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Ocular MR Imaging: Evaluation of Different Coil Setups in a Phantom Study

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Purpose: Small loop surface coils are generally recommended for ocular magnetic resonance (MR) imaging, but the optimal coil setup has not been systematically investigated. In this phantom study, we investigated which coil setup of those coils available for our MR imaging system provides the highest signal-to-noise ratio (SNR) in ocular MR imaging at 1.5 tesla.

Materials and Methods: Using a phantom to simulate the eyeball and the orbital fat, we employed loop surface coils of 4- and 6-cm diameter and a multi-channel head coil to obtain images using a T₁-weighted spin-echo sequence and then measured the SNR for each coil and coil combination.

Results: Use of the 6-cm loop coil alone yielded the highest mean SNR (27.5). Even in superficial regions (mesial and temporal), the SNR was higher using the 6-cm loop coil (33.6 and 45.5) than the 4-cm loop coil (28.0 and 33.8). Additional use of the head coil reduced the mean SNR to 10.4.

Conclusion: This quantitative analysis suggests that use of a 6-cm loop surface coil offers the best results in ocular MR imaging. Combinations of loop coils or additional use of a head coil cannot be recommended because higher noise degrades image quality.

Keywords: *coil, ocular MRI, signal-to-noise ratio*

Introduction

Magnetic resonance (MR) imaging of the eye is used to diagnose various pathologies involving the eyeball. Ocular MR imaging is indicated to investigate unclear ophthalmoscopic findings, such as retinal hemorrhage, retinal detachment, and unclear opacity of the globe. Its particular utility for assessing retinoblastoma before therapy has been reported.¹ Some institutions use ocular MR imaging to plan proton-beam therapy in uveal melanoma,² the most common primary intraocular tumor in adults.³ Rare diseases of the eye bulb, such as staphyloma/coloboma, may also require ocular MR imaging.⁴

Furthermore, MR imaging is indicated in most patients with orbital masses and can aid assessment of the extent of tumors and inflammatory lesions.⁵ Exophthalmus might be the first alarming symptom prompting further investigations. In the absence of incompatible metal, MR imaging can be useful in addressing traumatic damage to orbital content. It is a promising method in the evaluation of orbital wall fractures,⁶ even in occult blow out fractures⁷ or in children.⁸

The use of small coils is recommended for ocular MR imaging.⁹ A head coil can also be used to examine orbital content and has been found useful for comparing structures in the 2 orbits.^{10,11} Previous studies indicated that use of the appropriate coil is decisive in the success of orbital MR imaging.¹⁰ Earlier results also suggest that the use of a high resolution microscopy coil dramatically improves

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image resolution, enabling detailed assessment of the structures of the orbit and globe.¹²

However, we believe no study has systematically investigated which of the different standard surface coils and coil combinations used for MR imaging of the eyeball and orbital space provides the optimal signal-to-noise ratio (SNR). In particular, the additional use of a head coil has not been evaluated.

We performed this phantom study to determine which coil setup of the available coils of our MR imaging system provides the highest SNR in ocular MR imaging at 1.5 tesla.

Material and Methods

Phantom and MR imaging data acquisition

We simulated the eyeball with surrounding orbital fat using a lime pressed into a container of butter. The spherical-shaped lime consisted of approximately 90% water, 10% carbohydrates, and less than 1% proteins and fat and was chosen to reflect the high water content of the vitreous humor of the human eyeball. The butter, as a water-in-oil emulsion, consisted of 80% fat (26% of which was saturated). The lime was positioned in the butter to mimic the anatomic position of the globe within the orbital fat. The 4.5-cm diameter of the lime, larger than an average-sized eyeball, permitted us to measure the SNR of orbital structures adjacent to the eyeball. We acquired MR imaging scans on a 1.5T system equipped with a gradient system with maximum gradient amplitude of 45 mT/m and maximum slew rate of 200 mT/m/ms (MAGNETOM Avanto, Siemens Health Care Sector, Erlangen, Germany). After acquisition of a localizer scan, a T_1 -weighted spin echo (SE) sequence with 4-mm slice thickness was acquired in axial orientation using the following parameters: repetition time (TR), 500 ms; echo time (TE), 11 ms; matrix, 256×256 ; field of view (FOV), 120×120 mm; number of excitations, one; and bandwidth, 250 Hz/pixel. This sequence was acquired twice for each coil/coil combination to generate subtraction images to calculate noise. We acquired 5 images of the phantom and chose the slice intersecting the center of the lime for SNR measurements.

Coils and coil combinations

We investigated the following coils: a single-channel small loop surface coil of 4-cm diameter (small loop coil); a single-channel medium loop surface coil of 6-cm diameter (medium loop coil); an array of two 6-cm loop coils arranged perpendicular to each other (double loop array coil) (tem-

poromandibular joint coil, Siemens Health Care Sector, Erlangen, Germany); and an 8-channel circular polarized head coil (CP head array coil).

The two 6-cm loop coils in perpendicular orientation did not operate in a quadrature detection mode because both elements were connected to separate receive channels. This coil configuration resembles a phased array coil with 2 receive coil elements.

