Visual Optics and Biophotonics Lab.

A summary of our research in 2006-2007

The **mission** of the Visual Optics and Biophotonics Lab is the development of non-invasive techniques to study the optical and structural properties of the eye, and their application to the understanding of the biological mechanisms in vision (such as the development of myopia, accommodation or presbyopia), the early diagnosis of ocular conditions and the evaluation and optimization of surgical and therapeutical approaches.

The Visual Optics and Biophotonics Lab is lead by Prof. Susana Marcos, and it is formed by two postdoctoral researchers, seven predoctoral researchers and three research technicians. The lab develops interdisciplinary research. The collaborations with the Institute of Applied Ophthalmobiology (Universidad de Valladolid), Associated Unit with CSIC, and the Ophthalmology Unit of the Fundación Jiménez Díaz Hospital, Madrid, are of particular mention, for the application of the techniques developed in the laboratory to conditions of clinical interest. The group also mantains other national collaborations through a "Red Temática del Ministerio de Educación y Ciencia" in Visual Optics, and múltiple international collaborations with laboratories in Europe, United States and Australia. In the 2006-2007 period, the activity of the group has been funded by Grants of the Spanish Ministerio de Educación y Ciencia (Plan Nacional & PETRI programs), Frontier Intramural Projects (CSIC PIF Program), and a European Young Investigator (EURHORCs-ESF), as well as several industrial contracts with leader companies in ophthalmic optics, at the international and national level. The research track of the group has been recognized in 2006-2007 with two prestigious distintions from the European Optical Society and the International Comission for Optics.

What have we done? During this period, the research work of the group has focused on the development of technology for the characterization of the eye's optical and structural properties, development of experimental models in vitro and in vivo, measurement of the optical and geometrical properties of the corneal in normal and myopic subjects, and in young eyes as a function of accommodation, and the characterization and optimization of visual correction alternatives (laser ablation, intraocular lenses and contact lenses).

What techniques have we worked on? In particular, we have worked on the implementation of a laser ray tracing techniques for the measurement of ocular aberrations in normal eyes and patients; a laser ray tracing system and reconstruction algorithms of the gradient index distribution in the crystalline lens, a Hartmann-Shack wavefront sensor to measure ocular aberrations in animal models, a Purkinje imaging system to measure in vivo the radii of curvature of the anterior and posterior lens surfaces, and tilt and decentration of the crystalline and intraocular lenses, a Scheimpflug anterior segment imaging system, with optical and geometrical distortion correction algorithms; an anterior segment optical coherence tomography system (for cornea and crystalline lens); and adaptive-optics system (with a wavefront sensor and a magnetic deformable mirror for the measurement and real time correction of ocular aberration), with a channel to perform psychophysical measurements; a structured-illumination microscope for the acquisition of sectioned images of the cornea in vitro, also provided with a fluorescence channel. Figure 1 shows examples of images captured with some of these systems.

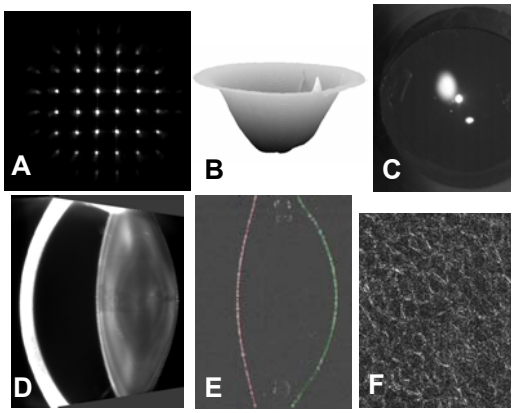

Figura 1. *A.Hartmann-Shack images captured in vivo in a chick eye with a wavefront senor. B. Image of the ablation crater in a plastic model for excimer laser ablation, obtained with non-contact microscopy-profilometry. C. Pupilary image of a pseudophakic patient (with an intraocular lens) showing the reflections from the different ocular components, obtaiend with a custom-developed Purkinje imaging system developed for phakometry and lens tilt and decentration measurements. D Anterior segment Scheimpflug image corrected for distortion, in a young subject in vivo. E. Cross-sectioned image of an intraocular lens in vitro capiured with a customed developed anterior segment optical coherence tomography system.. F.Microscopic image of the corneal endothelium in an enucleated porcine eye, captured with a custom-developed section structured-illumination corneal microscopy.*

In addition, we have set up experimental models in vitro (plastic model for corneal refractive laser ablation; physical model eye for the evaluation of intraocular lenses; in vitro porcine model for corneal biomechanics and corneal microscopy evaluation). We have also worked with animal models in vivo: form-deprivation myopia model in chicks; refractive surgery model (PRK) in chick; a wild-type mouse model (see Figure 2) and models in primates.

What basic mechanisms have we investigated? During this period, we have investigated the basic mechanisms of myopia development (a condition that affects 40% of the population in western countries). In particular, we have tested the hypothesis that ocular aberrations are a cause (or consequence) of myopia and the optical and structural changes that occur during ocular development, myopia development, and during the accommodation process.

The animal models allow longitudinal measurements in short periods, the manipulation of visual experience and cause-effect relationships in myopia development. In particular, by means of occlusion with diffusers, we have achieved ocular elongation and high-myopia in a chick model eye. We have shown that the retinal image quality increases during ocular development, both in the normal and the contralateral myopic eye. Alternatively, a refractive surgery treatment does not achieve to alter axial elongation, nor to induce changes in keratometry, although high order aberrations do increase. These results are consistent with a passive tuning of the ocular components, non-visually guided, and are indicative that aberrations are not a cause but a consequence of myopia development.

