Correlated with ciliary muscle anterior length (AL) (e.g. P < 0.001, r2
and temporal aspects, respectively, P < 0.001). AXL was positively
P < 0.001; left CM3: 0.14
mm and 0.16
mm and temporal aspects, respectively, P < 0.001; right CM3: 0.13
P < 0.001; left CM2: 0.30
mm and 0.32
mm for nasal and temporal aspects, respectively, P < 0.001; left:
3.65 ± 0.05 mm for nasal and temporal aspects, respectively, P < 0.001; left:
3.65 ± 0.35 mm and 3.88 ± 0.41 mm for nasal and temporal aspects,
respectively, P < 0.001). Temporal ciliary muscle thickness (CMT)
greater than nasal CML, in both eyes (right: 3.58 ± 0.40 mm and 3.85 ± 0.39
mm for nasal and temporal aspects, respectively, P < 0.001; left:
3.65 ± 0.35 mm and 3.88 ± 0.41 mm for nasal and temporal aspects,
respectively, P < 0.001). Temporal ciliary muscle thickness (CMT)
greater than nasal CMT at 2 mm and 3 mm from the scleral spur (CM2 and CM3, respectively) in each eye (right CM2: 0.29 ± 0.05 mm and 0.32 ± 0.05 mm for nasal and temporal aspects, respectively, P < 0.001; left CM2: 0.30 ± 0.05 mm and 0.32 ± 0.05 mm for nasal and temporal aspects, respectively, P < 0.001; right CM3: 0.13 ± 0.05 mm and 0.16 ± 0.04 mm for nasal and temporal aspects, respectively, P < 0.001; left CM3: 0.14 ± 0.04 mm and 0.17 ± 0.05 mm for nasal and temporal aspects, respectively, P < 0.001). AXL was positively
correlated with ciliary muscle anterior length (AL) (e.g. P < 0.001, r2
= 0.262 for left temporal aspect), CML (P = 0.003, r2 = 0.175 for right
nasal aspect) and ACD (P = 0.01, r2 = 0.181).

Conclusions: Morphological characteristics of the ciliary muscle in
etemetropic eyes display high levels of symmetry between the eyes.
Greater CML and AL are linked to greater AXL and ACD, indicating
ciliary muscle growth with normal ocular development.

Commercial Relationships: Richa Saigal, None; Leon N. Davies,
None; Amy L. Sheppard, None

Support: UK College of Optometrists Research Studentship (2013-
2016)

Program Number: 5997 Poster Board Number: B0146
Presentation Time: 12:00 PM–1:45 PM

Ciliary muscle morphology in emmetropia and ocular biometric correlates
Richa Saigal, Leon N. Davies, Amy L. Sheppard. School of Life and
Health Sciences, Aston University, Birmingham, United Kingdom.

Purpose: Recent studies have documented a link between axial
myopia and ciliary muscle morphology; yet, the variation in
biometric characteristics of the emmetropic ciliary muscle are not
fully known. Ciliary muscle morphology, including symmetry, was
investigated between both eyes of emmetropic participants and
related to ocular biometric parameters.

Methods: Anterior segment optical coherence tomography
(Zeiss, Visante) was utilised to image both eyes of 49 emmetropic
participants (mean spherical equivalent refractive error (MSE) ±
0.55; ≥ +0.75 D), aged 19 to 26 years. High resolution images
were obtained of nasal and temporal aspects of the ciliary muscle in
the relaxed state. MSE of both eyes was recorded using the Grand
Seiko WAM 5500; axial length (AXL), anterior chamber depth
(ACD) and lens thickness (LT) of the right eye were obtained using
the Haag-streit Lensstar LS 900 biometer. A bespoke semi-objective
analysis programme was used to measure a range of ciliary muscle
parameters.

Results: Temporal ciliary muscle overall length (CML) was greater
than nasal CML, in both eyes (right: 3.58 ± 0.40 mm and 3.85 ± 0.39
mm for nasal and temporal aspects, respectively, P < 0.001; left:
3.65 ± 0.35 mm and 3.88 ± 0.41 mm for nasal and temporal aspects,
respectively, P < 0.001). Temporal ciliary muscle thickness (CMT)
greater than nasal CMT at 2 mm and 3 mm from the scleral spur (CM2 and CM3, respectively) in each eye (right CM2: 0.29 ± 0.05 mm and 0.32 ± 0.05 mm for nasal and temporal aspects, respectively, P < 0.001; left CM2: 0.30 ± 0.05 mm and 0.32 ± 0.05 mm for nasal and temporal aspects, respectively, P < 0.001; right CM3: 0.13 ± 0.05 mm and 0.16 ± 0.04 mm for nasal and temporal aspects, respectively, P < 0.001; left CM3: 0.14 ± 0.04 mm and 0.17 ± 0.05 mm for nasal and temporal aspects, respectively, P < 0.001). AXL was positively
correlated with ciliary muscle anterior length (AL) (e.g. P < 0.001, r2
= 0.262 for left temporal aspect), CML (P = 0.003, r2 = 0.175 for right
nasal aspect) and ACD (P = 0.01, r2 = 0.181).

Conclusions: Morphological characteristics of the ciliary muscle in
emmetropic eyes display high levels of symmetry between the eyes.
Greater CML and AL are linked to greater AXL and ACD, indicating
ciliary muscle growth with normal ocular development.

Commercial Relationships: Richa Saigal, None; Leon N. Davies,
None; Amy L. Sheppard, None

Support: UK College of Optometrists Research Studentship (2013-
2016)

Program Number: 5998 Poster Board Number: B0147
Presentation Time: 12:00 PM–1:45 PM

Anatomically-accurate paraxial optical model of cymolagus lens
accommodation with continuous gradient
Fabrice Manns1, 2, Bianca Maceo Heilman1, 2, Arthur Ho1, 1, Jean-
Marie A. Parel1, 4, 1Ophthalmic Biophysics Center, Bascom Palmer
Eye Institute, University of Miami, Miami, FL; 2Biomedical Optics
and Laser Laboratory, Department of Biomedical Engineering,
University of Miami, Coral Gables, FL; 3Brien Holden Vision
Institute, Sydney, NSW, Australia; 4Vision Cooperative Research
Center, Sydney, NSW, Australia.

Purpose: To develop an anatomically-accurate model of the primate
crystalline lens with continuous refractive index gradient that predicts
the accommodative response.

Methods: We used data acquired on 6-year old cymolagus
monkey lenses (n=7, age=6.0 to 6.8 years) during simulation of
accommodation in a lens stretcher (Ehrmann et al, Clin Exp Opt,
2008). During stretching, lens power was measured with a system
based on the Scheiner principle. Anterior and posterior curvature
and thickness were obtained from cross-sectional optical coherence
tomography images (Uihlhorn et al, Vis Res 2008). An anatomical
model of the accommodating lens was created by averaging the
unstretched radii of curvature, unstretched thickness, unstretched
power, accommodation, curvature-power slope, and thickness-
power slope of the 7 lenses. The values were entered in a paraxial
lens model with continuous index gradient (Manns et al, ARVO
2008). The gradient is modeled as a set of spherical iso-indices
with radius that varies linearly from the equator to the surface. The
refractive index at the lens center and surface are set to be equal to
1.429 and 1.375 independent of accommodation (De Castro et al,
IOVS, 2013). A power-dependence is assumed for the axial index
variation: n(z)=1.429-0.054 z/tb, where t is the anterior or posterior
half-thickness. The power coefficient b was calculated so that the
accommodative response predicted by the optical model matches that
of the anatomical model.