We placed the surface coils directly on the container of butter to simulate the position of the coil on the face of a patient. When multiple coils were used simultaneously, separate images were reconstructed from each coil or, in the case of the head coil, from each coil element in addition to an image reconstructed from all coils/all coil elements. The double loop array coil is not compatible with the head coil. Therefore, the following coil setups and combinations were technically possible and used for the phantom measurements.

The first test arrangement consisted of a small loop coil (Fig. 1), medium loop coil (Fig. 2), double loop array coil with both elements used for signal detection (Fig. 2), and small loop coil and circular polarization (CP) head array coil with all elements used for signal detection (Fig. 1)

The second test arrangement consisted of a double loop array coil with only the superior element used for signal detection and a double loop array coil with only the temporal element used for signal detection.

The third test arrangement consisted of a small loop coil and CP head array coil with only the closer head element used for signal detection, a small loop coil and CP head array coil with only the farther head element used for signal detection, and

Fig. 1. Experimental setup of the phantom and the small loop coil as well as the setup with the small loop coil and the head coil. The large circle represents the lime. We placed 4 regions of interest (ROIs) in the lime.

Fig. 2. Experimental setup of the phantom and the medium loop coil as well as the setup with the double loop array coil. We positioned the elements superior and temporal to the phantom.

Fig. 3. T_1 -weighted spin-echo image of the phantom with the 4 regions of interest (ROIs) for calculation of signal-to-noise ratio (SNR).

a small loop coil and CP head array coil with only the small loop element used for signal detection.

Although the eyeball or orbital space would not be imaged using only the farther element of the head coil in the clinical setting, we used it here as a control for our experimental setup. In all cases, the built-in body coil was used for radiofrequency (RF) excitation with all receive coils detuned.

Quantitative image analysis

We calculated SNRs to identify the coil setup providing the highest image quality. We placed 4 regions of interest (ROI) of identical size (1.5 cm^2) in the pulp of the lime separated by the central column of lime (superficial mesial, superficial temporal, deep mesial, and deep temporal) (Fig. 3) and then measured the distances from the center of each ROI to the superior and temporal surface of the phantom. The loop surface coils were positioned adjacent to the surface of the phantom.

We measured the signal intensity (SI) of each ROI, and we measured the SI of noise and the standard deviation of noise (N) on the subtraction images using the same 4 anatomical ROI positions and size as we used to calculate SI on the unsubtracted images. We calculated the mean SI from all ROIs in the images obtained twice for noise calculation.

We calculated the SNR of each ROI as $\text{SNR} = \text{mean SI} / \text{N}$ of the noise and finally calculated the mean SNR from the four ROIs.

We acquired *in vivo* ocular images with a T_1 -weighted spin-echo pulse sequence using the small loop coil, medium loop coil, and head coil.

Results

We achieved the highest mean SNR (27.5) with the medium loop coil placed on the superior surface. Mean SNR decreased to 21.7 using the double loop array coil (2 medium coils arranged perpendicular to each other, one on the superior and one on the temporal surface). The mean SNR achieved with the small loop coil (21.0) was considerably lower than that achieved with the medium loop coil (Fig. 4). The medium loop coil yielded higher SNRs (33.6 and 45.5) than the small loop coil (28.0 and 33.8) even in superficial regions (mesial and temporal).

Additional use of the head coil decreased the mean SNR to 10.4 (Fig. 4). However, the range of SNRs measured in all 4 ROIs (superficial mesial 9.8, superficial temporal 10.5, deep mesial 10.7, deep temporal 10.4) was narrower than those observed with the small and medium loop coils.

The lowest mean SNR was measured when a single element of the head coil was used (the first 2 elements of the third test arrangement; $\text{SNR} = 6.9$ and 5.7).

Table 1 summarizes the SNRs calculated for each ROI and for each test arrangement.

Table 2 delineates the distances from the center of each ROI to the superior and temporal surfaces of the phantom.

Figure 5 shows *in vivo* ocular images taken for reference.

Discussion

Our systematic phantom study of several technically possible coil setups of loop surface coils and

Fig. 4. The medium loop coil (6-cm diameter) achieved higher signal-to-noise ratio (SNR) values than the small loop coil (4-cm diameter) in each region of interest (ROI). The small loop coil yielded higher SNR values when used alone than when used in combination with the head coil.

Table 1. Signal-to-noise ratio (SNR) calculated in each region of interest (ROI) for each test arrangement

ROI/Test arrangement	1.	2.	3.	4.	3.a.	3.b.	4.a.	4.b.	4.c.
Superficial mesial	28.0	33.6	17.3	9.8	14.9	10.8	6.1	6.0	20.6
Superficial temporal	33.8	45.5	28.3	10.5	21.0	21.0	6.0	6.9	25.0
Deep mesial	10.8	13.2	12.9	10.7	7.1	10.1	7.8	5.0	8.8
Deep temporal	11.2	17.8	28.2	10.4	13.5	24.1	7.6	4.9	9.4
Mean	21.0	27.5	21.7	10.4	14.1	16.5	6.9	5.7	16.0

1. Small loop coil
2. Medium loop coil
3. Double loop array coil: both elements used for signal detection
4. Small loop coil and CP head array coil: all elements used for signal detection
- 3.a. Double loop array coil: only the superior element used for signal detection
- 3.b. Double loop array coil: only the temporal element used for signal detection
- 4.a. Small loop coil and CP head array coil: only the closer head element used for signal detection
- 4.b. Small loop coil and CP head array coil: only the farther head element used for signal detection
- 4.c. Small loop coil and CP head array coil: only the small loop element used for signal detection

the head coil for ocular MR imaging confirms the superior SNR of loop surface coils.

