Original Article

A Pilot Study on the Application of FFE and SSh-TSE Sequences in Ocular MRI

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Abstract

Purpose: To preliminarily investigate the application value of rapid sequences FFE and SSh-TSE in ocular magnetic resonance imaging (MRI).

Methods: Ocular MRI was performed in 18 subjects without ocular conditions, and demonstration of 15 delicate anatomic structures on two sequences in each subject was rated by three proficient physicians.

Results: FFE sequence was comparatively advantageous in demonstrating delicate structures on ocular wall and ocular adnexa ($P<0.001$) over SSh-TSE; while SSh-TSE sequence better revealed the delicate anatomy within anterior chamber ($P<0.001$) and optic nerve sheath ($P<0.05$), with statistically significant differences compared with FFE.

Conclusion: Optimized FFE and SSh-TSE sequences are able to effectively eliminate the impact from motion artifact and thus result in desirable images with high spatial resolution. The application of high-resolution MR microscopic imaging technique has improved the ability to demonstrate delicate ocular structures. (***Eye Science 2011;26:173-179***)

Keywords: magnetic resonance imaging; rapid sequence; ocular anatomy

Assessment of intra-orbital structures is dependent on specialized investigation approaches and imageological tools. Commonly used specialized investigation approaches include laser polarimetry, laser ophthalmoscopy, gonioscopy and slit lamp examination. Due to low resolution, they are relatively limited in the demonstration of soft tissues and ocular microstructures[1]. Imageological tools include ultrasonic biological microscopy (UBM), optical coherence tomography (OCT) and ocular MRI. The former two better demonstrate the structures in anterior segment of the eyeball, but are applicable for a limited region and produce unfavorable results in revealing entire intra-orbital structures. Ocular MRI microscopic imaging technique is characterized by high-resolution image and is advantageous by providing extensive demonstration of the entire ocular structures. However, it has not been widely used in locomotory organs due to its lower imaging rate. The development and application of rapid imaging sequences have provided good solution for the motion artifact during imaging of locomotory organs. Eye ball is an organ with voluntary locomotion, while the application of rapid imaging sequences has eliminated the impact of motion artifact and thus improved the quality of the images, such as FFE and SSh-TSE sequences[2]. Both of them have been reportedly used in the imaging of patella, neuroimaging and angiogram, middle ear, and superficial gland ducts[3-6]. This study aims to conduct ocular MRI microscopic imaging using optimized fast field echo (FFE) and single shot-turbo spin echo (SSh-TSE) sequences with MR microscopic coil, and compare two sequences regarding their imaging advantages, so as to preliminarily investigate the application value of microscopic coil in ocular imaging.

Materials and methods

The study has been approved by ethics committee. After informed consent was obtained from 18 subjects (12 men and 6 women), ocular MR microscopic imaging was acquired. The mean age was 38 years (range from 20 to 73 years). Inclusion criteria: normal visual acuity as assessed by a proficient ophthalmologist, normal ocular movement, and no ocular conditions. Main exclusion criteria: those with contraindications of MR examination, for example,

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those with residual metal foreign body or implantation of prosthesis within the eyeball or orbit, placement of pacemaker, intracranial dissecting aneurysm, metal catheter, cochlear implant or placement of vascular filtration device and metal denture; other exclusion criteria included inability to stay in supine position for more than 30 min, such as claustrophobia.

In this study, a 1.5T dual-gradient magnetic resonance scanner (Philips; Achieva) was used for the scanning with FFE and SSh-TSE sequences, with microscopic coil as receiver coil (at the diameter of 23 mm). All subjects were kept in supine position, and a small piece of gauze was placed above the eyelid of the examined eye; then microscopic coil was fixed to the gauze and placed over the eye; the eyeball remained in the center of the coil. During the scanning, the subject was asked to stare at a fixed point (which was marked on above the main magnet) with both eyes at the beginning of each sequence. There was a 10-min break between intervals, and ocular movement was avoided to the extent possible.

