3818 - B545

Optical Power and Diameter of In Situ versus Isolated Primate Crystalline Lenses

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**Purpose:** To determine if the tension on the cadaver crystalline lens changes when the lens is isolated from its supporting framework.

**Methods:** Four whole pre-prosphyic human (average 32.26±6.6 years, range 26-44 years, ≤5 days postmortem) and twenty-four cynomolgus monkey (average 6.2±2.1 years, range 4-9 years, ≤1 day postmortem) eyes were carefully dissected leaving the lens, zonules, ciliary body, hyaloid membrane and anterior vitreous intact. The shape of the intact globe was preserved by bonding a fixed matching ring to the scleral surface. The lenses maintained in their supporting framework were immersed in a cell filled with DMEM at room temperature. Optical power was measured using a custom designed B-90 type lensmeter and its equivalent diameter was measured at 20X magnification on the unexplored shadowgraph. The lenses were then excised by cutting the zonules with Vannas scissors and immediately re-immersed in DMEM at room temperature. Optical power and equatorial diameter measurements were then repeated on the isolated lenses. Visibly swollen or delaminated lenses in the shadowgraph images were excluded.

**Results:** While only statistically significant in the monkey (p = 0.0003), for both species, there was an apparent decrease in the diameter and increase in the power when the lens was removed from its supporting framework (see Table).

**Conclusions:** The results suggest that the in situ cadaver lens is under residual tension.

3818 - B556

A Reconstruction Technique to Estimate the Gradient-Index Distribution of the Crystalline Lens Using Ray Aberration Data in vivo


**Purpose:** Human crystalline lens is known to have a gradient index (GRIN) distribution. Several reconstruction techniques have been proposed to estimate GRIN profiles using as input data the slopes of the rays deflected by the lens in a ray tracing set-up. However, ray deflections can only be measured as input data the slopes of the rays deflected by the lens in a ray tracing set-up. However, ray deflections can only be measured using transverse ray aberrations.

**Methods:** We have implemented reconstruction algorithms using the optimization toolbox of an optical design program (Zemax). The GRIN profile is modelled with a 2 parameter function and the biometry data of the lens is assumed to be known. We tested two types of input data in our algorithm: cosines of refracted rays by the lens (only available from in vitro measurements), and transverse ray aberrations (available both in vitro and in vivo using retinal spots). The average difference between the model and estimated GRIN profile (RMS) was used as a metric. In order to perform realistic simulations, we simulated the experimental errors in the setup that includes a 594-nm He-Ne, a laser scanning system (x-y galvanometer), a water cell chamber to place the lens under test, and two CCD cameras: one for viewing lateral ray deflections and the other conjugated to the focal plane to measure retinal transverse ray aberration (spot deviations). Calibrations were done on artificial lenses with known geometry. Image processing routines have been developed for ray detection.

**Results:** 1) Experimental errors in entrance ray coordinates were 11.5±0.8 μm, image processing errors in the estimation of cosines of the refracted rays estimated from ray deflections was 5.7±1.0°, and typical measurement variability in the transverse aberration was 0.08 mm. 2) Using the estimated experimental errors of the entrance ray in the simulations, we obtained an RMS reconstruction error of 9.71±2.74° when using the cosines of the refracted rays and an RMS of 2.85±1.21° when using the transverse ray aberrations.

**Conclusions:** Optimization procedures using ray angular deflections or ray transverse aberrations have been proved to recover the GRIN of the lens within the same order of error. These results indicate that if geometrical properties are known, it should be possible to estimate the GRIN lens in vivo using laser ray tracing.

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3817 - B555

Equivalent Refractive Indices of Isolated Human and Monkey Crystalline Lenses

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**Purpose:** To determine if the difference in lens power between cynomolgus monkey and human lenses is due to differences in the equivalent refractive index.

**Methods:** Measurements were performed on 13 human (26-82 years, average 47±10.8 years, and ≤5 days postmortem) and 24 cynomolgus monkeys (≤106 months, average 74.1±25.5 months, and ≤1 days postmortem) isolated lenses. The lenses were carefully extracted from whole globes to avoid capsular damage and immediately immersed in room temperature DMEM. Optical power was measured using a custom designed B-90 type lensmeter. The central sagittal thickness was obtained by fitting conic sections to the central 6mm zone of the anterior and posterior surfaces. In vivo imaging of the optical power measurements incorporating the measured lens biometric properties were used to determine the central equivalent refractive index of the isolated lenses.

**Results:** There was no significant difference in equivalent refractive index between the two species. The higher optical power of the cynomolgus lens is due to its smaller radius of curvature.

