnormalities.

The rabbits were then restrained in the dorsal position, and 0.4 mL of 100% $C_3F_8$ gas (PCR Research Chemicals, Gainesville, Fla) was injected into the center of the vitreous cavity of one eye through a sterile 0.45-$\mu$m filter (Millipore, Bedford, Mass) with a 30-
The eye on the left had been injected with C₃F₈ gas, which expanded and filled the whole vitreous cavity. No signals were detected in this region, except at the gauge needle positioned 1 mm from the corneal limbus. The anterior chamber was not tapped following the gas injection. Polymyxin sulfate ophthalmic ointment was then instilled under the fornices.

Magnetic Resonance Imaging

Silicone Oil Injection

Four days after intravitreous injection of C₃F₈, five rabbits were anesthetized and secured on the operating table in a lateral position. A peritomy was created at the 10 to 11 o'clock meridian of one eye, and a sclerotomy site was prepared 1 mm from the limbus. Using a surgical contact lens (MIRA, Waltham, Mass) and an operating microscope (Zeiss), the C₃F₈ bubble was replaced with 1 mL of 1000-centistoke silicone oil (KOKEN, Tokyo, Japan). The sclerotomy and peritomy sites were closed with separate 8-0 nylon sutures, and polymyxin sulfate ointment was applied to the conjunctiva.

Magnetic Resonance Imaging was performed 2 weeks following the intravitreous injection of silicone oil. In two cases, 0.5 mL of blood was drawn from the ear vein of the rabbits. After 0.4 mL of aqueous humor was drained from the limbus, 0.5 mL of autologous blood was injected into the center of the vitreous cavity, 1 mm from the limbus. MRI was performed again immediately after this injection.

Postoperative Procedures

Both the operated and unoperated eyes were examined using slit-lamp biomicroscopy, including fundus examination with a noncontact 90-diopeter lens, and indirect ophthalmoscopy daily for 1 week immediately after the operation and then again weekly.

MRI

Proton MRI was performed with a General Electric (Milwaukee, Wis) Signa 1.5-tesla body scanner using spin-echo and gradient-echo pulse sequences, both of which are standard imaging sequences. The pulse sequences and MR parameters, including TR (repetition time), TE (echo time), and tip angles are detailed in the figure legends. The in-plane resolution was 0.47 × 0.47 mm, with an image matrix of 256 × 256. Slice thickness was 3 mm for all sequences.

Results

C₃F₈ Injection

Maximal expansion of the gas bubble occurred by the 3rd day after C₃F₈ injection, at which time the vitreous cavity was completely filled with the gas. The gas bubble then gradually diminished until it was completely absorbed (approximately the 4th week).

Figure 1 shows the MR images of gas-injected rabbits 4 days after injection. In the spin-echo T1-weighted image of the control eye (Fig 1A), the anterior chamber, iris-ciliary body, lens, and vitreous cavity are clearly seen, with no pathology. In the gas-injected eye, most of the vitreous cavity, which the expanding gas then occupied, exhibited no signals; in the lower part of the cavity, however, the compressed vitreous gel could still be seen. In the T2-weighted image (Fig 1B), the vitreous cavity (except for the compressed vitreous of the
gas-injected eye) again showed no signals.

Figure 2 shows the images of the same rabbit 1 month after C₃F₈ injection. The T1-weighted spin-echo image (Fig 2A) of the control eye did not differ from that obtained 1 month before (Fig 1A). However, in the gas-injected eye, the signal-void area decreased, indicating gas reabsorption. The refilled vitreous cavity otherwise appeared normal. However, in the gradient-echo image (Fig 2B), the vitreous appearance was different: a high-signal-intensity region was seen in the center of the vitreous cavity. This is consistent with the finding, based on slit-lamp biomicroscopy and indirect ophthalmoscopy, that the condensed vitreous gel extended from the optic disc to the ciliary body. Slit-lamp examination also showed that there was more liquefied vitreous around the condensed vitreous. Further, the gradient-echo image with low tip-angle showed multiple rings surrounding the gas bubble (Fig 2C). By contrast, the vitreous cavity of the control eye appeared relatively homogeneous.