FFE sequence (TR/TE 1508/80; flip angle 90°; imaging matrix 512×512; FOV 40×40 mm; thickness of slice 2 mm; attempt of image acquisition 1; time of image acquisition 1.7 min) and SSh-TSE (TR/TE 1508/219; flip angle 90°; imaging matrix 256 ×256; FOV 40 ×40 mm; thickness of slice 2 mm; attempt of image acquisition 1; time of image acquisition 36s) sequence were used to collect axial, coronal and sagittal images from 18 subjects, with microscopic coil as receiver coil (at the diameter of 23 mm). Given consideration to the unintentional ocular movements in the volunteers, FFE and SSh-TSE sequences were particularly optimized by modifying some of the technical variables (reducing FOV and number of excitation and increasing imaging matrix), so as to effectively shorten time of image acquisition without compromising signal-to-noise ratio of the images. If images resulted from the scanning were substantially impacted by motion artifact, image acquisition might be repeated after a short break for the subjects, until optical images were obtained.

Imaging evaluation and statistical analysis

The ability of FFE and SSh-TSE sequences to demonstrate delicate ocular structures in 18 normal subjects was rated respectively. MR signal intensity was rated for different delicate structures with signal intensity of extra-ocular muscle as a control. A total of 15 delicate anatomic structures were evaluated, including pre-iris structures (5 structures: tarsal gland, cornea, iris, anterior chamber angle, and pupil), post-iris structures (8 structures: sheath of the eyeball, ligamentum suspensorium, ora serrata, conora ciliaris, lens, sclera, optic nerve sheath, and vitreous body) and para-iris structures (2 structures: lacrimal gland and extra-ocular muscle). The demonstration of these 15 microstructures was rated into 4 grades (1 point: not revealed; 2 points: vaguely revealed; 3 points: basically revealed; 4 points: clearly revealed) by two proficient imageologists and one proficient ophthalmologist. The ultimate scores must be agreed on by all three physicians.

Statistical analysis

SPSS13.0 software was used in the statistical analyses by rank-sum test for the ability of two sequences to demonstrate 15 pre-iris/post-iris/para-iris structures. $P<0.05$ was considered to indicate statistical significance.

Results

Demonstration of ocular microstructures with FFE and SSh-TSE sequences

Delicate ocular anatomic structures were well revealed as compared to the signal intensity of extra-ocular muscles. With FFE sequence, the structures that presented low signal intensity on T_1WI were: cornea, sheath of the eyeball, ora serrata, and sclera, among which the sheath of the eyeball presented the lowest signal intensity; the structures with high signal intensity included tarsal gland, zonula ciliaris, corona ciliaris, lens and lacrimal gland, among which tarsal gland had the highest signal intensity (Figures 1~3). Ciliary body was located between the root of the iris and the choroid, the anterior 1/3 segment of which was thicker, regarded as ciliary process; it presented slightly high signal intensity on T_1WI with FFE sequence due to its abundant vasculature. The serration at the junction of pars plana and choroid was named as ora serrata, which mainly formed by ciliary epithelial cells, and was clearly demonstrated on T_1WI coronal image with FFE se-

quence. Retina on the inner surface of choroid was revealed on some of the slices (presenting low signal intensity).Structures that presented low signal intensity on T_2WI with SSh-TSE sequences were: iris, anterior chamber angle, pupil, and corona ciliaris; structures with high signal intensity mainly included optic nerve sheath and vitreous body (Figures 4 and 5). Optic nerve was a part of the central nervous system, encapsulated by a layer of optic neurilemma, which was the continuation of three layers of meninges and was filled with cerebro-spinal fluid. It was quite identifiable on axial T_2WI image with SSh-TSE sequence (presenting high signal intensity). A radial ciliary body was seen (presenting low signal intensity) on coronal T_2WI images with SSh-TSE sequence.

