208 Crystalline Lens Dynamics and Accommodation

Monday, May 02, 2016 8:30 AM–10:15 AM
611/612 Paper Session
Program #/Board # Range: 1377–1383
Organizing Section: Visual Psychophysics/Physiological Optics

Program Number: 1377
Presentation Time: 8:30 AM–8:45 AM
Crystalline lens wobbling reveals similar accommodative ciliary muscle function in young and presbyopic subjects
Juan Taberneró, Maelle Le Gal, Emmanuel Chirre, Pedro Prieto, Pablo Artal. Laboratorio de Optica, Universidad de Murcia, Murcia, Spain.

Purpose: To investigate the activity of the ciliary muscle during accommodation as a function of age by quantification of the crystalline lens wobbling in two groups of young and presbyopic subjects.

Methods: An instrument was developed combining a high speed video recording of Purkinje images at 376 fps with a binocular open-view Hartmann-Shack sensor. Measurements of lens wobbling after forced saccadic movements were performed by analysing Purkinje images from the cornea and the lens. Accommodation dynamics was measured in a subsequent experiment by a 90 degree rotation of a hot mirror in the combined instrument, using exactly the same stimulus (two Maltese crosses subtending 1 degree), placed at infinity and at 4 D distance from the eye. Both measurements were taken under binocular unrestricted conditions. Ten young subjects (mean age 18 years old; SD 3 years) and 17 presbyopic subjects (mean age 49 years old; SD 6 years) participated in the study.

Results: The contraction of the ciliary muscle when accommodation was induced generated higher oscillations of the crystalline lens (wobbling) after forced saccades (9 degree amplitude). The increase in the amplitude of wobbling from far to near viewing conditions was found to be very similar in both young and presbyopic groups (78 ± 45 mm and 77 ± 83 mm respectively). On the other hand, the amplitude of accommodation decreased with age as expected (from 2.6 ± 0.4 D in the younger group to 1.0 ± 1.0 D for presbyopic subjects). There was individual variability, being larger in the older group. Both magnitudes, the change in the amplitude of wobbling with accommodation and the accommodative amplitude were uncorrelated. This suggests that the ability of the muscle to contract was not affected by age.

Conclusions: Crystalline lens wobbling with accommodation was similar for young and presbyopic subjects. These results support a purely lenticular-based theory of presbyopia and it might stimulate the search for new solutions to presbyopia by making use of a remaining contraction force still presented in the aging eye.

Commercial Relationships: Juan Taberneró, None; Maelle Le Gal, None; Emmanuel Chirre, None; Pedro Prieto, None; Pablo Artal, None

Program Number: 1378
Presentation Time: 8:45 AM–9:00 AM
ACCOMMODATIVE APPARATUS: MOVEMENTS IN PHAKIC AND APHAKIC EYES, INTERCONNECTIONS WITH THE VITREOUS AND PRESBYOPIA
Mary Ann Croft1, T Michael Nork1, Jared McDonald1, Gregg A. Heatley1, Elke Lütjen-Drecoll1, Paul L. Kaufman1. 1Univ of Wisconsin-Madison, Madison, WI; 2Institute of Anatomy II, University of Erlangen-Nuremberg, Erlangen, Germany.

Purpose: To further elucidate the structures involved with the accommodative mechanism and presbyopia.

Methods: In 14 rhesus monkeys (ages 6–23 yrs), maximum accommodative responses were induced by electrical stimulation of the E-W nucleus. Ultrasound biomicroscopy (UBM; 50 MHz, 35 MHz) and endscopy images were collected in the region of lens, ciliary muscle, zonular attachments and vitreous during the accommodative response. Images were collected before & after intra- or extracapsular lens extraction (ICLE, ECLE). Various contrast agents (i.e., triamcinolone) were used to enhance visualization of the intraocular structures and fluid movements during accommodation.

Results: Following ICLE, with no capsule or anterior zonular attachments to the ciliary processes (CP), CP movement velocity (0.28±0.13mm/sec; mean±sem) is reduced compared to the normal phakic eye (0.92±0.13mm/sec). Following ECLE with zonular attachments to the capsule and Wieger’s ligament remaining, CP movement velocity is increased slightly compared to the normal phakic eye. Following ICLE, with no zonular attachments to the capsule and only zonular attachments between the CP and Wieger’s ligament remaining, CP movement velocity is still robust (0.97±0.13 mm/sec).

In the normal phakic eye, continuous vitreous strands that extend from the posterior retina and attach to the pars plicata and to the pars plana were newly visualized (UBM and endscopy) and these strands move centripetally in concordance with the accommodative response. The anterior aspect of the vitreous lacunae, which extend from the central vitreous and attach peripherally to the vitreous zonule, contributes to the anterior hyaloid. The anterior hyaloid bows backward during accommodation and the compartment inside the lacunae narrows by 0.27±0.03mm. The lacunae could be part of the cistern structure reported by Jongbloed WL Doc Ophthalmol 1987.