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3819 - B557

Cataract and Wavefront Aberrometry

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**Purpose:** To determine the relationship between cataract type and higher-order aberrations (HOA). We examined seventy-eight eyes were evaluated of 101 subjects (mean age 73.43, SD 9.08) who presented consecutively to undergo cataract extraction and intraocular lens implantation. Root mean square (RMS) values were separately evaluated for the HOA components Total, THSI, High, Tcoma, TTrefoil, T5foil and HiAstg using the ZEMAX Optical Path Difference Scanning System. ARK-10000 aberrometer. Cataract was graded using the Lens Opacity Classification System (LOCS) III for type (Nuclear Opalescence/NO, Nuclear Color/NC, Cortical/C and Posterior/P) and severity (levels 1-6). CO-variance was used, comparing grouped NO and NC levels 2-5 with level 6, and between the level of combined NO/NC group and the RMS value for each HOA.

**Results:** There was a significant difference in the RMS values for each HOA between the level 5 compared to lower levels for P cataract and between level 6 compared to lower levels for NO and NC cataract. RMS values of C cataract did not differ between levels.

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Wednesday, May 9, 8:30 AM - 10:15 AM Hall B/C Poster Session 416. Crystalline Lens and Intraocular Scatter Organizing Section: VI Contributing Section: LE Copyright 2007 by the Association for Research in Vision and Ophthalmology, Inc., all rights reserved. For permission to reproduce any abstract, contact the ARVO Office at pubs@arvo.org. Commercial Relationships are noted at the end of each abstract by “None” or with codes.
3820 - B585
Straylight Improvement on Lens Extraction
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Purpose: To study straylight values among the population and in cataract surgery patients in order to evaluate possible gains and losses with the intent to consider straylight as an added tool for clinical decision making on cataract extraction.

Methods: In a multicenter European study active drivers were tested for prevalence of different ocular conditions relevant to driver licensing. A subset of the data on both eyes of all 2422 included subjects, in particular visual acuity, straylight (at 10 degrees) and LOCS III, was analysed. The eyes were divided into 4 groups according to slitlamp finding and LOCS classification as follows: 220 pseudophakic eyes, 3182 non-cataractous eyes (average LOCS score <1.5), 134 cataractous eyes (average LOCS score >3.0), and a rest group. Visual acuity was determined using logMar according to the modified ETDRS system in steps of 0.02 log units. Straylight was determined using the Compensation Comparison Method and displayed as the log of the straylight parameter s (log(s)). In the cataract surgery patients the C-Quant instrument of Oculus was employed, using this same method, but at 7 degrees straylight angle.

Results: The age dependence of straylight in the non-ctaractous group compared well to earlier data. An age norm for straylight was defined as follows: log(s) = constant + log(1+(age/65)), with the value of the constant = 0.90 for 10 degrees straylight angle and 0.87 for 7 degrees. So, on average, straylight doubles in non-ctaractous eyes by the age of 65, and triples by the age of 77. Population standard deviation around this age norm was about 0.30 log units. Most interesting was the finding that in pseudophakia, straylight values can be much improved not only compared to the cataract group, but also compared to the non-ctaractous group. Visual acuity and straylight were found to vary quite independently.

Conclusions: Lens extraction holds promise not only to improve upon the condition of the eye in case of cataract, but also to improve upon the “normal” (but strong) increase in straylight value, quite independently from visual acuity.

CR: T.J.T.P. Van Den Berg, Oculus C-Quant, T.

3821 - B559
Intraocular Scattering Estimation From Double-Pass MTFs
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Purpose: To estimate intraocular scattering by analyzing the modulation-transfer function (MTF) obtained from double-pass images. This method can be used in situations of clinical interest like in patients at different stages of cataract development.

Methods: Double-pass retinal images are influenced by both aberrations and scattering (Diaz-Douton et al. IOVS, 2006). Measurements of double-pass images were performed with a clinical instrument (OQAS, Visiometrics, Spain). To minimize aberrations effects we used entrance pupils of 2 mm in diameter. Defocus and astigmatism were corrected by using a Badal system integrated in the instrument and cylindrical trial lenses respectively. Under these conditions the effects of aberrations were severely reduced and MTFs obtained were mainly affected by intraocular scattering. To verify if the MTF worsening was due either to intraocular scattering or higher order aberrations, we measured the wavefront aberrations using a Hartmann-Shack wave front sensor. We performed radial profiles of the double-pass MTFs and the area under this curve was computed to estimate the degree of intraocular scattering. The normalization in the MTF was realized at the the 3rd digital frequency (1.6 cycles per degree), instead of the zero frequency, to minimize the effect of reflections and back-scattering.

Results: The procedure was applied in a group of 50 eyes: 10 normal young eyes as a reference and 40 eyes of cataract patients with different level of scatter whose ages ranged from 45 to 70 years. The double-pass measurements and the computed MTF areas presented a high repeatability. A few cases of cataract patients showed a lower repeatability. We found statistically significant differences in the MTF areas values between cataract and healthy patients (<0.001).

Conclusions: The method proposed allows us to quantify the degree of intraocular scattering and, because of the high-pass filter applied, only forward scattering was taken into account. In a future work comparison of this method with current subjective methods used presently should be performed.

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3822 - B560
Quantifying Intraocular Scattering in Cataract Patients
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Purpose: To develop an objective technique to measure intraocular scattering in patients at different stages of cataract progression.

