• Basic Research •

Ultraviolet light exposure and its penetrance through the eye in a porcine model

Hideki Fukuoka, Helena E. Gali, Jennifer J. Bu, Ruti Sella, Natalie A. Afshari

Shiley Eye Institute, Viterbi Family Department of Ophthalmology, University of California San Diego, La Jolla, CA 92093, USA

Correspondence to: Natalie A. Afshari. 9415 Campus Point Dr, La Jolla, CA 92093, USA. naafshari@health.ucsd.edu

Received: 2022-06-06 Accepted: 2022-12-14

Abstract

- **AIM:** To determine the amount of ultraviolet (UV) light irradiance that various layers of the eye receive as sunlight passes through the eye, and to investigate the protective benefits of UV light-blocking contact lenses.
- **METHODS:** Twenty-four porcine eyes were prepared in one of three ways: isolated cornea, cornea and lens together, or whole eye preparation. UV light irradiance was measured with a UV-A/B light meter before and after the eye preparations were placed over the meter to measure UV light penetration in each eye structure. In the whole eye preparation, a hole was placed in the fovea to measure light as it passed through the vitreous. Subsequently, UV-protective contact lenses were placed over the structures, and UV light penetrance was measured. Measurements of UV light exposure were taken outdoors at various locations and times.
- **RESULTS:** Cornea absorbed 63.56% of UV light that reached the eye. Cornea and lens absorbed 99.34% of UV light. Whole eye absorbed 99.77% of UV light. When UV-protective contact lenses were placed, absorption was 98.90%, 99.55%, and 99.87%, respectively. UV light exposure was dependent on directionality and time of day, and was greatest in areas of high albedo that reflect significant amounts of light, such as a beach.
- **CONCLUSION:** Cornea absorbs the majority of UV light that reaches the eye in this model. UV-protective contact lenses reduce UV exposure to the eye. Locations with high albedo expose the eye to higher levels of UV light.

- **KEYWORDS:** ultraviolet light; penetrance; contact lens; cornea; lens

DOI:10.18240/ijo.2023.02.02

Citation: Fukuoka H, Gali HE, Bu JJ, Sella R, Afshari NA. Ultraviolet light exposure and its penetrance through the eye in a porcine model. *Int J Ophthalmol* 2023;16(2):172-177

INTRODUCTION

Ultraviolet (UV) light designates a band of the electromagnetic spectrum that includes wavelengths from 10 to 400 nm. These wavelengths are shorter than that of visible light but longer than X-rays. UV radiation is present in sunlight and contributes to approximately 10% of the total light output of the sun. UV light waves have higher frequency and therefore higher energy than that of visible light. These high energy light waves are well-known as environmental human carcinogens that can cause skin cancer, sunburn, and damage to the eye.

The relationship between UV light and damage to the eye has been well established[1]. There is strong evidence that aging of the eye due to UV light exposure throughout a person's lifetime manifests in various ocular pathologies, including cataract, pterygium, and macular degeneration through the induction of oxidative stress[2-3]. Additionally, UV light is likely responsible for eyelid malignancies such as squamous cell carcinoma, basal cell carcinoma, and ocular surface squamous neoplasia[4-5]. A systematic study revealed the global prevalence of any cataract to be 17.20% with much higher prevalence in elderly populations[6], and age-related macular degeneration (AMD) has been found to be the most common diagnosis in retina practices across the United States[7]. The risk of developing these UV- and age-related eye diseases is expected to increase further due to environmental changes such as deleterious ozone depletion.

There remains limited inquiry into the amount of UV light penetrance to the eye and the amount of UV light absorbed by different anatomic structures of the eye. Studies on the human cornea showed an age-dependent effect on UV penetrance; a cornea from a 24-year-old was found to block over 45% of longer wavelength ultraviolet A (UVA) light and 90% of shorter wavelength ultraviolet B (UVB) light, whereas a cornea from the elderly was found to block 60% of UVA but 80% of UVB light[8-9]. Other studies on the topic have examined and quantified the degree of UV light that human and other mammalian retinas can detect and absorb, but there is high variability of UV light sensitivity among ages and macular pigment optical densities[10-11]. UV light protective contact lenses have shown promise in several studies as a way to mitigate UV light exposure, but a study that systematically measures UV penetrance to various eye structures in sequence with and without contact lenses is still needed[12-13].