Conclusions: The CP velocity data suggest that centripetal muscle movement can be robust in the absence of the lens/capsule so long as the zonular attachments between the CP and Wieger’s ligament are intact. The vitreous and the accommodative apparatus exhibit numerous interconnections throughout the eye – from front to back (i.e., pars plicata, pars plana, retina) and may have implications for accommodation, fluid dynamics, presbyopia and glaucoma.

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defocus. The purpose of this study was to quantify the peripheral defocus of the crystalline lens and its changes during simulation of accommodation in a lens stretching system.

**Methods:** Measurements were performed on 13 lenses from 8 cynomolgus monkey eyes obtained as part of a tissue-sharing protocol (age: 5.7 to 12.4 years, post-mortem time: 37+/−17 hours). The lenses were mounted in a motorized miniature lens stretching system (Bioniko, Miami, FL) that simulates accommodation by radial stretching. The mounted lenses were placed in a custom-built Laser-Ray Tracing (LRT) system designed to measure the lens power and aberrations on-axis and off-axis (Maceo Heilman et al, ARVO 2015). The LRT scanned a narrow 880 nm super-luminescent diode beam through the lens. An imaging sensor mounted on a motorized positioning stage below the lens recorded the spot produced by the refracted beam. Spot positions measured for 16 vertical heights along the beam were used to reconstruct the ray path and calculate lens power from the ray slopes. The LRT delivered 27 equally-spaced parallel rays over a 6-mm diameter zone along a single meridional plane. The beam delivery optics were mounted on a motorized rotation stage that pivoted around the lens to allow acquisition of off-axis spot patterns along the same meridional plane.

The lens power measured was in the unstretched and fully stretched state at incidence angles ranging from −20° to +20° in 2° or 5° increments.

**Results:** The on-axis lens power was 52.0±/-4.4D in the unstretched state and 32.7±/-6.1D in the stretched state. In both unstretched and stretched states, peripheral defocus was found to increase with increasing incidence angle. The peripheral defocus at 5°, 10°, 15° and 20° in the unstretched and stretched state is shown in Table 1.

**Conclusions:** The lens power increases peripherally. Stretching decreases the variation in power across the field. The results suggest that the lens contributes significantly to the peripheral optical performance of the whole eye and that accommodation changes the peripheral defocus of the lens.

<table>
<thead>
<tr>
<th>Peripheral defocus (D)</th>
<th>Unstretched</th>
<th>Stretched</th>
</tr>
</thead>
<tbody>
<tr>
<td>5°</td>
<td>0.2+/−1.8 D</td>
<td>−0.7+/−1.6 D</td>
</tr>
<tr>
<td>10°</td>
<td>1.3+/−2.2 D</td>
<td>1.2+/−1.3 D</td>
</tr>
<tr>
<td>15°</td>
<td>4.0+/−2.2 D</td>
<td>3.0+/−1.8 D</td>
</tr>
<tr>
<td>20°</td>
<td>9.8+/−1.6 D</td>
<td>7.5+/−2.8 D</td>
</tr>
</tbody>
</table>

Table 1: Average peripheral defocus (+/- SD).

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**Crystalline lens volume, diameter and equator estimates from OCT images: impact on future paradigms of cataract surgery**

**Purpose:** Measurement of crystalline lens geometry in-vivo is critical to optimize performance of state-of-the-art cataract surgery. To date, in-vivo accurate estimation of crystalline lens whole shape parameters is missing. In this study we estimate lens volume (VOL), equatorial diameter (Ø) and equatorial plane position (EPP). The method was validated ex-vivo and demonstrated in-vivo.

**Methods:** 27 ex-vivo human lenses (19-71 y.o) were measured and whole lens 3-D volumes were constructed from custom-developed OCT images provided with distortion correction and analysis tools. In-vivo conditions were simulated for these volumes, assuming that the only information within a given pupil size (PS) was available. A parametric model was used to estimate the whole lens shape from PS-limited data. The accuracy of the estimated shape parameters was evaluated comparing estimates from the whole lens data and PS-limited data ex-vivo. Finally, the proposed models were applied to in-vivo lens measurements in 2 young accommodating (0D-6D in 1.5D steps, PS 5mm) and 2 cataract (PS 4mm) eyes.

