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ORIGINAL ARTICLE

Remote manipulation of intraocular lenses using a magnetic field

Amir Sternfeld[1], Yoav Nahum[1,2]

[1]Department of Ophthalmology, Rabin Medical Center, Beilinson Hospital, Petach Tikva, [2]Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel

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Address for correspondence:
Yoav Nahum, Department of Ophthalmology, Rabin Medical Center, Beilinson Hospital, Petach Tikva 4941492, Israel.
Tel: +972 3 9376101; Fax: +972 3 9376104.
E-mail: yoav.nahum@gmail.com

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Abstract

Aim: The aim of this study was to evaluate the feasibility of non-contact manipulation of intraocular lenses (IOLs) using a remote magnetic field.
Materials and Methods: The present experimental *ex vivo* study was performed at a university medical center. A small neodymium iron boron (NdFeB) ferromagnetic chip was attached to a one-piece polymethylmethacrylate IOL with cyanoacrylate glue. The lens was manipulated using a bar-shaped and toroidal NdFeb magnet outside and inside of an artificial anterior chamber. The lens was then implanted in the capsular bag of a porcine eye that had undergone extracapsular lens extraction. A magnetic field was applied, and attempts to manipulate the lens in various directions were documented.
Results: While in the capsular bag, the IOL was successfully moved and rotated in all directions and axes of movement from a distance of up to 1 cm. The use of a bar-shaped magnet resulted in a more controlled movement than the use of a toroidal magnet. Manipulation of the lens into the ciliary sulcus was also successful. Approaching the magnetic chip with the handheld magnet from a close distance resulted in abrupt and unpredictable movements.
Conclusions: Ferromagnetic IOL can be remotely manipulated by an external magnetic field. The application of this concept may potentially enable non-invasive post-operative adjustment of IOL, particularly toric IOL. The design of devices for this purpose should take into account the non-linear increase in the force exerted by the magnetic field as the distance from the magnet decreases.

Introduction

Cataract removal and intraocular lens (IOL) implantation surgery holds some pitfalls that might hinder the attainment of desired refractive and visual acuity results. These include, for example, incorrect biometric measurements with consequent erroneous IOL power and lens mislabeling. Importantly, improper lens positioning or orientation can lead to misalignment of toric IOLs around the visual axis,[1] decentration of monofocal and, particularly, multifocal IOLs,[2,3] post-operative lens tilt,[4] and frank lens subluxation or dislocation.[5] Indeed, the introduction of toric and multifocal IOLs in recent years, together with growing patient expectations to be spectacles-free postoperatively, has increased the need for a novel means of controlled post-operative adjustment of IOL implants.

Various invasive and non-invasive adjustable-IOL technologies have been developed for this purpose, including light-adjustable lenses, liquid crystal IOLs with wireless control, and modular multicomponent IOLs.[6] In 2003, Matthews *et al.*[7,8] suggested the use of a magnetic field for the remote adjustment and readjustment of monofocal IOLs. They applied a screw-like mechanism in which an inner ferromagnetic cylinder containing the optic part of the lens was magnetically rotated inside an outer ring that contained the haptics. In this manner, the lens could be advanced or retracting to its desired anteroposterior location.[7,8] However, the concept was abandoned thereafter.

In a previous report, our group described the magnetization and remote manipulation of posterior corneal lamellar grafts.[9] The present complementary study describes our initial experience with the manipulation of a ferromagnetic IOL using a magnetic field.

Materials and Methods

Ferromagnetic IOL preparation and manipulation

A chip of a neodymium iron boron (NdFeB) magnet was attached with cyanoacrylate glue (Liquiband Optima, AMS plc, Cheshire, UK) to a one-piece polymethylmethacrylate (PMMA) lens (13.5 mm overall length; BAL-65, Hanita Lenses, Kibbutz Hanita, Israel), at the haptic-optic junction. The lens was placed on a rigid surface and manipulated with the use of a handheld NdFeB N48, epoxy-coated, sintered bar magnet and another toroidal magnet (T.M.M., Motion and Magnetic Technologies, Ramat Gan, Israel). The procedure was repeated using a second chip and one or two bar magnets. Manipulations were also carried out after placing the IOL inside a single use artificial anterior chamber (Horizon DSAEK system, Refractive Technologies, Cleveland, OH) filled with balanced salt solution (BSS). All manipulations under the different conditions were qualitatively documented.