The aim of our study was to quantify UV light exposure of the different eye structures in a porcine model by determining the amount of UV light irradiance received by the cornea, lens, and retina upon light exposure at various outdoor locations. In addition, the protective benefits of UV light blocking contact lenses and the effect of location, direction faced and time of day on UV light exposure were investigated.

MATERIALS AND METHODS

Ethical Approval All procedures performed in the study were in accordance with the Association for Research in Vision and Ophthalmology (ARVO) Statement for Use of Animals in Ophthalmic Vision and Research.

Twenty-four porcine eyes (Sierra Medical, Whittier, CA, USA), harvested from Yorkshire crossbreeds at six months of age and a weight of 200 to 250 pounds, were prepared less than one week post-mortem to isolate various structures of the eye. A porcine model was chosen due to its biological similarities to the human eye, in terms of both its size, anatomy, and architecture of the retina[14]. In eight eyes, cornea was removed so that the isolated cornea could be exposed to UV light, and UV light penetrance could be tested. In the second set of eight eyes, cornea, iris, and lens were isolated from the globe so that cornea and lens together could be tested. In the third set of eight eyes, the whole eyes were left intact, but a 5 mm diameter hole (maculostomy) was placed in the back of the retina on the fovea, identified by its temporal location to the optic disc and different color from surrounding tissue, so that the UV light penetrance through the cornea, lens, and vitreous could be tested. For this study, "eye structure" will hereby refer to the cornea preparation, the cornea and lens preparation, or the whole eye preparation.

Irradiance of the sun outdoors was measured during midday hours between 10:00 and 14:00 using an UV-A/B light meter (UV513AB; GENERAL TOOLS & INSTRUMENTS LLC, Secaucus, NJ, USA) designed to detect UV light between 280 to 400 nm wavelengths. The UV light meter was first placed in a box created to block sunlight, including UV light, to ensure that the UV light meter did not record any UV light exposure while it was in the box. A 1 cm diameter hole was placed on the top of the box. The detector portion of the UV light meter was attached to the underside of the hole in the box so that the only light reaching the detector was coming from a direct, perpendicular angle to the detector. This ensured that no background or stray UV light was being measured. To obtain a UV light measurement for exposure at baseline, the meter was placed facing skyward to measure UV light exposure while the detector was in the box. Next, one of the eye structures was placed over the hole of the box directly on top of the UV light meter, and a UV light exposure measurement was recorded to determine how much UV light passed through the structure being tested. The cornea was placed flat on the detector. The cornea and lens together were also placed flat on the detector. The whole eye preparation was placed slightly angled on the detector so that the light angle from the sun could shine directly through the cornea, lens, and vitreous to reach the hole in the fovea in a direct line: the visual axis. For each eye tested, one UV light measurement was taken at baseline without the eye present to establish baseline UV light exposure, and ten repeat UV light measurements were taken for each eye.

To ensure that the angle to the fovea did not impact UV irradiation and absorption rate in the whole eye structure group, three porcine eyes were obtained (Ward's Science, Rochester, NY, USA) and a 5 mm diameter hole was placed in the back of the retina to create a direct line for sunlight perpendicular to the center of the cornea: the optical axis. Ten measurements were taken both with the eye placed flat on the detector, and at a slight angle similar to the angle of the fovea, with corresponding baseline measurements.

Once ten measurements of UV light exposure were made for each individual structure, a new UV-blocking contact lens (Acuvue Oasys; Johnson & Johnson Vision; Jacksonville, FL, USA) was placed over the eye structure. Once in place, 10 more UV light measurements were made to determine how much UV light passed through the eye structure and contact lens together. In total, 20 measurements were made for each individual eye structure, which were then compared to the baseline UV light reading that each eye structure was exposed to during the time it was being tested. Averages UV light exposures were calculated for each eye, and these averages could be compared to baseline UV light measurements to determine the percentage of UV light that penetrated each eye structure. Average total UV exposure time for each eye was three to four minutes, the amount of time taken to perform all measurements of UV irradiation with and without the contact lens. Eye structures were stored in phosphate-buffered saline (PBS; pH=7.4; Corning Inc., Corning, NY, USA) when not in use during experimentation to prevent dehydration of the tissues. Furthermore, to prevent dehydration of the tissues during the measurement process, PBS solution was dropped onto the eye structures when dryness was observed, defined as a lack of moisture film or smoothness of the corneal surface. This typically occurred near the end of the measurement process for each eye structure.