Results: Unstretched radius: Anterior = 4.28+/0.43 mm and
posterior = 3.23+/0.11 mm; unstretched thickness = 3.91+/0.12
mm; unstretched power = 49.2+/3.6D; accommodation = 20.1+/6.1D; curvature-power slope: Anterior = 0.00646+/0.00102 mm/D
and posterior = 0.00525+/0.00097 mm/D; thickness-power slope = 0.042+/0.002 mm/D. The power coefficient increased non-linearly
from b=5.0 in the relaxed state to b=5.8 in the accommodated state.
The corresponding average/equivalent indices are approximately
independent of accommodation: 1.420/1.440 for the relaxed and
1.421/1.438 for the accommodated lens. The power coefficient,
average and equivalent index and their changes with accommodation
are consistent with results obtained using a gradient reconstruction
algorithm (De Castro et al, IOVS 2013).

Conclusions: The model with continuous gradient accurately predicts
the anatomical and optical accommodative response of cymolagus lenses.

Commercial Relationships: Fabrice Manns, None; Bianca Maceo
Heilman, None; Arthur Ho, None; Jean-Marie A. Parel, None
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Hildebrandt; the Henri and Flore Lesieur Foundation (JMP)
Experimental Protocols for Ex-Vivo Lens Stretching Tests to Investigate the Biomechanics of the Human Accommodation Apparatus

**Purpose:** To explore alternative experimental protocols to investigate the biomechanical behavior of the crystalline lens and zonules using ex-vivo stretching.

**Methods:** Radial stretching tests were conducted on the anterior segment (consisting of lens, zonules, ciliary body and sclera) of four pairs of presbyopic human donor eyes. A simple mechanical model is used to describe the behavior of the anterior segment when tested in this way. Each pair of samples was initially stretched with the ciliary body intact. One sample was re-tested after cutting the ciliary body radially and the other sample was re-tested after removing the lens.

**Results:** The external forces needed to stretch the sample with the ciliary body intact were significantly greater than for the tests in which the ciliary body had been cut. The forces measured with the ciliary body intact and lens in-situ, were comparable to the sum of the forces measured in the tests where the ciliary body had been cut (lens in-situ) and the forces measured in the tests on the intact ciliary body, with the lens removed.

**Conclusions:** When stretching tests are conducted on the anterior segment, significant circumferential tensions develop in the ciliary body. This means that the forces applied to the lens and zonules cannot be related directly to the forces applied by the external loading system. Radial cuts are introduced in the ciliary body prior to testing, however, this difficulty does not arise.

**Commercial Relationships:** Ralph Michael, None; Laura Pinilla Cortés, None; Gustavo A. Montenegro, None; Justin C. D’Antin, None; Marek Mikielewicz, None; Rafael I. Barraquer, None; Harvey J. Burd, None

Isolated human lens shape determined by tridimensional digital shadowphotogrammetry: A pilot study

**Purpose:** To examine the curvature of the anterior and posterior surfaces of isolated human crystalline lenses using a digital mini-shadowphotogrammetric system.

**Methods:** Crystalline lenses (n = 103, aged 1 month to 88 years) were isolated from eyes received from the Ramayamma International Eye Bank, Hyderabad, India. Axial thickness, equatorial diameter and surface curvatures (central 3 mm) were calculated from coronal and sagittal profiles of the lenses imaged using a custom-built shadowphotogrammetric system. The ratio of anterior radius to posterior radius as a function of age showed no age dependency (p>0.05) in both young (0.99 ± 0.24) and adult (1.51 ± 0.37) lenses, the difference between the two groups being significant (p = 0.001, Mann-Whitney test) (Fig. 2). Thickness (T) decreases from ~5.4 mm during infancy to ~4.2 mm by 5 years, and increases significantly with age from 14 to 88 years (T = 3.79 + 0.01*x, p<0.0001). The diameter shows an exponential relationship with age (y = 7.21x0.05).

**Conclusions:** The human crystalline lens anterior and posterior surface curvatures are quasi equal in very young isolated lenses. Lens curvatures stabilize around age 14.

**Commercial Relationships:** Ashik Mohamed, None; Heather A. Durkee, None; Fabrice Manns, None; Arthur Ho, None; Virenser S. Sangwan, None; Jean-Marie A. Parel, None; Robert C. Augusteyn, None

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Raksha Urs, Victor Hernandez and Andres Bernal provided technical support.
Performance of the crystalline lens in the accommodated eye of myopia
Jennifer Bruhns, Ji C. He. New England College of Optometry, Boston, MA.

Purpose: Accommodation of the eye is performed by deformation of the crystalline lens, and deficiency of the accommodation is believed to be a factor associated with myopia development. However, the lens performance during accommodation in the myopic eyes has not been well investigated. The purpose of this study was to measure optical and structural changes in the accommodated lens of myopic eyes.

Methods: A custom developed Hartmann-Shack wavefront sensor, integrated with a custom developed spectral domain optical coherent tomography (SD-OCT) system, was used to measure accommodative responses (AR) for 17 young adults (aged 21 to 39 yrs old, Rx from -0.75 D to -8.50 D with a mean of -4.50±2.44D). The wavefront sensor measured Zernike aberrations up to 7th order for the right eye when accommodative stimulation (AS) was presented for the same eye at 0.0, 2.0, 4.0 and 6.0D with a Badal system. The 840nm SD-OCT system, co-axially aligned with the wavefront sensor, was used to image the cornea and the lens.

Results: When accommodating 6D, the mean accommodative changes were 5.40±0.48D in refractive power and -0.03±0.04micron in spherical aberration. With 6D accommodation, the mean anterior chamber depth (ACD) was shortened by 0.28±0.06mm while the lens thickness (LT) was thicken by 0.31±0.07mm, and thus resulting in a backward movement of the posterior lens surface of 0.04±0.04mm. The mean anterior lens radius changed from 12.68±1.91mm at 0D to 8.99±1.69mm at 6D of accommodation. Whereas, the mean posterior lens surface was more curved. It ranged from 6.90±1.09mm in radius at 0D to 6.30±1.02mm at 6D accommodation. There was a significant correlation between the LT change and the ACD change (R² = 0.76, p<0.001).

Conclusions: Compared to a forward movement of the lens in the accommodated eye of emmetropia, as we reported in last ARVO, the lens moves backward more in the accommodated eye of myopia. The relatively more backward movement of the lens might contribute to the deficiency of accommodation in myopic eye and thus be associated with myopia development.

Commercial Relationships: Jennifer Bruhns, None; Ji C. He, None
Support: IR21EY021336

Effect of Orthokeratology on the dynamics of ocular accommodation
Yimin Yuan, YiLei Shao, Weigen Zhu, Meixiao Shen, Fan Lu. School of Ophthalmology & Optometry, Wenzhou Medical University, Wenzhou, China.

Purpose: To investigate the pattern of dynamic accommodative response of myopic eyes after orthokeratology.

Methods: Ten myopic children (mean ± SD age: 10.1 ± 2.4 years) who fitted orthokeratology lenses in both eyes were recruited. The right eye of each subject was investigated before dispensing, and 1 month, 3 month and 6 month after Orthokeratology. For each visit, accommodative stimuli was given by a Badal system. Meanwhile, dynamic accommodation was continuously recorded using Grandseiko WAM-5500 auto-refractor. Real-time imaging of the anterior segment was simultaneously performed using a custom-built ultra-long scan depth OCT based on CMOS camera. The values of accommodative response (AR), as well as anterior chamber depth (ACD), pupil diameter (PD), lens thickness (LT), anterior (LAC) and posterior (LPC) surfaces curvatures of the lenses were obtained. Then custom algorithms were developed to fit curves and to yield dynamic aspects (latency, peak velocity, and amplitude) for the changes of the above parameters.