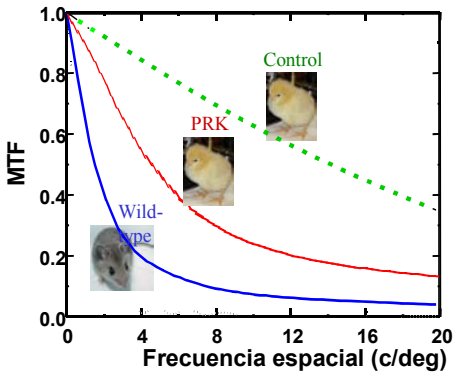

Figura 2. *Optical quality in terms of the average modulation transfer function (MTF) estimated experimentally in vivo from Hartmann- Shack high order aberrometry measurements. Data are for control eyes in a chick eye, eyes treated with PRK, and wild type untreated mouse eyes. Data are for 1-5-mm pupils. Average results from 7, 5 y 10 eyes respectively. (García de la Cera, Rodríguez, Marcos, Vision Research 2006; García de la Cera, Rodríguez, Merayo, Marcos, Vision Research 2007 y García de la Cera, Rodríguez, Schmucker, Schaeffel, Marcos, Vision Research 2006).*

Presbyopia affects 100% of the population older than 45 years. It is critical to know the dynamics of the crystalline lens to understand its aging process. We have used a primate model for accommodation and presbyopia (Rhesus monkeys) for the dynamic characterization in vivo of the geometrical changes in the crystalline lens during stimulated accommodation. In addition, we have measured the changes of the crystalline lens during static accommodation in humans (through Purkinje and Scheimpflug imaging).

What applications have we developed? The are currently no methods capable to avoiding myopia development or restoring accommodation. However, corneal refractive surgery, contact lenses or intraocular lenses are popular alternatives for correction. Our laboratory has pioneered the demonstration that spherical aberration is induced by laser refractive surgery and the identification of its causes. We have studied the effect of laser efficiency losses on corneal asphericity, in a plastic model eye, and we have proposed a method to optimize the laser ablation profiles by estimating a correction factor of those losses. Also, our lab has pioneered the evaluation of optical quality after intraocular surgery, providing the in vivo first measurements in the literature of the ocular aberrations of spherical intraocular lenses implanted in patients. More recently we have identified the relative contribution of the different factors to optical degradation in patients with IOLs: corneal incisión, lens design, lens tilt and decentration and foveal eccentric location. Individual measurements of corneal topography and ocular biometry have allowed the development of customized computer eye models in pseudophakic (Figure 3). We have also developed analytical tools for the customized design of monofocal intraocular leses (see Figure 4).

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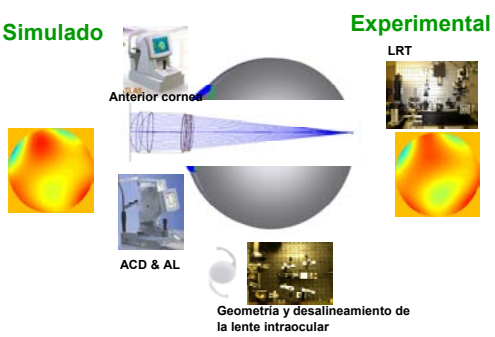

Figura 3. *Comparison of the high order wave aberration map in a pseudophakic eye, from a customized computer eye model and experimental laser ray tracing measurements on the same eye. The computer eye model incorporates experimental measurements of post-incision anterior corneal suface (Marcos, Rosales, Llorente, Jiménez-Alfaro, Marcos, JCRS 2007),in vivo tilt and decentration measurements of intraocular measurements through a Purkinje imaging system (de Castro, Rosales, Marcos JCRS 2007 y Rosales, Marcos JOSA 2006) and anterior chamber depth and axial length from optical biometry (Rosales, Marcos, Optics Express 2007)*

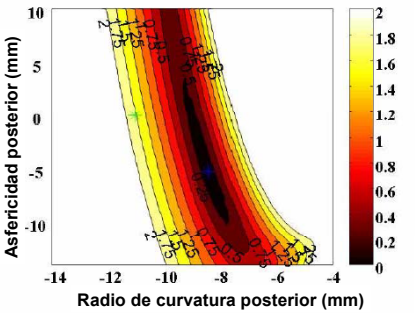

Figura 4. *Equivalent defocus map in a pseudophkic eye model as a function of design parameters of the posterior lens surface of an intraocular lens (for fixed values of the anterior surface and thickness) obtained through a new analytical tool for the design of intraocular lenses (Barbero, Marcos, Optics Express 2007 y Barbero, Marcos, Dorronsoro, Patent Application P200701217 2007, licensed to AJL Ophthalmics).*

What is next in our research program? For the new period, we have set the basis for the investigation of the visual impact of optical aberrations, the dynamic nature of ocular aberrations and the accommodation process, the role of the gradient index structure of the crystalline lens in accommodation and aging, biomechanical properties of the cornea, detection of ocular pathogens, and evaluation and optimization of ocular corrections by means of laser ablation, intraocular lenses and contact lenses.

Where to find more information (2006-2007 period)?

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