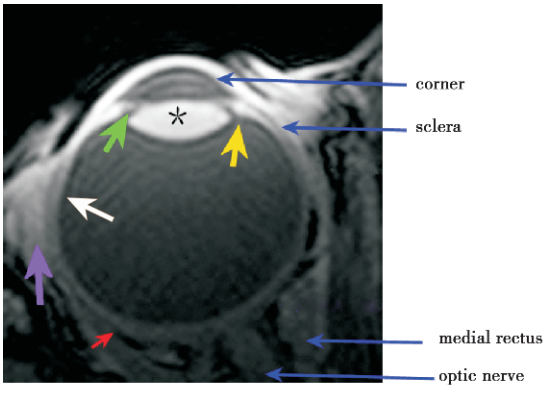

Figure 1 Axial FFE sequence T_1WI HR-MR image .The layers of the globe wall are depicted, as well as pars plicata (yellow arrow), iris (green arrow), retina (white arrow) Tenon's capsule(red arrow), Lacrimal-gland(purple arrow), lens(asterisk).

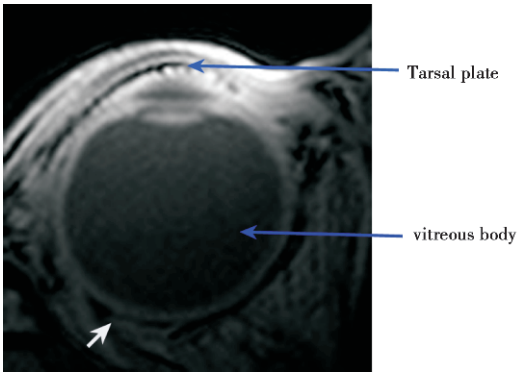

Figure 2 Axial FFE sequence T_1WI HR-MR image. The layers of the tarsal plate are depicted

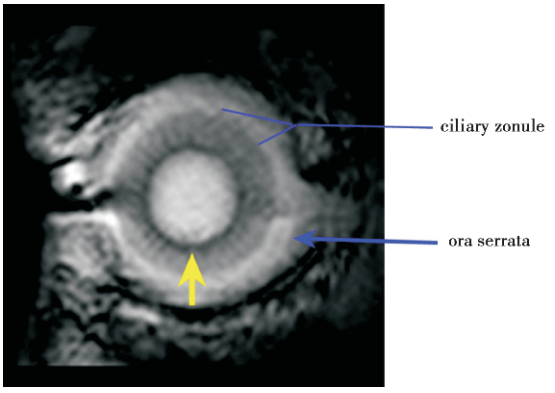

Figure 3 Coronal FFE sequence T_1WI HR-MR image. The layers of the ocular wall fine anatomy are depicted.iris (yellow arrow)

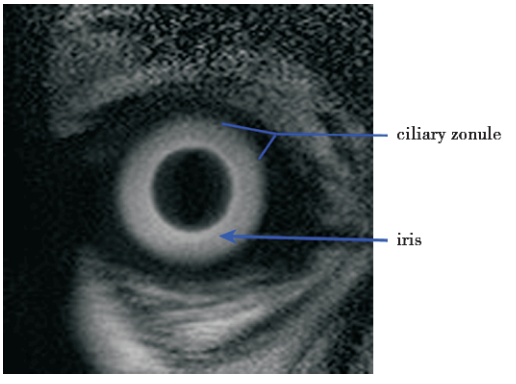

Figure 4 Coronal SSH-TSE sequence T_2WI HR-MR image. The layers of the ocular wall fine anatomy are depicted.

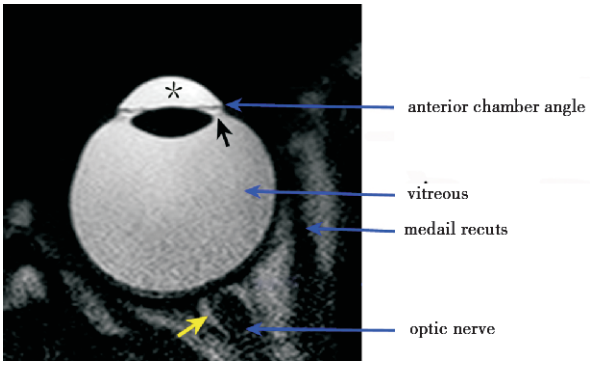

Figure 5 Axial SSH-TSE sequence T_2WI HR-MR image. The structure of anterior chamber are depicted, as well as iris (black arrow) and anterior chamber angle, optic nerve sheath (yellow arrow), anterior chamber (asterisk).