Results: The latency of AR decreased and the peak velocity of AR increased at 3 months and 6 month after orthokeratology compared to baseline (Re-ANOVA and post hoc t-test, P < 0.01). The amplitude of AR increased at 6 month after orthokeratology (P < 0.01). For non-accommodative condition, ACD, and the radii of ASC were found significantly decreased at 1 month, 3 month and 6 month after Orthokeratology compared to baseline (P < 0.01). Meanwhile, the LT was found significantly increased (P < 0.01).

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**Conclusions:** Dynamic accommodation was improved in myopic children after Orthokeratology. The morphology of anterior eye seemed to be more “accommodative” at relax status. This may suggest that the improvement of accommodation is a key factor for myopia control using Orthokeratology.

**Commercial Relationships:** Yinmin Yuan, None; Yilei Shao, None; Weigen Zhu, None; Meixiao Shen, None; Fan Lu, None

**Support:** National Natural Science Foundation of China (Grant No. 81170869)

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**Program Number:** 6004 **Poster Board Number:** B0153

**Presentation Time:** 12:00 PM–1:45 PM

**Accommodative changes of the wavefront aberration, lens shape and ciliary muscle in the emmetropic eyes of young adults**

*Ji C. He*, Jianghua Wang, Mian C. Wei, Jing C. Mao. 1New England College of Optometry, Boston, MA; 2Bascom Palmer Eye Institute, Miami, FL.

**Purpose:** Accommodation of the human eye involves a loop of biological and optical processes, including the ciliary muscle contraction, the lens shape deformation, and the change of ocular wavefront aberrations. But, inter-relationship of the accommodative changes between different accommodative components within the loop has not been well explored. The purpose of this study was to study the inter-relationship between the different components by in vivo measuring accommodative changes of the wavefront aberration, lens shape and ciliary muscle for emmetropic young adults.

**Methods:** A Hartmann-Shack wavefront sensor, integrated with two OCT systems, was developed to measure wavefront aberrations for 15 subjects (aged 22 to 27 yrs old; Rx from -0.50 to +1.00D) during accommodation. One OCT system was used to image the lens deformation while the other was aligned for imaging ciliary muscle contraction.

**Results:** Over a 6D accommodation, mean accommodative changes were: 5.43±0.26D in refractive power; -0.083±0.027 micron in spherical aberration, 44.4±7.5 and 24.0±21.3 (m-1) in curvature of the anterior and posterior lens surfaces respectively, 0.38±0.03mm in lens thickness (LT), and 0.065±0.048mm in the difference of ciliary thickness between 1.0mm and 3.0mm from the scleral spur. For individual eye, the change in anterior lens curvature was significantly correlated to the refractive power change (mean correlation coefficient r=0.97) and also to the change in the difference of ciliary thickness (mean r=0.81). The LT was negatively correlated to spherical aberration for every eye (mean r=-0.95).

**Conclusions:** For emmetropic eye, accommodative change in refractive power is in proportion to the changes in lens curvatures, which are in turn proportionally related to the change of ciliary muscle thickness. The results provide basic information for characterizing accommodation performance and also for designing accommodative intraocular lens.

**Commercial Relationships:** Ji C. He, None; Jianghua Wang, None; Mian C. Wei, None; Jing C. Mao, None

**Support:** NEI 1R21EY021336

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**Program Number:** 6005 **Poster Board Number:** B0154

**Presentation Time:** 12:00 PM–1:45 PM

**Accommodative response to electrical stimulation of the sclera of peripheral cornea in cats and porcines**

*Toshifumi Mihashi*, Yoko Hirohara, Tomomitsu Miyoshi, Suguru Miyagawa, Hiroyuki Kanda, Hajime Sawai, Takashi Fujikado, Thomas Drew, James S. Wolffsohn. 1Innovative Research Initiatives, Tokyo Institute of Technology, Yokohama, Japan; 2Product Technology Sec., Topcon Corp., Itabashi, Japan; 3Department of Integrative Physiology, Osaka University Graduate School of Medicine, Suita, Japan; 4Department of Applied Visual Science, Osaka University Graduate School of Medicine, Suita, Japan; 5Fundamental Technology Sec., Topcon Corp., Itabashi, Japan; 6School of Life and Health Sciences, Aston University, Birmingham, United Kingdom.

**Purpose:** We have reported that the changes in the accommodative response to electrical stimulation of the sclera of peripheral cornea (SSPC) were observed in enucleated porcine eyes (Mihashi et al, VPoptics, 2014). In this study, accommodative responses to SSPC stimulation in cats and porcines were investigated.

**Methods:** Two eyes of two cats under anesthesia and after they were sacrificed were studied. Three enucleated porcine eyes obtained from a local slaughterhouse were also studied. Trains of biphasic pulses (current, 3 mA; duration, 2 ms/phase; frequency, 40 Hz) were applied using a tungsten electrode (0.3mm diameter) from several orientations. Wavefront sensing with a compact wavefront aberrometer (Uday et al J Cataract Refract Surg, 2013) were performed before and 4 s (cat) and 10 s (pig) after the stimulations and wavefront aberrations including spherical errors were analyzed over a 4-mm pupil area.

**Results:** In the first cat under anesthesia, at three out of seven stimulus positions, 0.2 D hyperopic accommodative responses were observed and in two orientations, myopic responses were observed. For the other cat, weak accommodative responses including astigmatic changes were observed. In the sacrificed condition of the second cat, 0.1 D myopic response was observed for one stimulus orientation and the smaller responses were observed at six out of eight stimulus positions. No accommodative responses were elicited for the enucleated porcine eyes.

**Conclusions:** In the anesthetized cats, electrical stimulation of the SSPC induced accommodative responses; the responses were unstable and weaker than the responses by the ciliary nerve stimulations we observed in our previous study. Small accommodative responses were observed after one of two cats had been sacrificed, but no accommodative responses were detected in the enucleated porcine eyes. Further studies are needed to confirm difference in the accommodation functions in the two species.

**Commercial Relationships:** Toshifumi Mihashi, Topcon CorpÔêª (F); Yoko Hirohara, Topcon Corp. (E); Tomomitsu Miyoshi, Topcon; Suguru Miyagawa, Topcon Corp. (E); Hiroyuki Kanda, None; Hajime Sawai, None; Takashi Fujikado, None; Thomas Drew, Johnson and Johnson (F); James S. Wolffsohn, Johnson and Johnson (F)
Comparison of three methods to measure objective amplitude of accommodation

Yunyun Chen1,2, Wanning Jin3,2, Zhili Zheng4, Bjorn Drohe5,2, Hao Chen1,2. 1. School of Ophthalmology and Optometry, Wenzhou Medical University, Wenzhou, China; 2. WEIRC, WMU-Essilor International Research Centre, Wenzhou, China; 3. R&D Optics Asia, Essilor International, Wenzhou, China.

**Purpose:** To compare objective amplitudes of accommodation measured by autorefracation associated with a motorized Badal system in static and dynamic conditions and objective minus lens technique.