Preparation of enucleated porcine eyes for *ex vivo* IOL manipulation

The *ex vivo* study was performed at a university medical center using an enucleated porcine eye (Lahav Research Institute, Kibbutz Lahav, Israel). The eye was fixed to a rigid platform for standard extracapsular cataract removal. Briefly, after dissecting the superior conjunctiva, a 6-mm scleral tunnel was made using a crescent knife. An anterior chamber maintainer connected to a BSS-filled bottle was put through a paracentesis placed at 6 o'clock. The anterior chamber was entered and filled with a blue-staining solution (VisionBlue, DORC, Exeter, NH) and later replaced by a cohesive ophthalmic viscosurgical device (OVD; Healon, AMO, Libertyville, IL). A capsulorhexis was created, and the lens was extracted using a vectis under BSS flow. Crystalline lens remnants were aspirated from the capsular bag which was then filled with the OVD, and the IOL was implanted through the scleral tunnel using forceps. The scleral tunnel was closed with 10–0 nylon sutures. Manipulations were attempted with a bar-shaped magnet and qualitatively documented.

Results

Preliminary studies

After the ferromagnetized PMMA, IOL was placed on a rigid surface, and it was remotely rotated with a bar-shaped handheld magnet around its yaw axis and then attracted from a distance of about 2 cm. The lens rotation was smooth, reversible, and well controlled [Video 1]. We then tried to manipulate the lens using a toroidal handheld magnet, but this resulted in a fragmented and uncontrolled movement.

Thereafter, a second chip was glued to the second optic-haptic junction, and the same manipulations were attempted using one and then two identical bar-shaped magnets. This time we did not achieve controlled rotation of the lens but rather an unpredictable attraction toward the handheld magnet.

The second chip was detached from the lens, and the lens was placed inside a BSS-filled artificial anterior chamber. By holding a bar-shaped magnet at a distance of 1–2 cm from the lens, we were able to reproducibly generate lens rotation about the yaw axis and upward, tilt, and sideways movements. Similar attempts using a toroidal magnet resulted in uncontrolled and unpredictable movements. Therefore, the toroidal magnet was not used in the *ex vivo* experiments.

Ex vivo studies

We performed extracapsular lens extraction on an enucleated porcine eye and implanted the magnetic lens in the capsular bag, as described in methods. The cornea, facing upward, was approached from the side at the iris plane with the bar-shaped magnet from a distance of about 1 cm. Clockwise rotation of the IOL was easily and reproducibly achieved. Slight decentration and tilt movements toward the magnet were seen at the time of lens rotation [Video 2]. An effort to generate counterclockwise rotation was not successful, and at one point, as the magnet got closer to the lens, it was abruptly attracted and tilted toward the magnet [Video 3]. Thereafter, the lens was successfully manipulated into the ciliary sulcus by placing the magnet at a point diagonal to the limbus. The lens was easily rotated in the sulcus. Again, at closer proximity to the lens, it was sharply attracted to the magnet [Video 4].

On an attempt to repeat the above-mentioned manipulations using a toric IOL, we found that the induction of a clockwise rotation inside the bag and in the ciliary sulcus was more difficult and required closer proximity of the external magnet. Rotation, when achieved, was slower and therefore felt more controlled and precise.

Discussion

There are, at present, no non-invasive means to postoperatively adjust the refractive properties, position, and orientation of an implanted IOL. Although researchers developed a magnetically adjustable IOL based on a mechanically adjusted design already in 2003, the concept of magnetic attraction for the purposes of IOL manipulation failed to mature into clinical practice.[7,8] In the present work, we made a standard IOL ferromagnetic by adding a NdFeB particle on top of it and examined its behavior under remote manipulation by another magnet.

So far, the use of magnets in intraocular surgery has been limited to the retraction of ferromagnetic foreign bodies. On the one hand, intraocular cataract surgery appears to be an ideal platform for remote magnetic manipulation: The small working distances allow for the use of weaker and, therefore, safer magnets, and the transparency of the media permits continuous direct visualization of target tissues and objects during surgery. On the other hand, the actual magnitude and direction of magnet-assisted movement are a product of the force generated by complex magnetic fields, the friction between the manipulated object and its surroundings, gravity, and other factors. Moreover, magnetic attraction dramatically increases as the working distance decreases,[10] making the remote manipulation of intraocular objects less controllable and predictable than direct manipulation.