Methods: We combined double-pass retinal images and wave-front aberrations measurements to obtain an objective scatter index (OSI). Double-pass images were recorded using a clinical instrument (OQAS, Visiometrics SL, Spain) and aberrations were measured with a Hartmann-Shack sensor. For a defined pupil diameter, typically 4 mm, a synthetic double-pass image, only affected by the aberrations, was computed from the wavefront data. For each patient, two double-pass images were compared: the one directly measured, affected by aberrations and scatter, and the synthetic computed one, only including the impact of aberrations. A parameter was computed from the two double-pass images as the ratio of the light falling in an outer area as compared with the light in the central part of the image. The objective scatter index (OSI) was defined as the normalized difference of the two values from the real and computer generated double-pass images respectively.

Results: The procedure was applied in a group of 80 eyes: 20 normal young eyes as a reference and 60 cataract patients with different level of scatter, from mild to severe opacities. The scatter index OSI ranges from zero in an ideal, scatter-free eye, to 10 for an ideal eye fully affected by scatter. The normal young eyes present usually values below 1, early cataract eyes around 2 and in mature cataract eyes OSI was higher than 4.

Conclusions: An objective index (OSI) to quantify intraocular scatter in cataract eyes has been proposed. The procedure is robust and discriminates well among eyes with different amount of scatter. The procedure can be easily applied in the clinic and provides a quick and robust indication of the overall amount of scatter.

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3823 - B561
An Objective Classification Scheme for Cataracts
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Purpose: To propose a new objective scatter index (OSI) to rank and classify cataract patients. This classification scheme will be compared with a current subjective system.

Methods: We selected a population including a group of normal young eyes as reference, and patients diagnosed nuclear cataract (grades II, III and IV) according to the Lens Opacities Classification System (LOCS III). For each eye, we obtained an objective scatter index (OSI) by subtracting the relative intensity at an eccentric location from the total double-pass images: one registered by the OQAS instrument (Visiometrics SL, Spain), and other simulated considering only the eye's aberrations. Visual acuity was also measured using a forced-choice computer controlled procedure.

Results: We used the OSI values to classify each eye according to the degree of scatter. Young normal eyes had OSI values below 1, while the OSI for subjects in LOCS grade II were around 1 to 2. The use of the objective index showed some of the weakness of current subjective classification schemes. In particular, several subjects initially classified independently as grade II or III had similar OSI values, and in some cases even higher than subjects classified as grade IV. The objective data provided a better correlation with the measured visual acuity: OSI (r=0.35) versus LOCS III (r=0.21).

Conclusions: We propose an objective index based in analyzing double-pass retinal images to classify cataract patients. The method is robust, fully based in objective measurements; i.e., not depending on subjective decisions. This index could be used to objectively select patients for cataract surgery.

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3824 - B562

A New System to Measure Intraocular Scattering Based on Brightness

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Purpose: It is well known that the brightness of a test against a dark surround is strongly reduced when it is presented under glare conditions. The scattered light on the retina affects the visual process and there is a correlation between this stray light and the brightness reduction. We propose in this work to use this brightness reduction to assess the level of intraocular diffusion.

Methods: The system consists on a haploscopic configuration in which two semicircles are presented such that each of these semicircles falls on only one eye. One of the semicircles has a reference luminance (Lr) and the other an adjustable luminance (Lm). Simultaneously, a steady glare source (150 lux, temporal 25 degrees) falls on the eye that sees the reference luminance. The subject’s task was to match the brightness of the two semicircles. Matching luminance (Lm) was obtained for 5 values of Lr (4.5-58 cd/m²) and 5 normal subjects (62.75 ±75 years). Each Lm was the average of 5 different measurements. A control experiment was performed with no glare.

Results: Results show a systematic decrease of Lm with glare for all subjects and values of Lr. Lm/Lr without glare are nearly 1 for all subjects indicating no dependence of the measurement with the intraocular scattering associated to aging. The standard deviation of Lm/Lr decreases with increasing Lr.

Conclusions: Results obtained in this experiment suggest that the haploscopic configuration may be appropriate to evaluate the intraocular scattering. The fastness, which is of interest for some applications such as those related with clinical tests. However, the large errors found in the measurements suggest that the fast method of adjustments could be improved. One of the challenges that we face now is to solve the trade-off between fastness and precision.

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3825 - B563

Deterioration of Reading Performance and Ocular Higher Order Aberration in Subjects With Cortical Cataract

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Purpose: To investigate visual function including reading performance and contrast sensitivity, and also ocular higher order aberration in subjects with cortical cataract without opacity in the central pupil area.