**Methods:** Thirty-one young adults (age 23.35 ± 2.04 years) were enrolled in the study. Subjects’ refraction ranged from +0.25 to -6.00DS with astigmatism less than 0.50DC. Refractive errors were corrected by contact lenses. Accommodative response was measured using Grand Seiko WAM-5500 open field autorefractor. Accommodation was stimulated using a static (SB) or dynamic (DB) (speed 0.25D/s) Badal system with a high contrast distance fixation target or using minus lens technique (ML), the fixation target placed at 33 cm. Objective amplitude of accommodation was defined as difference between maximum and minimum responses for SB and DB, and as difference between maximum response and distance autorefracration for ML.

**Results:** Objective amplitudes of accommodation measured using SB and DB were similar (respectively 5.58 ± 0.85D and 5.62 ± 1.34D; p=0.80 Fisher LSD). Mean interdevice difference was SB-DB= -0.05D with 95% limits of agreement of [-1.12; 1.02] D. ML gave significantly higher accommodative responses compared to SB and DB (6.17±0.90D, p=0.05 Fisher LSD). Mean interdevice difference was ML-SB=+0.60D and ML-DB=+0.55D with 95% limits of agreement of respectively [-0.06; 1.47D] D and [-0.34; 1.44] D.

**Conclusions:** Static and dynamic Badal techniques underestimated objective amplitude of accommodation by approximately 10%, compared to minus lens technique. Minification of minus lenses and proximal cues of fixation target may be responsible for this difference.

**Commercial Relationships:** Yunyun Chen, Essilor Int. (F); Wanning Jin, Essilor Int. (F); Zhili Zheng, Essilor Int. (F); Bjorn Drohe, Essilor Int. (E); Hao Chen, Essilor Int. (F)

**Support:** International S&T Cooperation Program of China (Grant No. 2014DFA30940)

The effect of longitudinal chromatic aberration on the lag of accommodation and depth of field

Mateusz T. Jaskulski1,2, Ivan Marin-Franch1, Paula Bernal-Molina1, Norberto Lopez-Gil1,2. 1. Universidades de Murcia y Optometría, Murcia, Spain; 2. Universidad de Murcia, Instituto Universitario de Investigación en Envejecimiento, Murcia, Spain.

**Purpose:** Recently it has been proven that spherical aberration has influence over the depth of field (DOFi) and the accommodation lag. (Bernal-Molina et al., OVS, 2014). We study if the longitudinal chromatic aberration (LCA) also plays a role increasing the DOFi during accommodation, thus providing an effectively larger range of accommodation.

**Methods:** Wavefront aberration maps for three accommodative demands (AD) 0D, 2D, 4D were measured in 4 subjects using a custom-made adaptive optics system equipped with a Shack-Hartmann sensor, a deformable mirror (Mirao 52-e, Imagine Eyes), and a Badal system controlled by the subject. The accommodation was paralyzed with 2 drops of cyclopentolate (1%). The deformable mirror was then set to cancel out the paralyzed aberrations and add the ones obtained for each AD, to the end that the system simulated the optics of the accommodated eye. Subjects looked through the system including the mirror and a 5.7 mm artificial pupil at a target on an OLED microdisplay. The target consisted of 5 Sloan letters (0.1 logMAR) shown in sequence in B&W, red (R, 650nm), green (G, 550nm) and blue (B, 468nm). The luminance was in all cases constant at 12 cd/m2. By means of the Badal system, subjects indicated near and far borders of the perceived DOFi based upon the objectionable blur criterion. The DOFi of the cycloplegic eyes with all the aberrations corrected (VA < -0.3 logMAR) was also obtained in all color conditions.

**Results:** Intersubject mean values of DOFi were similar between different color conditions: for the AD of 0D we obtained 0.90±0.15D for B&W, 1.10±0.14D for R, 0.95±0.25D for G, and 0.91±0.12D for B. The mean DOFi was also stable between different simulated accommodation conditions, for example the B&W DOFi was 0.9±15D for 0D, 1.0±15D for 2D and 0.8±0.28D for 4D, and 1.0±0.10D for the fully corrected eye. The DOFi due to the chromatic aberration (the dioptric span between the outer limits of the R and B DOFi) was on average 1.9 times larger than the DOFi found for the B&W condition, for each of the AD’s.

**Conclusions:** The values of the B&W and monochromatic DOFi are similar and practically do not change for any of the simulated AD’s. However the DOFi due to the full range of LCA is nearly twice as large as the one obtained for the B&W. These results indicate that the presence of an accommodative lag should not be influenced by the presence of chromatic aberration.

**Commercial Relationships:** Mateusz T. Jaskulski, None; Ivan Marin-Franch, None; Paula Bernal-Molina, None; Norberto Lopez-Gil, None

**Support:** This work was supported by the Marie Curie ITN grant “AGEYE” 608049. Founded by an European grant ERC-2012-StG 309416-SACCO.

The dynamic accommodative response can be assessed objectively using a modified open field autorefractor. Previous studies have utilised the results of autorefraction to describe accommodative latency and lag. Accommodative facility is a subjective method, used in clinical practice for the assessment of the speed of accommodative change. This study proposes new metrics for assessing accommodative dynamics and relates these metrics to the measurement of accommodative facility.

**Methods:** Accommodative dynamics were measured using the Grand Seiko WAM 5500 autorefractor (RyuSyo, Japan) on 42 healthy adults (mean 30±8yrs, range 19–47yrs). A 4.00D accommodative stimulus was presented in 5-second cycles using the DynaWAM Badal adaption. A 4-parameter sigmoidal response function was fitted to each data set and used to determine: time taken to full accommodation (SoA) and disaccommodation (SoD), latency of accommodation (LoA) and disaccommodation (LoD). The total objective speed of accommodative change (oSoAC) was defined as:

$$\text{oSoAC} = \frac{\text{LoA} + \text{LoD}}{\text{SoA} + \text{SoD}}$$

**Program Number:** 6008 Poster Board Number: B0157

**Presentation Time:** 12:00 PM–1:45 PM

**Relationship between the subjective measurement of accommodative facility and the objective assessment of the dynamic accommodative response**

Nicola Szostek1, Hetal Buckhurst1, Christine Purslow2, Avril Collinson1, Phillip J Buckhurst1. 1. Faculty of Health and Human Sciences, Plymouth University, Plymouth, United Kingdom; 2. School of Optometry and Vision Sciences, Cardiff University, Cardiff, United Kingdom.

**Purpose:** The dynamic accommodative response can be assessed objectively using a modified open field autorefractor. Previous studies have utilised the results of autorefraction to describe accommodative latency and lag. Accommodative facility is a subjective method, used in clinical practice for the assessment of the speed of accommodative change. This study proposes new metrics for assessing accommodative dynamics and relates these metrics to the measurement of accommodative facility.

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$$\text{oSoAC} = \frac{\text{LoA} + \text{LoD}}{\text{SoA} + \text{SoD}}$$

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Results: The mean SoA: 2.45 s ± 1.32; SoD: 1.88 s ± 0.56; AF: 11.5 ± 6.5; oSoAC: 4.36 s ± 1.42; LoD: 1.04 s ± 0.50; LoA: 1.17 s ± 0.4; and sLoA: 0.93 s ± 0.41. The age of the subject was found to correlate with the measures of SoA (r = 0.339, p < 0.028), SoD (r = 0.415, p < 0.06), AF (r = 0.611, p < 0.001), and total oSoAC (r = 0.661, p < 0.001). However, neither metric for determining accommodative latency correlated with age (p > 0.05). AF showed a significant, inverse correlation with SoD (r = -0.454, p < 0.03), LoD (r = -0.325, p < 0.36) and oSoAC (r = -0.390, p < 0.11) but failed to show any significant association with SoA and both measures of accommodative latency (p > 0.05).