In the small confines of the anterior chamber, one abrupt movement of a rigid object can damage the iris, corneal endothelium, capsular bag, or zonular apparatus. Therefore, any use of intraocular magnetic attraction should include some mechanism compensating for its non-linear nature. This can be attained, for example, by complex real-time magnetic steering systems already utilized for the navigation of intravascular catheters.[11]

Interestingly, we found that the toric IOL tested in this study was more stable and resistant to abrupt movements and attraction to the external magnet when it was positioned in the bag or ciliary sulcus. This can probably be explained by the design of the toric IOL which was intended to minimize its post-operative rotation so that it remains aligned in the correct axis. Thus, repositioned toric IOLs could be a feasible option for magnetic manipulation, as they seem to be safer and allow for more accurate rotation. Moreover, they may serve as a potential tool for assessing post-operative stability by manufacturers of toric IOLs.

Another concern is the way by which an IOL could be magnetized. Ideally, the magnetic element of the lens, be it external or integrated, should be non-toxic, immunologically inert, and MRI-safe and should not interfere with the geometric and optical lens properties. Our results suggest that at least, for the purpose of lens rotation, a single magnetic element positioned at the optic-haptic junction could be a constituent of future design.

Our study is limited by its qualitative nature. Furthermore, only one lens design and only one method of magnetization were tested. We believe remote magnetic manipulation holds promise as a novel tool for the post-operative adjustment of IOLs. This work should serve as a basis for future studies of this surgical modality using the present and other designs.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Authors' Contributions

Study concept and design: Nahum and Sternfeld. Acquisition, analysis, or interpretation of data: Nahum and Sternfeld. Drafting of the manuscript: Nahum and Sternfeld. Critical revision of the manuscript for important intellectual content: Nahum and Sternfeld. Administrative, technical, or material support: Nahum and Sternfeld. Study supervision: Nahum and Sternfeld.

References

1. Visser N, Bauer NJ, Nuijts RM. Toric intraocular lenses: Historical overview, patient selection, IOL calculation, surgical techniques, clinical outcomes, and complications. J Cataract Refract Surg 2013;39:624-37.
2. Soda M, Yaguchi S. Effect of decentration on the optical performance in multifocal intraocular lenses. Ophthalmologica 2012;227:197-204.
3. Baumeister M, Bühren J, Kohnen T. Tilt and decentration of spherical and aspheric intraocular lenses: Effect on higher-order aberrations. J Cataract Refract Surg 2009;35:1006-12.
4. Avadhani K, Shakunthala A, Thirumalai SM, Prakash G. Tale of a twist: Progressive postoperative intraocular lens tilt from a twisted haptic. J Cataract Refract Surg 2015;41:1111-3.
5. Leon P, Pastore MR, Zanei A, Umari I, Messai M, Negro C, *et al.* Correction of low corneal astigmatism in cataract surgery. Int J Ophthalmol 2015;8:719-24.
6. Ford J, Werner L, Mamalis N. Adjustable intraocular lens power technology. J Cataract Refract Surg 2014;40:1205-23.
7. Matthews MW, Eggleston HC, Hilmas GE. Development of a repeatedly adjustable intraocular lens. J Cataract Refract Surg 2003;29:2204-10.
8. Matthews MW, Eggleston HC, Pekarek SD, Hilmas GE. Magnetically adjustable intraocular lens. J Cataract Refract Surg 2003;29:2211-6.
9. Nahum Y, Barliya T, Bahar I, Livnat T, Nisgav Y, Weinberger D, *et al.* Remote manipulation of posterior lamellar corneal grafts using a magnetic field. Cornea 2013;32:851-4.
10. Phelan A, Petocz P, Walsh W, Darendeliler MA. The force-distance properties of attracting magnetic attachments for tooth movement in combination with clear sequential aligners. Aust Orthod J 2012;28:159-69.
11. Di Biase L, Fahmy TS, Patel D, Bai R, Civello K, Wazni OM, *et al.* Remote magnetic navigation: Human experience in pulmonary vein ablation. J Am Coll Cardiol 2007;50:868-74.

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