Methods: Among the 150 subjects aged ≥53 years of a population based study (Munoz et al., 2005), 20 normal subjects (mean age ≥65 ±5.7 years) and 24 with cortical cataract and no opacification in a 3mm diameter area about the centre of the pupil (CS) (mean 66.0 ± 6.9 years) were selected. Each subject underwent an MNREAD+ test (Minnesota Laboratory & TWCU Oda-lab for Low Vision Research) for reading acuity, critical print size, and maximum reading speed; and ophtalmic evaluations employing particular tools including contrast sensitivity (CAT-2000 NTIIZ), bottom light scattering intensity (BSLI) of the crystalline lens (EAS-3000, NIDEK), and ocular higher order aberration (KR-9000WP, Topcon, Tokyo, Japan). Higher order aberration was divided into the 5 types; Trelto, Coma, Tetrafoil, 2nd-And-5th, and Spherical according to a Zernike Vector Map (installed in a KR-9000WP).

Results: No significant differences were observed between NS and CS in contrast sensitivity or BSLI around the lens axis. Reading acuity and maximum reading speed (mean 0.603, range 0.470-0.823) were significantly worse than those of NS (mean 0.628, range 0.544-0.772; P<0.05). The maximum reading speed of CS decreased with increase of opacification in the pupil area (P=0.457, P<0.05). In the fourth higher order aberration, ocular, corneal, and ocular-scleral aberration, were significantly higher in CS than in NS (P<0.05). There was a positive correlation between Tetrafoil aberration and the area of cortical opacification in a 6mm diameter area around the center of the pupil (r= 0.442, P<0.05).

Conclusions: In cortical cataract cases without opacification in the central pupil area, no obvious deterioration of contrast sensitivity was seen. However, the reading performance of these cases was weak. Forward light scattering of the cortical opacification and increasing of the higher order aberration may play important roles in this deterioration of quality of vision.

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3826 - B564

The Effect of Cataract Extraction on the Contractility of Ciliary Muscle Induced by Pilocarpine in Presbyopia

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Purpose: To evaluate the change of contractility of ciliary muscle induced by pilocarpine in eyes with presbyopia before and after cataract extraction by ultrasound biomicroscopy (UBM).

Methods: Clear corneal phacoemulsification with posterior chamber intraocular lens (AcrySof SA60AT, Alcon Laboratories) implantation was performed in 8 eyes of 8 subjects. UBM was performed with and without 2% pilocarpine instillation, before and 2 months after cataract extraction. Mean (±standard deviation) age was 62.25±6.0 years (range; 58-75 years). At each examination, images of the iridocorneal angle including ciliary muscle at the superior, inferior, temporal, and nasal quadrants were obtained. Axial length of ciliary body (CBAXL) and ciliary process-sclera angle (CPSA) were measured. Images of ciliary muscle were compared visually by Adobe Photoshop 7.0, and measured parameters were analyzed by paired t-test.

Results: CBAXL value with and without pilocarpine before cataract extraction was 2799±145 mm and 1700±157 mm, respectively, and this increase with pilocarpine instillation was not statistically significant (P=0.665). CBAXL value with and without pilocarpine after cataract extraction was 1774±203 mm and 1634±158 mm respectively, and this increase with pilocarpine instillation was statistically significant (P=0.033). Cataract extraction led to a significant increase of CPSA with and without pilocarpine instillation by 8.0±4.0 and 7.1±1.4°, respectively compared with those before cataract extraction (P=0.001 and P=0.000, respectively). Visually compared configurations of ciliary muscle changes were compatible with the analysis of measured parameters.

Conclusions: Ciliary muscle moved more forwardly by pilocarpine before cataract extraction, however pilocarpine induced inward movement of ciliary muscle increased after cataract extraction. This finding shows that a lenticular sclerotic component influences the contractility of ciliary muscle, and is related to the presbyopia.

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3827 - B565

Biometry of the Primate Lenses Capsule Pre-Post Endolenticular Extraction in Vivo

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Purpose: To determine if the capsular bag dimensions after endolenticular extraction can be predicted from the natural lens dimensions.

Methods: Experiments were performed on cadaver human (n=15, 8-76 years, <5 days postmortem) and cynomolgus monkeys (n=18, 5-14 years, <2 days postmortem) eyes. The eyes were prepared by bonding 8 PMMA segments on the sclera after removal of conjunctiva, adipose, and muscle tissues. The globe was dissected leaving a lens-zonule-ciliary body-sclera section with intact hyaloid and anterior vitreous. The section was transferred to an optomechanical lens stretcher (Pare, EVAS 1, ARVO 2002). The sclera between each segment was sectioned. Digital images of the lens were recorded through an operation microscope set at 10x. A mini-capsulorhexis (< 2mm diameter) was made in the peripheral region of the capsule, the lens content was removed, and the empty capsular bag diameter was measured on recorded digital images. The diameter of the natural lens and empty bag were compared. In 12 of the 19 cyno and 7 of the 15 human lenses, the diameter and thickness of the contralateral isolated natural lens were measured by shadowphotography. The surface area of the empty capsular bag was compared with the surface area of the contralateral eye, calculated using the equation of an ellipse.