Three contact lenses (Acuvue Oasys; Johnson & Johnson Vision; Jacksonville, FL, USA) were tested independently without any eye structure being placed underneath them in order to determine the UV light penetrance of the contact lens alone. A baseline UV light measurement was made, and ten UV light measurements were made with a contact lens in place.

Lastly, the UV light meter was taken to three outdoor locations at three different time windows of the day on the same day to determine comparatively the amount of UV light that reaches the eye under daily conditions. The locations selected were a beach (32° 51’ 24” N, 117° 15’ 26” W), a grocery store parking lot (32° 51’ 43” N, 117° 13’ 27” W), and a grassy field (32° 51’ 25” N, 117° 15’ 25” W). The beach was selected based on its known high levels of UV light exposure. The grocery store was selected to model an activity of daily living. The grassy field was selected as comparison to the beach because it does not have as much surface albedo, defined as the proportion of light or radiation that is reflected from a surface, due to the lack of reflectiveness of the grass as compared to light-colored sand.

Measurements at these three locations were taken at approximately mid-morning (around 9:00 *a.m.*), midday (around 12:00 *p.m.*), and mid-afternoon (around 3:00 *p.m.*). These times were selected because the sun changes angle throughout the day, which could impact how much UV light the eye receives at different times. To measure UV light exposure in these areas, the UV light meter was held 5’ 5” off the ground and perpendicular to the ground to mimic a person standing facing forward. The detector was pointed in northward, eastward, southward, and westward directions at 10° N, 90° E, 200° S, and 250° W, respectively. These directions were determined using a global positioning system (GPS) compass. Six measurements were taken in each of the four directions at three times during the day at each location, and averages of these measurements were made. With these measurements, UV light exposure to the eye could be compared based on location and time of day. Values are reported as mean with standard deviation.

RESULTS

Because baseline UV light exposure for each eye structure differed depending on the time of day that the eye structure was measured and the baseline UV light that it was exposed to, results were determined by calculating the percentage of UV light exposure that the eye structure absorbed as compared to baseline.

On average, the cornea allowed 36.44% of UV light to pass through it, absorbing 63.56% of UV light. For the cornea and lens together, the two structures allowed 0.66% of UV light to pass through, absorbing 99.34% of light. Lastly, the whole eye preparation (including the vitreous) allowed 0.23% of UV light to pass through, absorbing 99.77% of UV light. Table 1 depicts UV light penetrance through these various structures. UV light penetrance was not significantly different in measurements taken with the eye placed flat on the detector, and with the eye placed at a slight angle on the detector (0.53% *vs* 0.56%, *P*=0.81). When UV-protective contact lenses were placed over the eye structures, paired sample *t*-tests showed significantly decreased UV penetrance percentage through the cornea (1.10% *vs* 36.44%, *P*<0.0001), the cornea and lens together (0.45% *vs* 0.66%, *P*<0.001), and the entire eye (0.13% *vs* 0.23%, *P*<0.01), with contacts compared to without contacts. Measured UV penetrance comparison can be seen in Figure 1. The three Acuvue Oasys contact lenses that were tested allowed an average of 0.80% of light to pass through, absorbing 99.20% of UV light.

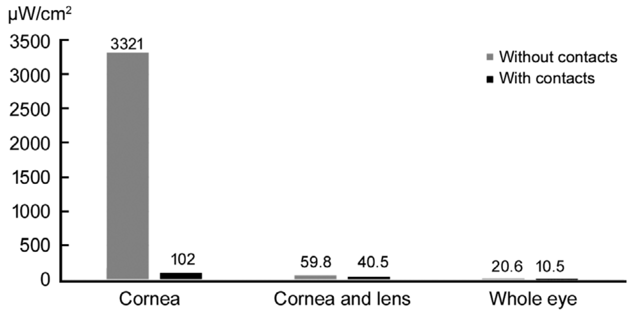

Figure 1 UV light penetrance through eye structures with and without UV blocking contact lenses.