Conclusions: The traditional assessment of accommodative latency via accommodative dynamics did not correlate with age or AF. The novel metrics of SoD, LoD and SoAC proposed in this study correlated with both AF and age and may provide additional insight into accommodative dynamics that relate to clinical measurements and patient symptoms.

Commercial Relationships: Nicola Szostek, Bausch and Lomb (F); Hetal Buckhurst, None; Christine Purslow, None; Avril Collinson, None; Phillip J Buckhurst, Bausch and Lomb (C)

Support: Baulsh and Lomb: Unrestricted PhD grant

Program Number: 6009 Poster Board Number: B0158
Presentation Time: 12:00 PM–1:45 PM
Calculating Accommodative Optical Response in Young and Pre-presbyopic Eyes using Paraxial Schematic Eye Models
Viswanathan G. Ramasubramanian, Adrian Glasser: College of Optometry, University of Houston, Houston, TX.

Purpose: Ultrasound biomicrocopy (UBM) studies on young and pre-presbyopic subjects show that the accommodative optical response (AOR) can be predicted in a population from each UBM measured biometry parameter using linear relationships between AOR and accommodative biometry changes, with standard deviations of less than 0.55 D. Here, ocular biometry parameters measured for different accommodative states were used to construct accommodating paraxial schematic eyes (SE) to predict the AOR.

Methods: The ocular parameters measured were corneal thickness, anterior and posterior corneal radii of curvature (from OCT), anterior chamber depth, lens thickness, anterior and posterior lens radii of curvature (from UBM) and axial length (from A-scan ultrasound). UBM parameters were measured while subjects accommodated to different stimulus demands. The AOR to the same stimulus demands was measured objectively with a Grand-Seiko (GS) autorefractor. Subjects included 24 young and 24 pre-presbyopes. Paraxial SE models were constructed for all subjects for all accommodative states. Standard and iteratively calculated lens equivalent refractive index values were used. Individual SE models were also constructed for all subjects using the average change in each UBM parameter for each stimulus demand from the baseline unaccommodated state in each subject population. The AOR calculated from the SE models were compared with the GS measured AOR from each subject.

Results: The slopes and r² values of the linear regressions between individual schematic eye calculated and GS measured AOR for the young subjects were 0.77 and 0.86 and for the pre-presbyopic subjects were 0.64 and 0.55. The mean difference in AOR (GS individual SEs) was -0.27 D for the young subjects and 0.33 D for the pre-presbyopic subjects. In the individual eyes, the mean ± SD of the absolute differences in AOR between the GS and SEs for the young and pre-presbyopic subjects was 0.50 ± 0.39 D and 0.50 ± 0.37 D, respectively. For average SEs, the mean ± SD of the absolute differences in AOR between the GS and SEs for the young and pre-presbyopic subjects was 0.77 ± 0.88 D and 0.51 ± 0.49 D, respectively.

Conclusions: Individual paraxial SE models calculated from measured ocular biometry parameters offer better prediction of AOR than from individual biometry parameters in young and pre-presbyopic subject populations.

Commercial Relationships: Viswanathan G. Ramasubramanian, None; Adrian Glasser, None
Support: NIH R01 EY017076, NIH P30 EY07551

Program Number: 6010 Poster Board Number: B0159
Presentation Time: 12:00 PM–1:45 PM
Measurement of Accommodation with High Dynamic Range Using a Shack-Hartmann Wavefront Sensor and Dual Channel Accommodation Stimulus
Victor M. Hernandez¹, ², Marco Ruggeri¹, Fabrice Manns¹, ², Jean-Marie A. Pare³, ¹. Ophthalmic Biophysics Center, Bascom Palmer Eye Institute, Miami, FL; ²Department of Biomedical Engineering, University of Miami, Biomedical Optics and Lasers Laboratory, Coral Gables, FL; ³Vision Cooperative Research Centre, Sydney, NSW, Australia.

Purpose: To develop a combined Shack-Hartmann wavefront sensor and modified extended range dual-channel Badal optometer stimulus for the dynamic refractive measurement of accommodation with high dynamic range without refractive correction, and with a long working distance to allow coupling with an Optical Coherence Tomography system for simultaneous lens biometry.

Methods: We designed a system that combines a superluminescent diode emitting at 750 nm and a Shack-Hartmann wavefront sensor (WFS150-5C, Thorlabs; Newton, NJ) equipped with a 4-f relay system via a hot mirror to a two channel (far/near) accommodation stimulus (Figure 1). The 4f relay system uses f=100 mm lenses to provide a working distance sufficient to allow future combination with an anterior segment OCT system. The accommodation stimulus was designed to present a 10 D stimulus in subjects with refractive error ranging from −10 D to +6 D. The far target channel is used as a baseline and adjusted to provide a stimulus at the far point of the subject. The near target channel is adjusted manually to provide the desired amount of accommodation stimulus. The stimulus is presented via a microprocessor-controlled 1.8” liquid crystal display. Switching the displays on/off provides a step-stimulus that allows measurement of the dynamic accommodative response. The system was mounted on an adjustable motorized slit-lamp table. Preliminary experiments were performed on 4 subjects (age range: 24-49, refractive error range: -8 D+1.75 D) following an IRB-approved protocol. The accommodative response to a stimulus ranging from 0 D to -6 D in 2 D was measured for the right eye of each subject.

Results: The system was able to measure the accommodative response in all subjects when the stimulus was switched from far to near.

Conclusions: The preliminary experiments demonstrate the feasibility of the design.
Uniformity of Accommodation across the Visual Field

Tao Liu, Vidhyapriya Sreenivasan, Larry N. Thibos. School of Optometry, Indiana University, Bloomington, IN.

Purpose: Optical blur due to accommodative error in peripheral vision has been implicated in myopia development and progression. We investigated the uniformity of focusing errors over central retina as a function of accommodation demand in young adult and juvenile subjects.

Methods: A laboratory scanning wavefront aberrometer (Wei & Thibos, Opt Express. 2010;18/2:1134-43) uses rotating mirrors to pivot a laser probe beam (850 nm) about the pupil center to place a “retinal beacon” at a random sequence of 37 retinal locations over the central 27° of visual field. For each retinal location, beacon light reflected out of the eye is de-scanned by the same mirrors and then directed to a conventional Shack-Hartmann wavefront sensor for analysis. The visual stimulus was displayed on an achromatic micro-display in a Badal configuration. Aberrations were measured at 8 levels of accommodative demand (1D steps of target vergence starting 1D beyond the estimated far point). Accommodative error is the difference between target vergence and the eye’s refractive state as measured by defocus Zernike coefficient C_{0} (in diopters).

Results: For most adult subjects, ocular refractive state changed uniformly over the central visual field as the eye accommodated. Accuracy of accommodation across the visual field is similar to that measured in the fovea. Thus loss of image quality due to accommodative errors, which potentially drives myopia, will be similar across the central retina.

Conclusions: Ocular refractive state changes uniformly over the central visual field as the eye accommodates. Accuracy of accommodation across the visual field is similar to that measured in the fovea. No systematic difference between emmetropic and myopic eyes was evident.