Results: The diameter of the unstretched empty capsular bag increases as a function of age in both humans and cynomolgus monkeys (p<0.04 and p<0.02, respectively). The surface area of the empty capsular bag also increases as a function of age (p<0.10 human and p=0.02 cyno). The ratio of empty capsular bag diameter to natural lens diameter is constant (±0.10% of all ages (ratio=0.83). The ratio for empty bag surface area to natural lens surface area is also constant for both species for all ages (ratio=0.85).

Conclusions: The empty lens capsule diameter can be predicted from normative data on intact lenses.

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3828 - B566  
Mechanics of the Capsular Bag and Zonules in Rabbit and Human Donor Eyes: A Comparative Study  
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Purpose: The present study is a continuation of a human donor eye study that assessed lens capsular bag elasticity with and without mechanical interaction of the zonules (ARVO 2006). As the rabbit is a good animal model for IOL studies, it is our goal to compare the mechanical properties of the young rabbit lens capsular bag to that of the aged human donor eye in order to better understand the dynamics of the capsular bag during accommodation in the non-aged human aphakic eye. 

Methods: Six fresh New Zealand White (NZW) rabbit donor eyes from 3 rabbits approximately 3.5 months in age and 2.9 kg in weight and six fresh human donor eyes, ages 60 to 68 (approximately 72 hours postmortem) were studied. White-to-white diameter, equatorial diameter and axial length were measured. The cornea and iris were removed and the capsulorrhexis and the lens capsule bag diameter were measured in two axes before and after lens extraction. The same measurements were made ex vivo after cutting one-fourth, one-half or all of the zonules. All measurements were performed using digital calipers with an accuracy of ±0.01 mm. 

Results: The mean natural lens diameter of the NZW rabbit was 10.42 mm compared to 9.92 mm in the human eye. The mean lens capsule bag diameter slightly decreased following lens extraction to 10.33 mm in the rabbit and increased slightly in the human to 10.29 mm. Following refilling with Healon and complete zonular removal, the mean lens capsule bag diameter was 9.72 mm in the rabbit and 9.08 mm in the human. There is a mean difference of 0.7 mm between the natural lens of the young rabbit and a capsular bag that has no zonules that is not longer than which was similar to the aged human donor eye. Thus, with the zonular attachment, the isolated capsular bag diameter decreases to less than its natural crystalline lens size by approximately 0.7 mm. 

Conclusions: The 3.5 month old NZW rabbit eye appears to be similar to the aged human-eye and may be a reasonable model for the evaluation of intracocular lenses designed to work with lens capsular elasticity in facilitating accommodation in the pseudophakic eye. 

Support: None.

3829 - B567  
Construction of a Computer Mesh Model of the Anatomical Human Crystalline Lens Fiber Ultrastructure  
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Purpose: To construct an automated FEA mesh generation algorithm capable of building the fiber ultrastructure of the human crystalline lens. 

Methods: An algorithm was designed in C++ and Direct3D that built successive layers of fibers in a manner consistent with the known natural suture geometry of the lens based on Kuszak et al (2004). The model can be "grown" from the embryonic nucleus, layer by layer, to the outer cortex and lens capsule. The geometric constraints were determined and coded such that 3, 6 and 9 branch suture/fiber layers could be created with arbitrary fiber widths/thicknesses. The mathematical rules governing the placement of individual fiber bundles, such as the ratio of suture length to lens diameter and the ratio of anterior to posterior suture length, among many others, for each layer were derived such that a complete, anatomically based FEA model could be achieved. Additionally an algorithm was created to generate a variable thickness capsule model with appropriate zonule attachment points. 

Results: The algorithms described were used to create FEA models with various configurations of welded and free-sliding fiber geometries. The models were exercised using LS-Dyna and provided a mechanism to study fiber dynamics underacommodative loads and their contribution to the shape change of the refractive surfaces of the lens. 

Conclusions: Computer automated fiber mesh generation algorithms provide a novel way to build FEA lens models in order to examine the contributions of each aspect of the lens fiber ultrastructure. 

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3830 - B568  
Viscoelastic Behavior of the Lens Soluble Proteins  
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Purpose: This work is an extension and validation of work previously presented on lens crystallin viscoelasticity to increase our understanding of this subject which is essential for gaining insight into the process of accommodation. 

Methods: Fresh porcine lenses were decapsulated and lenses were homogenized. This homogenate was ultracentrifuged to separate the soluble and insoluble proteins. The viscoelastic behavior of the lens soluble proteins was characterized using a cone-and-plate rheometer at 37°C in steady shear, creep, and dynamic protocols. 

Results: The lens soluble proteins exhibit a large degree of shear thinning, with a low-shear asymptotic viscosity of 28.1 Pa.s. They behave as a liquid under all conditions, exhibiting a minimum loss tangent at a frequency of 0.65 Hz. In the included graph, the viscosity in the creeping flow regime is fitted with the Kriger-Dougherty equation for concentrated nonspherical particles. Equilibrium viscosity measurements were modeled using the rate process-based Powell-Eyring model, which describes the shear-thinning behavior of viscoelastic suspensions. 