Table 2 shows the effect of location, direction, and time of day on UV light exposure. UV exposure was greatest in areas with high albedo, with a paired *t*-test matching for direction showing that overall UV exposure was significantly greater at the beach than either a grass field or parking lot (*P*<0.0001 for both). The highest exposure occurred when the UV light detector was pointed in a coordinate direction that was facing the sun at a time when it was lower in the sky. For example, at the beach, the highest UV light recorded was 5616 μW/cm^2 at 3:45 *p.m.* facing 250° west (Table 2). This time and direction correspond with the sun lowering in the sky as it sets in the west. This angle subjected the horizontally facing UV light detector to a more direct angle of sun. In contrast to this, the same beach location at the same time recorded a UV light exposure of 1452.5 μW/cm^2 when the detector was facing 90° east. This direction corresponded to the sun shining from behind the detector, exposing the detector to a less direct angle of sunlight.

DISCUSSION

In our study we have explored UV light penetrance to various anatomical structures of the eye and ways to reduce penetrance both through UV light-blocking contact lens and environmental factors such as location, angle, and time of

Table 1 UV light penetrance and percentage penetrance through eye structures

Structure	UV measured (μW/cm^2)		Penetrance	UV measured with CL (μW/cm^2)		[a]Penetrance
	Baseline	Through structure	(%)	Baseline	Through CL + structure	(%)
Cornea 1	10210	5105	50.00	10400	208	2.00
Cornea 2	8973	3966	44.19	8917	107	1.20
Cornea 3	8593	4262	49.60	8650	173	2.00
Cornea 4	8531	3131	36.70	8523	75.0	0.88
Cornea 5	8513	2835	33.30	8529	58.0	0.68
Cornea 6	10156	2153	21.20	10100	70.7	0.70
Cornea 7	8925	2624	29.40	8902	73.0	0.82
Cornea 8	9196	2492	27.10	9208	48.8	0.53
Average±SD	9137±688	3321±1020	36.44±10.6	9153±718	102±58.1	1.10±0.58
Cornea+lens 1	10255	56.4	0.55	10296	27.8	0.27
Cornea+lens 2	8947	67.1	0.75	8964	50.2	0.56
Cornea+lens 3	8597	57.6	0.67	8653	42.4	0.49
Cornea+lens 4	8446	47.3	0.56	8457	38.9	0.46
Cornea+lens 5	8482	70.4	0.83	8518	47.7	0.56
Cornea+lens 6	10192	53.0	0.52	10238	43.0	0.42
Cornea+lens 7	8944	63.5	0.71	8962	47.5	0.53
Cornea+lens 8	9188	63.4	0.69	9034	26.2	0.29
Average±SD	9131±721	59.8±7.66	0.66±0.11	9140±728	40.5±9.05	0.45±0.11
Whole eye 1	10118	17.2	0.17	10000	10.0	0.10
Whole eye 2	9091	30.0	0.33	9333	11.2	0.12
Whole eye 3	8630	23.3	0.27	8385	10.9	0.13
Whole eye 4	8316	15.8	0.19	8500	10.2	0.12
Whole eye 5	8600	12.9	0.15	8300	8.3	0.10
Whole eye 6	10000	23.0	0.23	10000	14.0	0.14
Whole eye 7	8893	24.9	0.28	8800	13.2	0.15
Whole eye 8	9158	17.4	0.19	3882	6.6	0.17
Average±SD	9100±652	20.6±5.66	0.23±0.06	8400±1949	10.5±2.41	0.13±0.02

[a]Percentage penetrance of UV light was computed by dividing UV measured through the structure and/or contact lens, over baseline UV measured in the absence of any structure. CL: Contact lens; UV: Ultraviolet.

Table 2 UV Light measured by location, direction, and time

Direction	UV Measured (μW/cm^2)		
	Beach at 09:00	Grass at 09:00	Parking lot at 09:00
250° W	1662.83	1255.83	914
10° N	1899.33	1358.33	1648.33
90° E	4931.5	4136.17	4230.83
200° S	1483	1083	947.33
	Beach at 12:00	Grass at 12:00	Parking lot at 12:00
250° W	1947.33	1441	942.33
10° N	1818.83	1265.50	1466.5
90° E	1707	1389.83	1579.67
200° S	2055.17	1516.83	1254.17
	Beach at 15:00	Grass at 15:00	Parking lot at 15:00
250° W	5616	4764.50	5258.17
10° N	1635	1139	1108.33
90° E	1452.50	1004.5	1006.67
200° S	2129.50	1507.5	921

UV: Ultraviolet.