SNR is a criterion for image quality; high SNR may enhance visualization of ocular pathologies. Ocular tumors, such as uveal melanoma or retinoblastoma, can infiltrate surrounding tissue, such as the sclera or optic nerve. Detailed information on possible infiltration may influence patient management. Moreover, planning of proton-beam therapy in patients with uveal melanoma requires images

that delineate tumor volume as accurately as possible.

Small surface coils were used for ocular and orbital MR imaging as early as 1985,¹³ 1986 (13-cm diameter),¹⁴ 1988 (12-cm diameter),¹⁵ 1991 (13.97-cm or 5.5-inch diameter),¹⁶ and 1996 (5-cm and 4-cm diameters).^{17,18} In the literature, coils of 4- to 6-cm diameter are known as globe coils and used to examine superficial parts of the orbit and the eyeball in particular. Coils of 8- to 12-cm diameter are

called orbital coils and used to examine external eye muscles or compare structures in both orbits.¹⁰

Combining surface coils to form so-called phased arrays has been shown to improve SNR,^{19,20} but our combination of different coils was not equivalent to a phased array coil. The double loop array coil (2 medium coils arranged perpendicular to each other) decreased the SNR considerably, possibly because of coupling between the coils. In a phased array coil, the coil elements must not couple inductively. Mutual coupling results in a split of the original resonance peak of each element into 2 resonances symmetrically distributed around the original coil element resonance. With the shift in resonance frequency, the coil sensitivity and, hence, SNR decreases, which probably explains the decrease in SNR using the double loop array coil in our experiment. However, these results may differ between scanners because the SNR of multi-coil systems as

well as that of combinations of independent coils can depend on the degree of intrinsic mutual-coupling among the coil elements and the receiver design.

One main finding of this study is that the use of one medium loop coil of 6-cm diameter provided the highest mean SNR in imaging the simulated eyeball. This coil yielded a higher SNR than the small loop coil of 4-cm diameter even in superficial (mesial and temporal) regions. Therefore, the medium loop coil may be best suited for dedicated imaging of the lacrimal gland and the eyeball.

Another major finding is that the additional use of the head coil or head coil element next to the orbit considerably decreases the SNR. This finding suggests that the head coil should be turned off when images of the eye are acquired with small surface coils, such as in children with retinoblastoma when the head coil is necessary for acquiring images of the entire brain to depict trilateral retinoblastoma.¹

The lowest SNR was measured using the head coil only, suggesting that unilateral imaging of the eye and orbit using only the head coil should be discouraged based on our phantom results. The head coil is certainly useful in acquiring images of both orbits for comparison,¹⁰ such as in diseases affecting the eye muscles, like Grave's disease, and it may also be useful in patients who are very sensitive to and may not tolerate well the direct contact of the surface coil with the face.

One limitation of our study is that we had no 8- to 12-cm loop coil available for testing and comparison with the smaller surface coils. However, coils of larger diameter are expected to offer lower SNR for superficially located structures, such as the eyeball.

Our study is also limited because we did not in-

Table 2. Distance from the center of each ROI to the superior and temporal surface of the phantom. The loop surface coils were positioned directly adjacent to the surface of the phantom

Distance to (cm):	Superior surface	Temporal surface
<i>Small loop coil</i>		
Superficial mesial	2.1	3.7
Superficial temporal	2.0	2.0
Deep mesial	4.1	3.2
Deep temporal	4.0	1.5
<i>Medium loop coil and Double loop array coil</i>		
Superficial mesial	2.1	3.8
Superficial temporal	1.9	2.2
Deep mesial	4.0	3.3
Deep temporal	4.2	1.6

Fig. 5. T₁-weighted spin-echo image of a subject's right eyeball using the small loop coil (a), medium loop coil (b), and head coil (c).

investigate patients and could not therefore assess such patient-specific factors as motion artifacts to draw conclusions for patient scanning. However, our study was intended to compare several coils and coil combinations in a reproducible setting, excluding potential bias from differences in coil positioning in different patients.

Also, the magnetic field strength of our scanner was 1.5T. Previous publications indicate that an even higher SNR in ocular MR imaging can be achieved by scanning at 3T; however, higher susceptibility to motion artifacts seems to limit its clinical benefits.²¹ Few studies on ocular and orbital imaging compare use of 1.5 with 3T.^{21,22}

Conclusion

In conclusion, this quantitative analysis suggests that ocular MR imaging may be best performed using a loop surface coil of 6-cm diameter. Additional use of the head coil or combinations of loop coils is discouraged because increased noise degrades image quality.

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