Conclusions: The lens soluble proteins contribute to the viscous portion of the lens' viscoelastic behavior. The sigmoidal shape of the equilibrium viscosity - shear rate relationship indicates two primary flow regimes. At low shear rates, interparticle forces dominate, resulting in a very high viscosity. As shear rate increases, the inertial forces dominate, destroying non-covalent or weak interactive forces between the crystallin molecules, and the viscosity approaches that of the solvent. The excellent fit of the Powell-Eyring model indicates that the dispersion behaves as a viscoelastic suspension. Shear thinning behavior allows large changes in accommodation to occur with less force than would be necessary if the fluid behaved as a Newtonian fluid. 

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3831 - B569  
Experiments and Computations for Simulating Unconfined Compression of Porcine Ocular Lenses  
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Purpose: Understanding the mechanics of lens accommodation can assist in the diagnosis of early presbyopia as well as identify potential clinical treatments and lens prospecthe implantation strategies. Presbyopia is attributed to changes in ciliary muscle function, as well as changes in the mechanical properties of the lens substance, lens capsule, and zonules, presumably. The precise relationship of these changes, however, is not well described. 

Methods: Fresh 6-9 month porcine eyes obtained one day after slaughter are dissected to extract the lens, which is then immersed for testing in a cup full of Balanced Salt Solution (BSS) warmed to 39.2°C (pig body temperature) to reduce as much as possible the non-physiological effects of testing in-vitro. A loading ram then cyclically compresses the lens along its anterior-posterior axis at various displacement rates up to 30% nominal strain. Force is measured, and digital photographs are taken at various stages of deformation to obtain a crude measure of cross-sectional deformation. Parameters for a large deformation hyper-viscoelastic constitutive model are fit to experimental data by optimizing an axissymmetric finite element model against experimental data. The lens capsule and substance are assumed to be nearly incompressible (negligible volume change), and constitutive parameters are fit separately for the capsule and substance. 

Results: The force-displacement curves at certain displacement rates for lenses extracted from pairs of eyes can be fit by the optimized parameter-fitting finite element analysis. It was found that lenses needed to be tested immediately upon receipt as even one day later it was observed that the lens substance degraded. Freezing did not preserve the mechanical properties of the lens substance. 

Conclusions: Unconfined compression loading is not physiological, such that the lens changes curvature through relaxation and tension in the zonules attached to the equatorial region of the lens capsule, but it provides a simple means for measuring the mechanical properties of the whole lens. Once confidence is gained in modeling the whole lens—which involves higher resolution mechanical testing of the individual components (capsule and substance)–as well as the zonules, a mechanical model can be loaded in a physiological manner using finite element analysis to attempt to predict the mechanics of lens accommodation, and in turn any influence by change in the mechanical properties of the lens substance and capsular bag. 

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3832 - B570
Modeling Elasticity Distribution in a Presbyotic Lens
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Purpose: There are many theories describing accommodation and presbyopia. Based on recent measurements in our lab and others, we focus on modeling the contribution from general lens elasticity and the elasticity distribution. These measurements show a constantly varying elasticity as a function of radial distance.

Methods: We have developed a finite element model that approximates this varying elasticity as nine spherically concentric layers within the lens. This distribution is based on our measurements and optical microscopy of layer geometry. We do not just model physiology but vary parameters in the model to separate the biomechanical effects of elasticity distribution from the increase in composite elasticity.

Results: The model verifies that an average elasticity increase does produce accommodation loss. For a soft average lens with an average Young's modulus of 0.67 kPa, a ciliary muscle force of 0.05 N produces a change in optical power of 0.3 D. In a hard average lens (Young's modulus ~ 4.0 kPa) the same force produces a change of only 0.06 D. Results also show that a lens with a soft center will accommodate more than a lens with a hard center even though both have the same average elasticity. For a ciliary muscle force of 0.05 N, the soft center model produces a change in optical power of 0.32 D while the hard center lens with the same average elasticity produces a change of 0.30 D. Of course, in actual physiology both mechanisms would simultaneously affect accommodation in addition to mechanisms proposed by other theories.

Conclusions: This new model indicates that the elasticity distribution significantly contributes to accommodation loss. Methods for correcting presbyopia need to address not just average lens softening but the location of the softening.

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3833 - B571
Flexibility Increase of Human Donor Lenses After Femtosecond Laser Treatment (fs-Lentotomy)
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Purpose: According to Helmholtz' theory of accommodation one of the mayor reasons for the development of presbyopia is the increasing sclerosis of the lens. One concept to overcome this hardening of the lens is to regain its flexibility by inducing gliding planes inside the lens. Femtosecond laser pulses are a suitable tool for this treatment.

Methods: Showing in former work that we could increase the flexibility of enucleated porcine (ex vivo) lenses up to 25%, we focused our recent work on human autopsied lenses. The age of the human donors ranged between 30 and 70 years. We performed our work first with laser pulse with a repetition rate of 5 kHz and a pulse duration of 130 fs, later on we used a 100 kHz laser system with a pulse duration of 440 fs which reduced treatment time. For an evaluation of the gain in flexibility the lenses were rotated before and after treatment and the changes in the lens' thickness were measured with Fisher's spinning test. In addition we measured the thickness and diameter of the lenses before and after the treatment.