Commercial Relationships: Tao Liu, None; Vidhyapriya Sreenivasan, None; Larry N. Thibos, None
Support: P30EY019008
A pilot study on effects of sustained accommodation on the optics of the human eye

Jason Shen, Frank Spors, Don Egan, Chunming Liu, Xiangyun Liu.

College of Optometry, Western Univ of Hlth Sciences, Pomona, CA.

Purpose: Myopia often presents and progresses throughout the school years and it has been hypothesized that high levels of near work may contribute to its development. The optics change during near work; for example, lag of accommodation might be related to myopia progression. This study is to investigate the possible changes of the optics of the eye during the sustained near work.

Methods: A commercial Shack-Hartmann aberrometer was modified to be an open field instrument in order to achieve unobstructed visual field. Twenty-one low myopes were recruited into the study with only their left eyes being measured. Subjects were instructed to watch a 15 minutes long video displayed on a computer screen placed 50 cm in front of the eyes. Measurements were taken at one minute intervals while the subjects were directed to fixate on a central Maltese Cross target. Up to six-order Zernike coefficients were recorded and analyzed. Both a small sample non-parametric signed rank test and paired t-test were used for statistical data analysis.

Results: The averaged mean spherical equivalent (MSE) refractive error decreased in the first 9 minutes at the rate of 0.06 D per minute. After 9 minutes, MSE showed more fluctuation with time. Changes of 3rd-order coma were more pronounced than changes in other higher order aberration terms. 4th order spherical aberration consistently decreased during the first 7 minutes. Compared to 2nd order defocus change, higher order aberrations had no significant impact to the changes of the optics of the measured eyes within 15 minutes of accommodation (p > 0.05).

Conclusions: The accommodation of the eye decreases first, but later shows more fluctuation with sustained near work. Optical changes in the eye with prolonged near work appear to be mainly caused by the changes in the 2nd order defocus term rather than by higher order wavefront errors in the eye.

Commercial Relationships: Jason Shen, None; Frank Spors, None; Don Egan, None; Chunming Liu, None; Xiangyun Liu, None

Program Number: 6014 Poster Board Number: B0163
Presentation Time: 12:00 PM–1:45 PM

Pseudoaccommodation in children after congenital cataract surgery and implanted with monofocal intraocular lens: incidence and mechanisms

Charlotte Marie Dénier1, Pascal Dureau2, Catherine Edelson3, Georges Caputo4. 1Hôpital Necker, Paris, France; 2Fondation Rothschild, Paris, France.

Purpose: Some pseudophakic patients implanted with monofocal intraocular lens (IOL) have good near visual acuity with their distance correction. This apparent accommodation has been called “pseudo-accommodation”. The objective of this study was to evaluate the prevalence of pseudo-accommodation in children after bilateral congenital cataract surgery, without amblyopia, and to define its mechanisms.

Methods: We included 40 eyes of 23 children aged 6 to 18, with a corrected distance visual acuity above 8/10 and a normal near visual acuity (P2) with +3 addition. We also included a group of 14 pseudophakic adults, with a corrected distance visual acuity superior to 8/10 and a normal near visual acuity (P2) with +3 addition. Pseudo-accommodation was defined as a near visual acuity better than P4 with the distance correction and without addition. Prevalence of pseudo-accommodation was calculated in each group. In order to determine the factors accounting for pseudo-accommodation in children, we compared the group of children with pseudo-accommodation with that of adults without pseudo-accommodation under several parameters: refraction, axial length, corneal topography, aberrometry, pupillary diameter, implant’s shift after cyclophotolysis measured with OCT-SD.

Results: In the children group, 36 (90%) had a near visual acuity equal to P4 without addition. Among the 28 included adults eyes, 2 (7%) had pseudo-accommodation. When we compared the 36 children eyes with pseudo-accommodation and the 26 adults eyes without pseudo-accommodation, we found that spherical equivalent, implant’s power, corneal multifocality and corneal higher-order aberrations (mainly coma and trefoil) were significantly higher in the group with pseudo-accommodation, while pupil diameter and implant’s shift were statistically the same in both groups. Axial length was smaller in the pseudo-accommodation group.

Conclusions: Pseudo-accommodation in pseudophakic children is a poor known phenomenon. With this study, we have highlighting its high prevalence among non-amblyopic children. In children no mechanism has ever really been identified. This study found several possible mechanisms to explain pseudo-accommodation in children: a high power of the IOL and a small axial length, maximizing the effect of the IOL’s shift, corneal multifocality and corneal higher-order aberrations.

Commercial Relationships: Charlotte Marie Dénier, None; Pascal Dureau, None; Catherine Edelson, None; Georges Caputo, None

Program Number: 6015 Poster Board Number: B0164
Presentation Time: 12:00 PM–1:45 PM

Accommodation in young adults wearing multifocal soft contact lenses under long- and short- wavelength lighting

Manbir Nagra1, Christine F. Wildsoet2. 1Aston University, Birmingham, United Kingdom; 2UC Berkeley, Berkeley, CA.

Purpose: Several studies have suggested accommodative lags may serve as a stimulus for myopic growth, and while a blurred foveal image is believed to be the main stimulus for accommodation, spectral composition of the retinal image is also believed to influence accommodative accuracy. Of particular interest is how altering spectral lighting conditions influences accommodation in the presence of soft multifocal contact lenses, which are currently being used off-label for myopia control.

Methods: Accommodative responses were assessed using a Grand Seiko WAM-5500 autorefractor for four target distances: 25, 33, 50, and 100cm for 30 young adult subjects (14 myopic, 16 emmetropic; mean refractive errors (±SD, D) -4.22±0.67 respectively). Measurements were obtained with four different soft contact lenses, Single vision distance (SVD), Single vision near (SVN), Centre-Near (CN) and Centre-Distance (CD) (+1.50 add), and three different lighting conditions: red (peak λ, 632nm), blue (peak λ, 460nm), and white (peak λ, 560nm). Corrections for chromatic differences in refraction were made prior to calculating accommodative errors.

Results: The size of accommodative errors was significantly affected by lens design (p<0.001), lighting (p=0.027), and target distance (p=0.009). Mean accommodative errors were significantly larger with the SV lenses compared to the CD and CN designs (p<0.001). Errors were also significantly larger under blue light compared to white (p=0.004) and a significant interaction noted between lens design and lighting (p<0.001). Blue light generally decreased accommodative lags and increased accommodative leads relative to white and red light, the opposite was true of red light (p<0.001). Lens design also significantly influenced direction of accommodative error (i.e. lag or lead) (p<0.001). Interactions with or between refractive groups were
not found to be statistically significant for either the magnitude or direction of accommodative error (p>0.05 for all).

**Conclusions:** Accuracy of accommodation is affected by both lens design and by wavelength of lighting. These accommodative lag data lend some support to recent speculation about the potential therapeutic value of lighting with a spectral bias towards blue during near work for myopia, although such treatment effects are likely to be more subtle under broad compared to the narrow spectrum lighting conditions used here.

**Commercial Relationships:** Manbhir Nagra, Coopervision (R); Christine F. Wildsoet, None

**Support:** Part-funded by an internal Aston University grant

**Program Number:** 6016 Poster Board Number: B0165

**Presentation Time:** 12:00 PM–1:45 PM

**Relationship between the subjectively and objectively determined depth of focus of the human eye using defocus curves**

**Alexander Leube**, Arne Ohlendorf, Juan Tabernero, Siegfried Wahl.

**Purpose:** The study compared the depth of focus (DoF) of the human eye, calculated from objective image quality metrics (IQM) and subjectively measured defocus curves.