Comparison between FFE and SSh-TSE sequences on their advantages in revealing delicate ocular anatomy

When analyzing the scores obtained by two se-

quences in terms of tissue demonstration, statistical results (Tables 1 and 2) showed that both sequences were capable of revealing delciate ocular anatomic structures. FFE sequence better demonstrated cornea ($Z=-5.609$, $P<0.01$), tarsal gland ($Z=-5.290$, $P<0.01$), sheath of the eyeball ($Z=-5.291$, $P<0.01$), ora serrata ($Z=-5.315$, $P<0.01$), corona ciliaris ($Z=-4.806$, $P<0.01$), sclera ($Z=-5.551$, $P<0.01$) and lacrimal gland ($Z=-5.916$, $P<0.01$). However, SSh-TSE sequence presented advantages in revealing iris ($Z=-3.898$, $P<0.01$), anterior chamber angle ($Z=-5.775$, $P<0.01$) and optic nerve sheath ($Z=-2.258$, $P<0.05$). No significant differences were noted in the demonstration of vitreous body, lens, pupil, zonula ciliaris and extra-ocular muscle.

Table 1 Comparison on statistics grade result between FFE and SSH-TSE sequences

Location	FFE sequence mean-score	SSH-TSE sequence mean-score	Vulation of Z	Vulation-of P
Pars plicata	2.38	1.00	–4.806	<0.01
Ciliary-zonule	2.83	2.50	–0.095	0.94
Ora serrata	3.33	1.00	–5.315	<0.01
Optic-nerve-sheath	1.83	2.67	–3.174	<0.05
Lens	4.00	4.00	0	1.00
Vitreous	4.00	4.00	0	1.00
Tarsal- gland	3.05	1.00	–5.290	<0.01
Anterior-chamber-angle	2.00	4.00	–5.775	0.988
Extraocular muscle	3.38	3.44	–0.036	<0.01
Lacrimal-gland	4.00	1.00	–5.916	<0.01
Iris	2.72	3.33	–3.898	<0.01
Cornea	3.22	1.11	–5.609	<0.01
Sclera	3.22	1.11	–5.551	<0.01
Pupil	2.22	1.17	–4.925	<0.01
Tenon's capsule	3.22	1.00	–5.291	<0.05

Legends to chart

Abbr. PP-pars plicata, CZ-Ciliary-zonule, LE-lens, TG-Tarsal-gland, EM-Extraocular muscle, SCL-sclera, OS-ora serrata, ONS-Optic-nerve-sheath, VIT-vitreous, ACA-Anterior-chamber-angle, LG-Lacrimal-gland, IR-iris, COR-cornea, P-pupil, TP-Tenon's capsule.

Discussion

With continuing progress in the technology of coils, microscopic coil has been increasingly used in clinical settings. Plane resolution of ocular MRI scanning has evolved from originally 0.4 to 0.1 mm

