In vivo 7.1 T magnetic resonance imaging to assess the lens geometry in rabbit eyes 3 years after lens-refilling surgery

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PURPOSE: To evaluate the utility of high-resolution magnetic resonance imaging (MRI) in assessing the normal and refilled lens geometry in rabbits after lens-refilling surgery.

SETTING: University of Rostock, Rostock, Germany.

DESIGN: Experimental study.

METHODS: High-resolution ocular MRIs were acquired (7.1 T ClinScan) using a 2-channel coil with 4 coil elements and T2-weighted turbo spin-echo sequences (slice thickness 700 μm, field of view 40 mm × 40 mm) in rabbits after lens refilling surgery combined with intraoperative treatment to prevent lens epithelial cell proliferation. Single slices were used to assess the refilled lenses 3 years postoperatively.

RESULTS: The entire geometry (cross-sectional area, radius of curvature, axial and equatorial diameters) of the crystalline and refilled lenses was visualized by in vivo 7.1T MRI 3 years postoperatively (in-plane resolution: 125 μm × 125 μm). In refilled eyes, the capsule and the homogenous silicone polymer remained in close contact with no visible interface. The dimensions of the refilled lens were significantly smaller than those of the crystalline lens of the contralateral eye.

CONCLUSIONS: High-resolution MRI allows in vivo visualization and analysis of the spatial arrangement of the lens in rabbit eyes after lens refilling surgery and overcomes a number of major limitations in the quantitative evaluation of the lens shape. Further efforts are required to optimize the amount of polymer injected during lens refilling to achieve a predictable refractive outcome after lens refilling surgery.

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One of the ultimate challenges in cataract surgery is to restore accommodation. Although lens-refilling procedures with flexible polymer have the potential to bring progress in this field,[1] their success has been hampered by a variety of difficulties. These include phacoemulsification through a microcapsulorhexis, sealing the microcapsulorhexis, variability in lens dimenions,[2] and secondary cataract formation resulting in loss of elasticity of the refilled lens capsule. In particular, lens capsule volumes vary widely from patient to patient. High-precision control when injecting a flexible polymer also poses significant challenges.[1] Only the optimum amount of polymer will allow adequate lens refilling and yield the necessary changes in lens curvature for accommodation.[3]

During follow-up after lens-refilling procedures, it is essential to be able to assess the refilled lens shape without anamorphic distortion. Advances in anterior segment imaging modalities have been significant in recent years, especially with the advent of ultrasound biomicroscopy (UBM),[4] Scheimpflug imaging,[5] and optical coherence tomography (OCT).[6] However, these methods have major limitations when used to evaluate the shape of the entire lens after lens-refilling surgery. The iris pigment is an obstacle when attempting to view the important structures of

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the lens equator in all optical methods except UBM. However, UBM is vulnerable to distortion due to different sound velocities in different ocular and related media. In summary, all acoustic and light-detection methods are subject to image distortion by the intervening surfaces and require mathematic remodeling.[7]

Magnetic resonance imaging (MRI) is a valuable tool in the field of medical imaging. The eye is an ideal tissue for MRI because of its wide variation in water content. Magnetic resonance imaging relies solely on uniform field strength to give true anatomic proportions. Increasing the field strength of the static magnetic field (high field) results in an improved signal-to-noise ratio. This is associated with enhanced spatial resolution and a shorter scanning time. A larger static magnetic field can be achieved by enlarging the magnet or by reducing the internal magnet diameter. Typical diameters for a small-animal high-resolution magnetic resonance imager are 5 to 30 cm. Therefore, although access to high-field magnetic resonance technology is limited at present, especially for use in humans,[8,9] small-animal high-resolution magnetic imaging units are opening new horizons in experimental intraocular imaging.

The goal of the present study was to use MRI with a 7.1 T device to assess the lens geometry in rabbit eyes after lens-refilling surgery and to compare this with the lens geometry in the unoperated contralateral eye. In the refilled eyes, pharmacologic treatment of the capsular bag was performed to prevent secondary cataract development.

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MATERIALS AND METHODS

The Ethics Committee, University of Rostock, approved this study. Animal experiments were performed in compliance with the Association for Research in Vision and Ophthalmology Statement for the Use of Animals in Ophthalmic and Vision Research.

Lens-Refilling Surgery

Polymer lens-refilling surgery was performed in eyes of New Zealand white rabbits (aged 12 to 15 weeks). The rabbits were anesthetized with a mixture of 30 mg/kg ketamine hydrochloride and 5 mg/kg xylazine hydrochloride. Before surgery, the pupil was dilated with tropicamide (Mydrum) and phenylephrine hydrochloride ophthalmic solution (Neo-Synephrine 10.0%). A 3.0 mm clear corneal incision was created. Heparin–natrium 5000 (heparin sodium 5000 IU/0.2 mL) was injected into the anterior chamber, followed by an injection of sodium hyaluronate 1.0% (Healon). A clear corneal paracentesis was created with a 15-degree microsurgical knife. A high-frequency capsule opening device (Oertli Instrumente AG) was used to create a peripheral continuous curvilinear minicapsulorhexis with a diameter of 1.5 to 2.0 mm approximately 2.0 to 3.0 mm from the equator. Endocapsular phacoemulsification was performed using a Megatron I-Plus and a P2 handpiece (Geuder AG), with infusion through a second paracentesis into the anterior chamber. This was followed by bimanual capsule polishing.

The empty capsular bag was treated with a drug-loaded solution to prevent secondary cataract development (see below). As a preparatory step, sodium hyaluronate 2.3% (Healon5) was injected into the anterior chamber to protect the corneal endothelium. The drug-loaded ophthalmic viscosurgical device (OVD) solution used to lyse and/or kill the lens epithelial cells (LECs) was then injected to inflate the capsular bag. After 5 minutes the drug-loaded solution was carefully aspirated bimanually using the phacoemulsification device. A purpose-designed silicone membrane plug[10] with a diameter of 2.7 mm was inserted in the capsular bag through the capsulorhexis. The empty capsular bag was filled with the polymer through the capsulorhexis beneath the plug by inserting a 25-gauge cannula into the bag and injecting the refilling polymer until the surgeon judged that the capsular bag was completely filled. The cannula was retracted and the plug was positioned to close the capsulorhexis. The OVD was flushed from the anterior chamber with saline solution via the incisions.

Both incisions were sutured with 10-0 nylon, and the anterior chamber was reinflated with injected saline solution. Finally, all rabbits received a subconjunctival injection of gentamicin 40 mg/mL–gentamicin 10 mg/mL (Refobacin) as well as prednisolone acetate (Inflanefran Forte) and ofloxacin (Floxal) for 14 days.

Slitlamp examination and photographic documentation were performed under general anesthesia (using the protocol described above) after 1, 3, and 6 months and then every 3 months up to 3 years postoperatively. The corneal endothelium was analyzed using in vivo confocal laser scanning microscopy (CLSM) (Heidelberg Retina Tomograph II + CLSM, Heidelberg Engineering GmbH). After a 3-year follow-up, a 7.1 T MRI was performed in vivo.

Refilling Polymer

A silicone-based tercopolymer was used for lens refilling. This material does not float because its density is slightly