**Methods:** 15 subjects with a mean age of 25.5±3.3 years and a mean spherical equivalent refractive error of M=−0.45±0.26D participated and mydrias was assessed using three drops of 1% cyclopentolate (assessed three times with 10 min between applications). Monocular subjective defocus curves (range: ±1.5D in 0.5D steps) were measured in a distance of 5m in the fully corrected dominate eye using a 4mm artificial pupil. The DoF was calculated as the dioptric range under the defocus curve at the threshold “maximum visual acuity [logMAR] + 0.1”. A commercial aberrometer (i.Profiler® Plus, ZEISS, Germany) was used to assess the ocular wavefront. The point spread function (PSF) and the optical transfer function (OTF) were analyzed of the single wavefront aberrations for a 4mm pupil, using Matlab (MathWorks, Natick, USA). The DoF was calculated using the augmented visual Strehl-Ratio of the OTF (VSOTFa) at the thresholds 80% and 50% of the maximum value as well as the visual Strehl-Ratio of the PSF (VSPSF) at a threshold of 50% of the maximum value. A two-tailed Student’s t-test was used for statistical analysis.

**Results:** Using the VSOTFa, the DoF was 0.41±0.08D for the 80% and 0.76±0.11D for the 50% threshold, while the DoF was 0.71±0.12D for the VSPSF at the 50% threshold. Subjective assessment of the DoF gave a mean value of 0.70±0.23D and showed a correlation to the individual RMS of the higher order aberrations (RMS HOA) (r=0.677, p=0.006). DoF was significantly different for 80% VSOTFa (p=0.001) and 80% VSPSF (p=0.001) compared to the subjective DoF, while the DoF at 50% VSOTFa (p=0.349) and 50% VSPSF (p=0.730) was not. Nevertheless, there was no significant relationship between the metrics and subjective measurements of DoF (50% VSOTFa r=0.20; 50% VSPSF r=0.24). Individual thresholds for VSOTFa showed a significant correlation with the RMS-value of the HOA (r=-0.621, p=0.013).

**Conclusions:** The estimation of the DoF using the VSOTFa and the VSPSF at a 50% threshold showed no significant difference to the subjectively measured DoF, but lacked a significant correlation. To predict the DoF from objective wavefront measurements, we propose the use of the VSOTFa at an individual threshold that is estimated from the RMS HOA.

**Commercial Relationships:** Alexander Leube, None; Arne Ohlendorf, ZEISS Vision international GmbH (E); Juan Tabenero, None; Siegfried Wahl, ZEISS Vision international GmbH (E)

**Program Number:** 6017 Poster Board Number: B0166

**Presentation Time:** 12:00 PM–1:45 PM

**WAVEFRONT ANALYSIS OF HIGHER-ORDER ABERRATIONS IN PATIENTS WITH HIGH MYOPIA**

**Santiago Delgado-Tirado, Yazmin Báez-Peralta, Lucia Gonzalez-Buendia, Iztiaor Fernandez, Miguel José Maldonado, Rosa Coco.**

**Ophthalmology, IOBA, Valladolid, Spain.**

**Purpose:** We performed a prospective, observational and analytical study to elucidate the correlation between axial length (AXL) and higher-order aberrations (HOAs) in patients with high myopia (>-6D). It is believed that an increase in HOAs is correlated with a significant decrease in quality of vision, especially under scotopic conditions.

**Methods:** We analysed 95 eyes from 51 high myopic patients, with a median age of 43 years. Patients presenting any corneal or lens disease that could interfere in their aberrometry values, and those suffering any macular disease evidenced by OCT (3D OCT-2000 FA plus, Topcon) were excluded. Wavefront analysis of corneal, internal and ocular aberrations was performed with a Hartmann-Shack aberrometer (Wavefront®8 Analyzer KR-1W, Topcon). In order to assess the relationship between both variables the Spearman correlation coefficient was used.

**Results:** A statistically significant positive correlation between AXL and internal spherical aberration was detected for the whole sample. Besides, a statistically significant positive correlation between AXL and internal tetrafoil aberration, was observed.

**Conclusions:** According to our results, patients with high myopia show greater values of HOAs. Thus, it appears to be a positive correlation between AXL and internal aberrometry. This findings may help to understand why patients with high myopia reiterated complain about its poor quality of vision, despite of having an optimum correction of their refractive error and a good visual acuity.

**Commercial Relationships:** Santiago Delgado-Tirado, None; Yazmin Báez-Peralta, None; Lucia Gonzalez-Buendia, None; Iztiaor Fernandez, None; Miguel José Maldonado, None; Rosa Coco, None

**Program Number:** 6018 Poster Board Number: B0167

**Presentation Time:** 12:00 PM–1:45 PM

**Numerical simplification of ray tracing for non-circularly symmetric models of the human eye**

**Danilo Andrade de Jesus, D Robert Iskander.**

**Wroclaw University of Technology, Wroclaw, Poland.**

**Purpose:** To simplify numerical analysis of ray tracing techniques in application to models of the human eye.

**Methods:** Recently a method that simplifies calculation of geometrical points spread function has been proposed for circularly symmetric systems (Gagnon et al., App. Opt. 2014). The method is based on Chebyshev polynomials and it is realized with the help of Matlab Chebfun toolbox – a new tool for computing with functions developed at Oxford University (www.chebfun.org). An extension of this method to 2D non-circularly symmetric systems is proposed. In this method, surfaces, rays, and refractive indices are all represented in functional forms being approximated by Chebyshev polynomials. Although generalization from one dimensional to two dimensional Chebyshev polynomials is not trivial (i.e., not all properties of 1D Chebyshev polynomials are present in their 2D representations), there are many benefits of using them including the ease of surface representation, manipulation of multiple surface designs, and the...
ability to represent gradient index (GRIN) type lenses. Such a representation appears to be an ideal tool for performing ray tracing in anatomically correct eye models such as the one proposed by Liou and Brenner (JOSA A, 1997).

**Results:** A two-dimensional Chebyshev function based ray tracing procedure for an arbitrary number of surfaces and arbitrary surface shapes has been developed. The Liou and Brenner anatomically accurate model of the human eye has been used for evaluating the method (Figure 1). Computational complexity (assessed as the CPU time) increases with the addition of each surface in a linear form indicating that the method has a great computational potential to be used for more intricate eye models in which, for example, the crystalline lens is described with multiple surfaces.

**Conclusions:** Performing ray tracing with Chebfun toolbox substantially simplifies calculations as it is based on object oriented programming with handle functions. Realization of the ray tracing technique in Matlab is particularly attractive among researchers for whom other ray tracing optical engineering packages such as those employed in Zemax are more cumbersome and sometimes difficult to acquire.

An example of chebfun-based ray tracing using the anatomically correct eye model of Liou and Brenner (JOSA A, 1997) where all the distances corresponds to millimeters.

**Commercial Relationships:** Danilo Andrade de Jesus, None; Robert Iskander, None

**Support:** FP7-PEOPLE-2013-ITN, AGEYE 608049

**Program Number:** 6019 **Poster Board Number:** B0168

**Presentation Time:** 12:00 PM–1:45 PM

**Wide-field schematic model of the Human Eye with Asymmetrically Tilted and Decentered Lens**

James Polans, Bart Jaeken, Ryan P. McNabb, Lucia Hervella, Pablo Artal, Joseph A. Izatt, Biomedical Engineering, Duke University, Durham, NC; *R&D, VOPTICA SL, Murcia, Spain; Ophthalmology, Duke University, Durham, NC; Laboratorio de Optica, Universidad de Murcia, Murcia, Spain.