**Results:** Crystalline lens VOL was estimated within 96 % accuracy (mean errors across lenses ranging from 8.67±6.62 to 6.88±5.98 mm³, for 4-5 mm PS). EPP was estimated with <50 µm (errors of 42±37 to 36±32 µm). Errors in Ø were 0.24±0.20 to 0.20±0.22 mm. VOL of the ex-vivo lenses increased at rates of 1.16 mm³/year, r=0.74, P<0.001; Ø increased at 8 mm/year, r=0.39, P=0.10; and relationship EPP/thickness slightly shifts forward. Lens VOL in-vivo remained almost constant with accommodation (Ø=1±0.13, Ø=2±0.7 mm³, Ø decreased at 0.03 mm/D, r=0.95, P=0.009 and EPP shifts backward 2.5 µm/D, r=0.94, P<0.01. In the cataract eye, the estimated lens values were VOL=200.3 and 215.7 mm³, Ø=9.50 and 9.70 mm, and EPP=2.076 and 2.229 mm (distance from anterior lens) in S#1 and S#2 respectively.

**Conclusions:** Quantitative OCT with dedicated image processing algorithms allows accurate estimation of whole shape human crystalline lens parameters, as demonstrated from ex-vivo measurements, where entire lens images are available. Patient-specific eye models that include the information on lens VOL and EPP are critical for better IOL selection (based on ray tracing instead of traditional regression formulas), and will help in presbyopia-correcting paradigms including crystalline lens refilling and accommodating IOLs.

**Commercial Relationships:** Eduardo Martinez-Enriquez, None; Mengchan Sun, None; Judith Birkenfeld, None; Pablo Perez-Merino, None; Miriam Velasco-Ocana, None; Susana Marcos, PCT/ES2012/070185 (P)

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**Peripheral depth cues for accommodation stimulation**

**Purpose:** To analyze the effect of realistic images that have peripheral depth cues on the accommodative response.

**Methods:** Monocular accommodative responses (AR) at 2 D and 5 D of Accommodation Stimulation (AS) were measured with PowerRef II (Plusoptix, Inc.) when subjects looked randomly at 4 different scenes: one real scene comprising well known objects at different depth planes (real); and three virtual scenes comprised by different 2-dimensional pictures seen through a Badal lens. First image consisted on a fixation target and a white even surrounding (white); second image consisted on a photography of the real scene taken in conditions that closely mimic a healthy standard human eye performance (peripheral blur); and finally the third image was the same previous photography but rendered with a depth of focus to

**Commercial Relationships:** CARLES OTERO MOLINS1, 2, Mikel Aldaba1, 2, Bea Martínez-Navarro3, Jaime Pujol1, 2,1 Dalvar Research Center - Universitat Politècnica de Catalunya, Terrassa, Spain; 2 Centre for Sensors, Instruments and Systems Development, Universitat Politècnica de Catalunya, Terrassa, Spain; 3 Image and Multimedia Technology Center, Universitat Politècnica de Catalunya, Terrassa, Spain.

**Presentation Time:** 9:30 AM–9:45 AM

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infinite (peripheral sharpness). In all cases the field of view of the scene displayed was roughly 25° and the fixation target was a Maltese cross subtending 2°.

**Results:** 30 right eyes from healthy young subjects were measured in this study. The achieved statistical power was of 0.99. At 2 D of AS the repeated measures ANOVA did not show statistically significant differences in the AR among the 4 scenes (p>0.07) and the mean AR differences were below 0.25 D in all cases. At 5 D of AS, the repeated measures ANOVA was statistically significant (p<0.05) and the corresponding Bonferroni post-hoc tests showed the following mean AR differences ± SD (p-value) between the real scene and the virtual ones: real-white=+0.66 D ± 0.03 D (p=0.01); real-peripheral sharpness=+0.43 ± 0.03 D (p=0.07); real-peripheral blur=-0.25 ± 0.04 D (p=0.89).

**Conclusions:** It is clinically shown that accommodation is inaccurately stimulated in Badal optometers that display a stimulus poor in depth cues. Contrary, AS can be clinically accurate in the same Badal optometer when displaying a realistic image rich in peripheral depth cues, even though these peripheral cues (also referred to retinal blur cues) are shown in the same plane as the fixation target. These results have important implications in stereoscopic virtual reality systems that fail to represent retinal blur appropriately.

Photographs of the real scene projected in the Badal optometer at different distances: top left at 5 D, top right at 2 D and bottom right at 0 D of AS. The bottom left image is rendered to depth of focus to infinite (peripheral sharpness) and projected at 5, 2 and 0 D of AS.