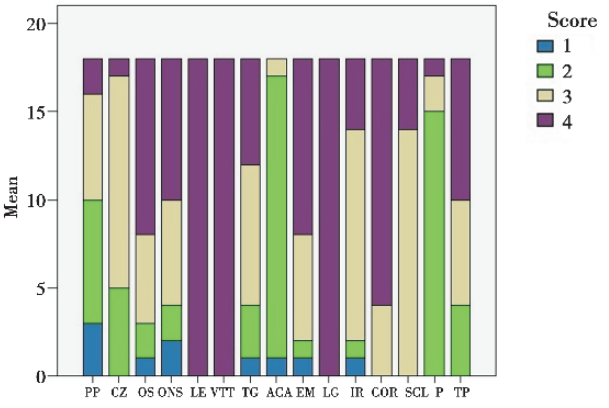

Chart 1 The display case of orbit fine anatomy of FFE sequence

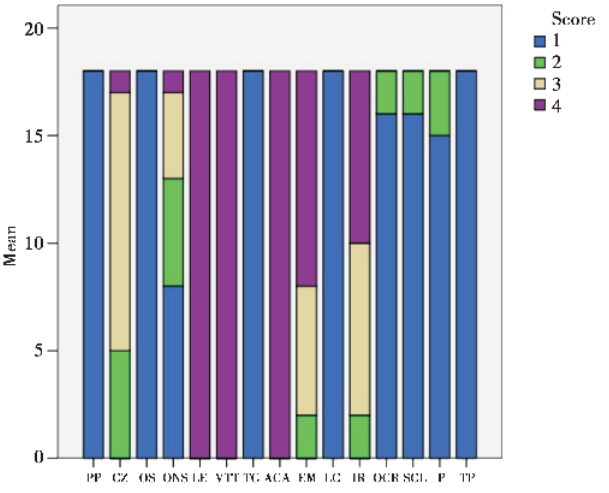

Chart 2 The display case of orbit fine anatomy of SSH-TSE sequence

by now. Based on the size, microscopic coils can be classified into larger coils (with a diameter of 47 mm) and smaller coils (with a diameter of 23 mm). The application of microscopic coil has narrowed down the scope and the depth of imaging, making it suitable for small-FOV imaging of superficial structures, which would require better signal-to-noise ratio. Previous study has proven the application of microscopic coil in high-resolution MRI can provide better demonstration of superficial anatomic structures, and has been used in the eye, gland ducts, small joints of the extremities, patella, and fibrocartilage complex[6-11]. A large amount of available studies have shown the application of microscopic coil can significantly improve spatial resolution and signal-to-noise ratio of the images as compared to regu-

lar surface coil, making it advantageous in revealing delicate ocular anatomy[12-15]. In this study, a smaller coil with a diameter of 23 mm was used as receiver coil, which was more proper for small-FOV imaging as compared to 47 mm microscopic coil by providing high spatial resolution and better identification of delicate structures on the eye wall.

In recent years, MR microscopic coil has been increasingly used in the orbit.To better demonstrate orbital anatomic structures, some scientists have attempted to introduce conventional spin echo (SE) sequence[12,13], and rapid acquisition with relaxation enhancement (RARE) sequence[15] into ocular microscopic imaging. Georgouli et al and Theodora et al[12,13] utilized conventional SE sequence in ocular microscopic imaging, and confirmed that some of the delicate structures were well revealed on ocular layers. However, since it took longer time to acquire images with conventional SE sequence, much motion artifact was caused, leading to substantial impact on the quality of the images. In addition, a larger FOV was used in their investigations, so that it was not possible to explicitly reveal some structures on the wall of the eyeball.SSh-TSE sequence has been adopted in this study.Serving as a rapid imaging sequence, SSh-TSE can thus overcome the shortcomings of conventional 2D-TSE sequence, including longer scanning time, more motion artifact and lower spatial resolution. As a result, acquired images present less distortion. RARE sequence is also a rapid imaging sequence, with scanning variables that are basically the same as the ones used in SSh-TSE sequence. Tanitame et al used RARE sequence to evaluate the characteristics of anatomic structures in anterior segments (including position and thickness of the lens, position and shape of the iris, depth of anterior chamber and magnitude of anterior chamber angle) and yielded results generally consistent with those from gonioscopy; therefore, they believed RARE sequence could well assess the alteration in the structures of anterior chamber before surgery in patients with glaucoma[15]. However, only one sequence was used by the scientists in this study, whereas this sequence was not quite competent in revealing post-orbital structures, and was highly susceptible to individual error. An SSh-TSE sequence was used for the MR microscopic imaging in this study, thus FOV was reduced as appropriate (40×40 mm) and imaging matrix modified to 256×256; it turned out that the quality of the images was not compromised. Assessment of structures in anterior chamber showed that the structures including iris, anterior chamber angle and lens were well revealed, and results of imaging were generally consistent with those reported in a previous literature[15]. Statistical results confirmed it was better than FFE sequence in terms of demonstrating structures within anterior segment ($P<0.05$). Furthermore, this sequence could well identify delicate retro-ocular structures, such as optic nerve sheath ($Z=-2.258$, $P<0.05$), which have never been described in previous literatures. Due to the interference from the high signal intensity of anterior and posterior chambers and the lens, as well as the circular low signal intensity around the eyeball, delicate anatomic structures on the wall of the eyeball were not explicitly revealed, and the normal relationship between the sheath and the wall of the eyeball was basically unidentifiable, which was similar to those reported in previous study[2].