**Purpose:** More accurate schematic eye models would aid in the design of advanced ophthalmic instrumentation, including OCT, SLO, fundus cameras and fluorescence imagers. Since the aberrations of the human eye vary strongly with retinal eccentricity, it becomes increasingly important to have an optically accurate eye model for the design of instruments requiring a wide field-of-view. We propose a schematic eye that reproduces the aberrations of the human eye across a wide visual field.

**Methods:** The model eye was built to reproduce the experimentally measured wavefront aberrations for 4-mm pupil recorded for the central 80° of the horizontal meridian (101 eyes) and 50° of the vertical meridian (10 eyes). These data were acquired using a custom scanning Shack-Hartmann wavefront sensor [1]. Optical modeling software (Zemax) and a reverse building eye modeling technique were used to optimize a merit function. We developed a custom surface in order to allow the model to be more easily incorporated into the design of imaging instruments.

**Results:** Across the entire field-of-view, the eye model shows excellent agreement with the measured data both comprehensively and for low-order and high-order aberrations (Fig. 1). In comparison to previous eye models (Fig. 2), our schematic eye excels at reproducing the aberrations at the peripheral retina. Tilt and decentration of the crystalline lens permits our model to mimic the asymmetries of the aberrations found in real eyes.

**Conclusions:** Our proposed model shows great promise towards the design of wide-field imaging instruments, and it has the potential to provide further insights in the study of the peripheral optics of the human eye. Also, we outline a robust eye modeling technique that is capable of predicting trends beyond those defined explicitly in the optimization routine.

Plots showing Zernike aberrations versus retinal eccentricity across the horizontal meridian: oblique astigmatism (a), defocus (b), vertical astigmatism (c), horizontal coma (d), oblique trefoil (e), spherical aberration (f), mean sphere (g), and cylinder (h). Error bars correspond to the standard deviation in the measured data (101 eyes).

Commercial Relationships: James Polans, None; Bart Jaeken, Voptica (E); Ryan P. McNabb, None; Lucia Hervella, Voptica (E); Pablo Artal, Voptica (I), Voptica (P), Voptica (S); Joseph A. Izatt, Biopigen Inc (I), Biopigen Inc (P), Biopigen Inc (S)

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Program Number: 6020 Poster Board Number: B0169
Presentation Time: 12:00 PM–1:45 PM

Higher order statistical eye model for normal eyes
Jos J. Rozema1, 2, Pablo Rodriguez Perez3, Rafael Navarro3, Marie-Jose B. Tassignon1, 2.

Purpose: This work presents a stochastic model capable of generating an unlimited number of random, but realistic biometry sets, including the corneal elevation, intraocular distances and wavefronts, with the same statistical and epidemiological properties as the original data it is based on.

Methods: One cohort of 312 eyes of 312 healthy Caucasian subjects (aged 20 – 60 years) was measured with an autorefractometer, Scheimpflug imaging (Oculus Pentacam), optical biomter (Haag–Streit Lenstar) and an aberrometer (Tracey iTrace). The corneal elevation maps, represented by Zernike coefficients, were compressed using Principal Component Analysis, leaving a total of 17 parameters to describe the variability of the ocular biometry. These data were then fitted with a linear combination of three multivariate Gaussians through an Expectation Maximization algorithm, which has been shown to give a good representation of the ocular biometry in a population. Based on this fit a stochastic model was built that generates an unlimited number of random biometry sets, from which total wavefronts and other ocular parameters can be calculated. Equality between the original and the synthetic data was assessed using non-parametric “two one-sided” tests.

Results: The wavefronts calculated using the measured biometry were significantly equal to the originally measured wavefronts (two one-sided Wilcoxon test, p < 0.05), confirming the accuracy of the ray tracing algorithm. Subsequently, the stochastic model was used to randomly generate the biometry of 1000 eyes and calculate the associated wavefronts by ray tracing. For both the biometry and the wavefront this synthetic data were significantly equal to the originally measured data (two one-sided Mann–Wilcoxon test, p < 0.05), thus making them statistically indistinguishable.

Conclusions: The statistical eye model is able to produce synthetic biometry data that is indistinguishable from actual biometry. As such this model may be an interesting alternative to static eye models for researchers in visual optics that do not have access to biometry data.

Commercial Relationships: Jos J. Rozema, None; Pablo Rodriguez Perez, None; Rafael Navarro, None; Marie-Jose B. Tassignon, None

Support: Flemish Agency for Innovation by Science and Technology, grant IWT/110684

Program Number: 6021 Poster Board Number: B0170
Presentation Time: 12:00 PM–1:45 PM

A Cross-correlation Model of the Effect of Higher and Lower-order Aberrations on Stereopsis in Keratoconus
Sangeetha Metlapally1, Vinay K. Nilagiri2, Tiffanie T. Yu1, Shrikant R. Bhuradwaj2, Clifton M. Schor2, 1Optometry, University of California, Berkeley, Berkeley, CA; 2L V Prasad Eye Institute, Hyderabad, India

Purpose: Inter-ocular differences and averages of higher-order aberrations (HOAs) both co-vary with stereo-acuity in keratoconus (Sarkar et al., IERG, 2014). This study modeled the effects of inter-ocular differences in phase noise and contrast induced by these wavefront errors on stereo-acuity in keratoconus.

Methods: Lower-order aberrations (LOAs) and HOAs were measured in 9 keratoconus cases and 5 control subjects, post-cycloplegia with 6 mm diameter pupils, either unaided or through RGP contact lenses (CLs), using a Shack-Hartmann irx3™ wavefront aberrometer. Refractive data and stereo-depth thresholds were measured through spectacles and CLs under the same conditions to compare low and high magnitudes of HOAs. Phase effects were modeled from the horizontal cross-correlation functions of random dot patterns convolved with point-spread functions of right and left eyes. Contrast effects were modeled with retinal image quality (IQ) metrics computed for each eye using aberrations scaled to 4 mm diameter pupils. Analyses of variance were performed to investigate the contribution of inter-ocular differences in phase noise and contrast to the empirical stereo-depth thresholds.

Results: Stereo-thresholds ranged from 36 – 872 arc sec in cases and from 29 – 134 arc sec in controls. Some of the variance seen in the empirical stereo-thresholds in keratoconus obtained with spectacles (i.e. with HOAs uncorrected) was explained by the signal to noise ratio derived from the cross-correlation functions (r = -0.59; R² = 0.36; p < 0.05). The width of the cross-correlation function, estimated from the standard deviation, was moderately correlated with stereo-thresholds obtained with spectacles (r = 0.43; R² = 0.18; p = 0.13). Inter-ocular differences in IQ metrics chosen to highlight contrast differences due to HOAs (VSOTF, VSMTF), showed little or no relationship to the stereo-thresholds.

Conclusions: Inter-ocular HOA differences in keratoconus subjects introduce phase noise in the disparity domain that affect the fidelity of disparity signals for stereo-depth perception. The contribution of contrast differences from HOAs is small in comparison. However, small residual LOAs could have a larger contrast-difference effect on stereopsis.
Commercial Relationships: Sangeetha Metlapally, None; Vinay K. Nilagiri, None; Tiffanie T. Yu, None; Shrikant R. Bharadwaj, None; Clifton M. Schor, None