day. Our study shows that cornea can absorb the majority of UV light that reaches the eye. Cornea is the anterior-most structure of the eye, and so it follows that about two-thirds of UV light that reaches the eye is absorbed by this structure. This finding is in line with previous studies demonstrating a similar UV light absorption profile of the cornea[15-16]. Because roughly two-thirds of UV light that reaches the eye is absorbed by the cornea, the lens is left to absorb about one-third of the UV light that reaches the eye in total. This indicates that UV-protective measures such as contact lenses can absorb a significant amount of UV light that would have otherwise been delivered to the cornea and lens, with the potential to reduce incidence of UV-related pathologies in these structures such as cataract. Furthermore, patients can also be counseled to identify environmental factors in which they may benefit more from UV-protecting contacts or other sun protection options such as sunglasses. We found that time of day (mid-morning and afternoon) and albedo (areas with reflective surfaces such as cars and beaches) can increase UV radiation, but the largest determinant of UV radiation appeared to be angle. When facing directions that allow for a more direct angle of sun exposure to the eye, UV light exposure was almost three times as high in the same location. This is especially important to know for people with outdoor occupations who spend a significant amount of time in high exposure areas, such as life guards, who may be at increased risk of higher levels of UV light exposure[17].

Because UV-protective contact lenses do not cover the conjunctiva, presumably the risks of pterygium and pathologies occurring outside of the cornea are not reduced with contact lens wear. Additionally, it has been shown that tears provide antioxidant protection to the surface of the eye. However, aging eyes may have less tear flow and therefore are more prone to the oxidative stresses of UV light[18]. With less tear flow in an area that is not covered by contact lens wear, it may be even more important for elderly patients to be counseled on the use of sunglasses or protective lens.

There are several sources of variability and factors that could have affected the outcome and results in our study. Variability in weather and cloud cover on the days that the eye structures were tested could have resulted in differing intensities of UV light on the days that the eye structures were tested. To account for this, the percentage calculation of UV light that reached the UV light detector compared to the UV light at baseline was used to determine results. Additionally, there was a natural evaporation of moisture of the eye structures throughout the measurement process. To minimize this, each structure tested was quickly removed from solution and placed on the UV light meter, and measurements were recorded. Because of sun exposure and the resulting heat, some evaporation did occur toward the end of the measurement process, to which solution was applied as soon as dryness was observed. Still, this can be limited by observer subjectivity and environmental lighting, and therefore some variability in moisture content could exist. Future experimentation could re-hydrate the tissue using a fixed time interval. Corneal edema was minimized by using pig eyes that were less than one week post-mortem, however different daily post-mortem degeneration processes and age of animal at time of extraction could have also produced some variability in the data given evidence of light scatter based on corneal surface and transparency[19]. While pachymetry was not measured in this study, previous studies have shown that corneal thickness measured with a pachymeter increases after repeated UV light exposure[20]. We also did not record corneal endothelial cell count, which could also account for some variation in data.

While the UV light meter could detect the amount of light that was able to bypass the eye structure that was being tested, we were unable to test what happened to the light that was not able to pass through each structure. More investigation should follow to determine if the eye structures that were tested absorbed, scattered, or reflected the UV light. Additionally, because we used a UVA/B combination light meter, a distinction between UVA and UVB light wavelength and respective penetration through the eye structures was not determined.

In conclusion, in our study cornea and lens together prevented 99.34% of UV light that reached the eye to pass through to the retina. UV protective contact lenses significantly reduce UV exposure to all portions of the eye, but especially to the anterior segment. We also explore ways that environmental factors such as location and time of day can impact UV light exposure. With the anterior structures of the eye being most impacted by UV light and with the effectiveness of UV-protective contact lenses, protecting anterior eye structures with UV-blocking contact lenses could reduce the risk of UV light-mediated eye disease and aging.

ACKNOWLEDGEMENTS

Foundation: Supported by Research to Prevent Blindness, New York, NY, USA.

Conflicts of Interest: Fukuoka H, None; **Gali HE,** None; **Bu JJ,** None; **Sella R,** None; **Afshari NA,** None.

REFERENCES

1 McCarty C, Taylor HR. Light and risk for age-related eye diseases. Nutritional and environmental influences on the eye: CRC Press; 2021:135-150.