Results: Depending on age and the applied cutting pattern the lens thickness increased up to 0.4 mm after the laser treatment leading to a theoretical increase of refraction power of several diopters. The rotation experiments showed an increase of elasticity for all eyes. The flexibility could be increased in average about 70% compared to the measurements before treatment. Since the age of the human donors had a broad range, leading to different degrees of lens hardening, the variance of the measured flexibility changes was up to 30%.

Conclusions: fs-laser induced cuts in the lens lead to a gain in lens flexibility and an increase in thickness after the laser treatment. Therefore this might be a possible presbyopia treatment in phakic eyes. Further investigations which show a correspondence of gain in flexibility and change of accommodative power in vivo as well as wound healing studies have to be performed.

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3834 - B572
Modification of Lens Mechanics of Human Cadaver and Porcine Lenses Using Photodisruptive Laser to Change Lens Power and Increase Flexibility
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Purpose: To investigate the use of photodisruption techniques on the mechanics of the lens to allow for shape modification and increased flexibility in human cadaver lenses and in-vitro porcine lenses.

Methods: All lenses received treatment using a 1064 nm wavelength ultrafast laser. The laser pulses were confined to a volume of less than 6 mm in diameter and 3 mm in length. A porcine lens was divided into three equal groups. In the first porcine group of lenses was subject to full laser treatment while in the second porcine group a 1.5 mm diameter in the center of the lens was spared, which we predicted with our FE model will increase the power in the lens. The third porcine group was used as a control. Also, seven human cadaver lenses, mean age 52.8 yrs received a treatment that spared the center. Before and after the lenses were laser treated, all the lenses were measured with a synchronous strob microscope and a light source, which reduced treatment time. For an evaluation of the gain in flexibility the lenses were rotated before and after the lens treatment. Therefore this might be a possible presbyopia treatment in phakic eyes. Further investigations which show a correspondence of gain in flexibility and change of accommodative power in vivo as well as wound healing studies have to be performed.

Results: Depending on age and the applied cutting pattern the lens thickness increased up to 0.4 mm after the laser treatment leading to a theoretical increase of refraction power of several diopters. The rotation experiments showed an increase of elasticity for all eyes. The flexibility could be increased in average about 70% compared to the measurements before treatment. Since the age of the human donors had a broad range, leading to different degrees of lens hardening, the variance of the measured flexibility changes was up to 30%.

Conclusions: fs-laser induced cuts in the lens lead to a gain in lens flexibility and an increase in thickness after the laser treatment. Therefore this might be a possible presbyopia treatment in phakic eyes. Further investigations which show a correspondence of gain in flexibility and change of accommodative power in vivo as well as wound healing studies have to be performed.

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3835 - B573
The Use of an Off Axis Slit Laser Camera System for Determining Photodisruptive Laser Placement in Lenses

Purpose: Determining lens shape and A/P is important for accurate placement of photodisruptive laser patterns in the lens. The purpose of this study was to investigate the use of an off axis slit laser camera system to guide the placement of a photodisruptive laser in various lenses.

Methods: A 780nm slit laser was made incident on aplanated porcine and rabbit eye at approximately 30 degrees with respect to the normal. The laser was then scanned across the aplanated eye while images of the illuminated cross section were collected using an off axis camera system. The off axis camera system was at an angle of approximately 25 degrees with respect to the normal of the incident plane of the aplanated lens. The camera was stopped down so that the aplanated anterior segment and the lens were in focus. After images were captured, the imagery was used to determine the placement of a photodisruptive laser pattern in the eye. The eye was then treated using a photodisruptive laser. The accuracy of the placement laser was then determined through the use of microscopy and ultrasound.

Results: Although the lens is an age dependent gradient structure having a unknown varying index of refraction, it was found that the slit laser camera system was accurate for effective placement of the photodisruptive laser. Based on ultrasound imaging measurements (E-Technologies MHF-I) the slit laser camera system was able to place the photodisruptive laser treatment patterns to within 100 microns of the desired location within the lens.

Conclusions: The off axis slit laser camera system allows for accurate placement of photodisruptive laser treatment patterns within the lens.

Support: None
3836 - B574
The Potential of Photodisruption Laser Treatment of the Crystalline Lens to Rupture the Lens Capsule
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Purpose: To evaluate the potential for a photodisruption laser to rupture the crystalline lens capsule during a laser surgical treatment that does not strike the capsule directly.