Silicone Oil Injection

The rabbits underwent MRI 2 weeks after silicone oil injection. In the T2-weighted spin-echo image (Fig 3A), three regions were clearly visualized with the following features:

- In the upper part of the vitreous cavity there was a low-signal-intensity region, corresponding to the gas bubble.
- In the middle part, the high-signal-intensity region corresponding to the silicone oil had, in addition, a bright band to the left and a dark band to the right of the silicone oil area.
- At the bottom of the eye, an intermediate-signal-intensity region was observed, corresponding to the refilled vitreous cavity.

Figure 3B shows a T1-weighted spin-echo image of the same rabbit immediately after the intravitreous injection of autologous blood, which entered both silicone oil and vitreous regions. The fresh blood
FIGURE 3: (A) Spin-echo image (TR/TE = 2000/90 msec) showing, from top to bottom, gas, silicone oil (with chemical-shift artifacts), and the vitreous gel (eye on the right). (B) Spin-echo image (TR/TE = 500/20 msec) of the same rabbit after intraocular injection of 0.5 mL fresh blood (arrowheads), which appears in the silicone oil and continues into the vitreous as a region with a T1 shorter than that of either silicone oil or vitreous.

demonstrated T1's shorter than those of either the silicone oil or the vitreous and is readily recognized (arrowheads).

DISCUSSION

Since C$_2$F$_8$ (or other gases) produces no MR signals, its presence in the eye can easily be detected (Fig 1). The only other ocular tissue that does not produce any significant signals is the lens nucleus (because it has extremely short T2's). Further, in gradient-echo images, because of magnetic susceptibility specific to this imaging sequence, multiple rings are seen accentuating the gas bubble (Fig 2C). Since the lens nucleus does not exhibit such phenomena, it can easily be distinguished from the gas bubble.

Detection and differentiation of silicone oil is also facilitated by the presence of chemical-shift artifacts surrounding the silicone oil region, particularly with T2-weighted imaging (Fig 3A). This phenomenon is caused by the so-called "chemical-shift effect," which can be explained as follows: MRI is essentially a mapping of proton signals, the majority of which are from water. Protons from silicone oil molecules resonate at a frequency slightly different from that at which water-protons do (in NMR spectroscopy terms, the former resonate at 4.35 ppm, while the latter do so at 4.75 ppm). The silicone oil image is therefore "shifted" in the present case to the left of its actual physical position. In effect, the image is "cut out," moved slightly to the left, and superimposed on the remaining eye image. The net result is the appearance of a bright band (because of signal contribution from both the vitreous and silicone oil) and a dark band that has no signals. This chemical-shift effect is not seen in ocular lesions such as fresh intraocular hemorrhages, which also have a short T1. By itself, the short T1 also can be used to distinguish blood from vitreous (Fig 3B).

Overall, MR images provide information about the status of tamponades and vitreous. They are especially useful in eyes with opaque media, and, with appropriately selected pulse sequences, they can be used to differentiate vitreous, gas, silicone oil, and hemorrhages. In cases with these components, MRI can replace ultrasonography and provide an accurate picture of the evolving clinical morphology of the eye.

MRI of the eye is still in its infancy; micro-imaging and three-dimensional image reconstruction techniques are currently being developed in our laboratory. These techniques will allow calculation of tissue/lesion volume and resolution of retina-vitreous interaction.

Although the present high cost of MRI prevents its widespread use, it is worth noting that ocular imaging using surface coil signal receivers typically requires less scan time than brain scans. For example, a 0.5 to 2 min/eye with T1-weighted imaging, and in our experience, a total machine time of 10 to 20 minutes, is needed to scan both eyes. By contrast, the brain requires multiple scans lasting 45 to 60 min/session.

REFERENCES

2. Thresher RD, Ehrenberg M, Machemer R. Gas-mediated