2 Hatsusaka N, Yamamoto N, Miyashita H, Shibuya E, Mita N, Yamazaki M, Shibata T, Ishida H, Ukai Y, Kubo ER, Cheng HM, Sasaki H. Association among pterygium, cataracts, and cumulative ocular ultraviolet exposure: a cross-sectional study in Han people in China and Taiwan. *PLoS One* 2021;16(6):e0253093.

3 Zhou HJ, Zhang HN, Yu AQ, Xie JJ. Association between sunlight exposure and risk of age-related macular degeneration: a meta-analysis. *BMC Ophthalmol* 2018;18(1):331.

4 Hollhumer R, Williams S, Michelow P. Ocular surface squamous neoplasia: population demographics, pathogenesis and risk factors. *Afr Vis Eye Health* 2020;79(1).

5 Chen L, Bellone RR, Wang Y, Singer-Berk M, Sugasawa K, Ford JM, Artandi SE. A novel DDB2 mutation causes defective recognition of UV-induced DNA damages and prevalent equine squamous cell carcinoma. *DNA Repair* (*Amst*) 2021;97:103022.

6 Hashemi H, Pakzad R, Yekta A, Aghamirsalim M, Pakbin M, Ramin S, Khabazkhoob M. Global and regional prevalence of age-related cataract: a comprehensive systematic review and meta-analysis. *Eye* (*Lond*) 2020;34(8):1357-1370.

7 Rosenblatt TR, Vail D, Saroj N, Boucher N, Moshfeghi DM, Moshfeghi AA. Increasing incidence and prevalence of common retinal diseases

in retina practices across the United States. *Ophthalmic Surg Lasers Imaging Retina* 2021;52(1):29-36.

8 Delic NC, Lyons JG, Di Girolamo N, Halliday GM. Damaging effects of ultraviolet radiation on the cornea. *Photochem Photobiol* 2017;93(4):920-929.

9 Mallet JD, Rochette PJ. Wavelength-dependent ultraviolet induction of cyclobutane pyrimidine dimers in the human cornea. *Photochem Photobiol Sci* 2013;12(8):1310-1318.

10 Hammond BR Jr, Renzi-Hammond L. Individual variation in the transmission of UVB radiation in the young adult eye. *PLoS One* 2018;13(7):e0199940.

11 Douglas RH, Jeffery G. The spectral transmission of ocular media suggests ultraviolet sensitivity is widespread among mammals. *Proc Biol Sci* 2014;281(1780):20132995.

12 Notara M, Behboudifard S, Kluth MA, Maßlo C, Ganss C, Frank MH, Schumacher B, Cursiefen C. UV light-blocking contact lenses protect against short-term UVB-induced limbal stem cell niche damage and inflammation. *Sci Rep* 2018;8(1):12564.

13 Chandler H. Ultraviolet absorption by contact lenses and the significance on the ocular anterior segment. *Eye Contact Lens* 2011;37(4):259-266.

14 Sanchez I, Martin R, Ussa F, Fernandez-Bueno I. The parameters of the porcine eyeball. *Graefes Arch Clin Exp Ophthalmol* 2011;249(4):475-482.

15 Doutch JJ, Quantock AJ, Joyce NC, Meek KM. Ultraviolet light transmission through the human corneal stroma is reduced in the periphery. *Biophys J* 2012;102(6):1258-1264.

16 Meek KM, Knupp C. Corneal structure and transparency. *Prog Retin Eye Res* 2015;49:1-16.

17 Modenese A, Gobba F. Occupational exposure to solar radiation at different latitudes and pterygium: a systematic review of the last 10 years of scientific literature. *Int J Environ Res Public Health* 2017;15(1):37.

18 Ivanov IV, Mappes T, Schaupp P, Lappe C, Wahl S. Ultraviolet radiation oxidative stress affects eye health. *J Biophotonics* 2018;11(7):e201700377.

19 Spadea L, Maraone G, Verboschi F, Vingolo EM, Tognetto D. Effect of corneal light scatter on vision: a review of the literature. *Int J Ophthalmol* 2016;9(3):459-464.

20 Čejka Č, Ardan T, Širc J, Michálek J, Beneš J, Brůnová B, Rosina J. Hydration and transparency of the rabbit cornea irradiated with UVB-doses of 0.25 J/cm^2 and 0.5 J/cm^2 compared with equivalent UVB radiation exposure reaching the human cornea from sunlight. *Curr Eye Res* 2011;36(7):607-613.