Methods: A finite element analysis simulation using LS-Dyna was performed on a model of a lens capsule where the variation in capsule thickness, Young's modulus of elasticity and particularly the failure stress and failure strain, as published by Krag (1996) for porcine lenses and Krag (2003) for human lens capsule. A unique attribute of the non-linear finite element analysis program LS-Dyna, which is the automobile industry standard for crash safety evaluation, is the inflatable air bag model. We created models of lens capsules that can be inflated to the point of capsule failure for several animal species to simulate the effect of a photodisruption laser which creates gas bubbles which increase lens volume. We inflated the lens capsule until rupture and evaluated the change in thickness and volume at the time of rupture and compared that to laboratory measurements of expansion due to laser treatment. Mechanical strength of four rabbit lenses were measured using a custom device, with separate measurements for anterior and posterior capsules.

Results: The posterior capsule is the first to rupture during inflation in all models. Human lens capsule are relatively strong and do not show capsule rupture for simulated moderate laser treatment. The measured failure stress for the rabbit posterior capsule averaged 0.45 N/mm² which is approximately 8 times weaker than Krag (2003) had shown for 60 year old human posterior capsules.

Conclusions: Human lens capsule models do not rupture for moderate photodisruption laser treatment while similar levels of laser treatment in rabbit lenses may cause rupture of the posterior capsule.

Support: None

3838 - B576
Lens Culture System for Long Term Study of Porcine Lenses Pre and Post Laser Photodisruption Treatment
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Purpose: To study the effects of photodisruption in a lens over time, a culture system is needed to maintain lens health. We have developed a lens culturing system that is able to maintain the health of porcine lenses for periods exceeding a month post mortem. Additionally, our results show that we are able to maintain the health of photodisrupted lenses.

Methods: Lenses were excised from room temperature porcine eyes less than 4 hours post mortem and then placed in well plates. The lenses were inspected for damage, placed in a wash solution, and then placed in culture medium. The wash solution and culture media consisted of a Modified Liquid medium M199 that was adjusted to a pH of 7.6. The cultured lenses were kept in an incubator at 37°C and in a 4% CO₂/96% air atmosphere for the duration of the experiments with the media solution being replaced every 48 hours. Lenses health was determined by using the AlamarBlue assay and qualitative cell proliferation, cytotoxicity and viability. It incorporates resazurin and resorufin as a fluorometric-colorimetric oxidation-reduction indicator that fluoresces in response to cell metabolism reduction. After 1 week of pre-incubation, the fluorescence levels of the lenses were measured with a fluorescence multi-well plate reader. The readouts obtained at week one were taken as baseline and were compared to subsequent readouts taken weekly along with photography documenting the clarity of the lenses.

Results: The fluorescence multi-well plate reader reported that the control lenses were viable for periods over a month, on average only losing 17% of their initial metabolic rate. We found that when normalized, the average lens metabolic activity decayed at an exponential decay rate of approximately 0.05 per week. During the test period, the clarity in the lenses dropped minimally until the fifth week when the experiment was terminated. When lenses were treated with the laser, the average metabolic rate did not decrease.

Conclusions: We have been able to maintain viable lens specimens for a period of one month post mortem for use in photodisruption experiments. The lenses showed both clarity and metabolic activity. In addition we have been able to maintain lenses that have been photodisrupted for periods in excess of a week with active metabolic rates. This ability to extend the life of lenses has aided in the further study of lens photodisruption.

Support: None

3837 - B575
Measurement of Temperature Rise in Porcine Crystalline Lenses from a Photodisruption Laser
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Purpose: Ultra short pulsed lasers, such as femtosecond or picosecond lasers are known to produce smaller thermal energy than nanosecond laser pulses but it is not known whether such ultra short pulse lasers will still produce sufficient thermal energy to be harmful to the lens. Therefore we seek to measure the temperature rise inside a porcine lens due to irradiation using a photodisruption laser.

Methods: Eleven cultured porcine lenses, whose dimensions were approximately 1mm EQ by 7mm A/P were used which were sufficiently clear as measured visually using a low spatial frequency target behind the lens. The posterior lens capsule was pierced with a scalpel and a 1mm diameter thermocouple probe was inserted into the center of the posterior of the lenses approximately 2mm above the posterior pole. The thermocouple was compared to a known, recently calibrated immersion probe and was within 0.2 degrees C for the experimental temperature range. 1064nm wavelength ultrashort pulsed laser shots were fired in a pattern 4mm in diameter and 3mm in A/P immediately above the thermocouple. Approximately 500mW average power was used in 10 lenses with 6 of the lenses receiving 7 seconds of treatment duration and 4 of the lenses receiving 22 seconds of treatment duration. One lens received a factor of 3 times the energy and average power required for reliable photodisruption.

Results: The results indicate an average of less than 1 degree temperature rise (range of 0 to 2 degrees) for the 500mWatt irradiation for 7 seconds duration and less than 3 degree temperature rise (range of 2 to 3 degrees) for the 22 second treatment. In all cases the lens returned to within 1 degree of the initial temperature within 30 seconds after treatment ended. The 3 times normal energy/power caused a 5 degree maximum temperature rise, but returned to within 1 degree of the initial within 5 seconds after treatment ended.

Conclusions: Ultra short pulsed lasers in the vicinity of 500mWatt average power range do not significantly cause temperature rise inside the crystalline lens.

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