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**Support:** DPI2014-56850-R

**Program Number:** 1382

**Presentation Time:** 9:45 AM–10:00 AM

**Is the fovea the apposite location for investigating the effect of accommodation on posterior eye conformation?**

**Parmerinder K. Randhawa¹, Miguel F. Ribeiro², Amy L. Sheppard³, Leon N. Davies³. ¹Ophthalmic Research Group, Aston University, Birmingham, United Kingdom; ²Clinical & Experimental Optometry Research Lab (CEORLab), University of Minho, Braga, Portugal.**

**Purpose:** Previous studies have investigated transient changes to axial eye length during accommodation, with the presumption that maximum eye elongation occurs along the visual axis. Yet, it is unknown whether the visual axis is the most appropriate datum to measure these changes, and whether axial elongation is consistent across the posterior eye. Consequently, this study addresses three questions: 1) does peripheral eye length alter with accommodation; 2) is the effect of accommodation on eye length homogenous across the retina; and 3) does the maximum change in eye length occur at the fovea or at another eccentric location(s).

**Methods:** Eye length measurements were obtained from the right eye of 29 participants (age 20.9 years (SD 2.10), MSE -1.34 D (SD 1.52)), consisting of 13 myopes (MSE -2.81 D (SD 0.98)) and 16 emmetropes (MSE -0.14 D (SD 0.38)) with the IOLMaster. Data for the axial length and six eccentric fixation points (5°, 15°, 25°) in both the horizontal (nasal and temporal) and vertical (superior and inferior) planes, corresponding to the central 50° (14 mm) of the posterior pole, were collected in random order, whilst subjects viewed a Maltese cross target for one minute at three accommodative demand levels (0 D, 4 D, 8 D). Corneal topography was also measured. Eye length data were converted back to optical path length using the equation OPL = (GL + 1.367)/0.7711. The data were used alongside a semi-customised eye model, based on the individual corneal topography and Navarro eye model, to compute the retinal intercept coordinates. Subsequently, the retinal sagittal height was calculated and a best conic curve was fitted.

**Results:** The sagittal height increased with accommodative effort indicating retinal stretch, which was homogenous across the posterior pole. The maximum increase to the sagittal height occurred between 7 mm nasal retina and 4.5 mm temporal retina as well as 1.5 mm in the inferior retina, rather than solely at the visual axis. The retinal sagittal height was invariant with accommodation for the whole cohort, along both meridians, although, there was a significant effect of refractive error on the axial length (F, 0.067 p=0.009), with the greatest elongation occurring within the myopic cohort.

**Conclusions:** The findings suggest that, during accommodation, the vitreous may exert pressure on the posterior pole producing the observed uniform eye elongation.

**Commercial Relationships:** Parminder K. Randhawa, None; Miguel F. Ribeiro, None; Amy L. Sheppard, None; Leon N. Davies, None

**Program Number:** 1383

**Presentation Time:** 10:00 AM–10:15 AM

**Patterns of accommodation in lens-simulated anisometropia**

Apoorva Karsolia, Lawrence R. Stark. Marshall B Ketchum University, Fullerton, CA.

**Purpose:** Accommodation in anisometropia may respond consensually and produce a yoked accommodative response, or respond independently leading to asymmetrical accommodation responses (anisoaccommodation). A prospective, randomized study was conducted to examine the effect of conflicting accommodative stimuli in isometric individuals (inter-ocular difference ≤ 0.5 D) with ±2 D lens-induced anisometropia and to assess the effects of viewing (binocular or monocular), anisometropia level, test distance and time on the patterns of the accommodative response.

**Methods:** Dynamic accommodation responses were measured in 16 young, visually-normal isometropic subjects with the Grand Seiko WAM 500 Autorefractor. In the 2 sessions, the viewing condition (monocular or binocular; direct or consensual), the testing distance (400 cm, 38.6 cm and 20.5 cm) and anisometropia level (+2 D, -2 D or no anisometropia) were randomized for each subject. In each dynamic trial, accommodation at the 5° ±0.5 second and 20° ±0.5 second was analysed to understand the patterns of the accommodative response. A within-subjects analysis of variance (ANOVA) assessed the factors in the model.

**Results:** A significant effect of target distance and anisometropia level was found in the group (p < 0.0001). Time as a factor was not statistically significant. Post hoc Tukey analyses showed that...
3 hypothesized models of accommodation (least accommodative effort, accommodation towards tonic accommodation, and accommodation driven by ocular dominance) were significantly different from the actual binocular responses (p < 0.0001), and that 3 other models (maximum accommodative effort, weighted average of two eyes, and full anisoaccommodation) were not significantly different from the actual responses. ANOVA demonstrated a more pronounced difference between the hypothesized patterns of accommodation at the near viewing distance.

**Conclusions:** In the group, three hypothesized models of accommodation were better at predicting the accommodation response in lens-simulated anisometropia. These were the strategies of maximum accommodative effort, weighted average of two eyes, and anisoaccommodation. It is possible that 3 sub-groups of subjects follow each of the 3 strategies separately. Alternatively, individual subjects might switch between the 3 strategies during extended viewing.

**Commercial Relationships:** Apoorva Karsolia, None; Lawrence R. Stark