FFE sequence imaging is characterized by sensitivity to the signal of tissues, with high signal-to-noise ratio in acquired images. In addition, it can provide evident tissue contrast for tissue containing more fluid in a shorter repetition time, thus explicitly demonstrating delicate structures[6]. Richdale et al used FFE sequence to obtain 3D ocular microscopic images, and confirmed the advantages of using microscopic coil in revealing delicate ocular anatomy (vitreous body, structures of anterior chamber, and ciliary body) under high field intensity[2]. But 7TMR scanner increased the impact of motion artifact on the quality of images while increasing signal-to-noise ratio in the images, when compared to regular 1.5T scanner. In addition, the usage of certain surface coil as signal receiver would gradually reduce the signal-to-noise ratio of retro-ocular image, and consequently retro-ocular structures were poorly revealed. In this study, an optimized FFE sequence was used, together with a microscopic coil (a diameter of 23 mm), which was better for small-FOV imaging, in order to improve spatial resolution, shorten scanning time, and increase signal-to-noise ratio of the im-

ages and thus better identify some of the delicate structures on the wall of the eyeball. Our study clearly demonstrated the corona ciliaris (presenting slightly high signal intensity due to its abundance of vasculature), which was located at the anterior 1/3 segment of the ciliary body, and ora serrara (low signal intensity) at the junction of pars plana and choroid. The demonstration of these delicate structures have not been described in previous literatures. The structures including cornea, sclera, tarsal gland, sheath of the eyeball and zonula ciliaris were equally clearly revealed ($P<0.05$); retina was located between the choroid and the vitreous body; due to the interference by the high signal intensity of choroid, retina was poorly revealed in previous study[2]. In this study, however, FOV was modified to 40 × 40 mm and imaging matrix modified to 256×256, retina was seen on some slices.

Motion artifact remains an important factor associating with the quality of image. Although retro-ocular anesthesia is a feasible approach to reduce motion artifact and to obtain better image, it is an invasive approach[16]. Obata et al suggested that motion artifact in the images could be effectively reduced by asking the patients to stare at a fixed point during the scanning[14]. FFE and SSh-TSE sequences serve as rapid MR imaging sequences. In current study, subjects were asked to stare during the examination, and great efforts were taken to reduce the number of excitation and to shorten scanning time. All subjects were highly cooperative during the scanning, and thus motion artifact had little impact on the quality of the images. The quality in all images was satisfactory, and no subject was excluded due to poor quality of the images.

Still, this study was inadequate in the following aspects. First of all, there is no specific criterion that could be used to rate the definition of the demonstration of delicate ocular anatomic structures, and the scoring of the demonstration was susceptible to subjective factors. Secondly, the study results were positively related to how cooperative the subjects were, that is, they were subject to individual errors.

Study results show that FFE and SSh-TSE sequences have respective advantages in displaying delicate structures. As a non-invasive investigation, ocular MR microscopic imaging technique is characterized by high-resolution image, extensive demonstration of the entire ocular structures, and explicit visualization of delicate ocular anatomic structures as compared to other imageological techniques. Therefore, it is capable of providing valuable objective evidence for the diagnosis of ocular diseases.

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