Association of Age, Stature, and Education With Ocular Dimensions in an Older White Population

Kristine E. Lee, MS; Barbara E. K. Klein, MD, MPH; Ronald Klein, MD, MPH; Zoe Quandt, BS; Tien Yin Wong, MD, PhD

Objective: To describe ocular biometry relationships in older white adults.

Methods: Ocular dimensions were measured with partial coherence laser interferometry in 1968 persons (aged 58-100 years, 59% female) seen at the fourth examination of the Beaver Dam Eye Study. Generalized estimating equations–modeled associations of age, sex, height, and education with ocular dimensions: axial length, corneal curvature radius, and anterior chamber depth.

Results: The mean axial length was 23.69 mm; mean corneal curvature radius was 7.70 mm; and mean anterior chamber depth was 3.11 mm. Participants younger than 65 years had larger eyes (longer axial length, greater corneal curvature radius, and deeper anterior chamber depth) than persons aged 75 years or older. Mean axial length was 23.86 mm, 23.66 mm, and 23.55 mm in people aged 64 years and younger, 65 to 74 years, and 75 years or older, respectively. Generally, larger eyes were observed in men (vs women) and in taller (>178 vs ≤158 cm) and more educated (>16 vs <12 years) persons. Adjustment for height accounted for all sex differences. Age differences in axial length were attenuated ($P = .06$) after adjustment for both height and education.

Conclusion: In this older white population, age and sex variations in ocular dimensions are partially explained by differences in stature and education.

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Biometric measurements of the globe, such as axial length (AL), corneal curvature radius (CR), and anterior chamber depth (ACD), have been found to differ by sex and age from childhood through adulthood.[1-5] These measures also differ by stature[5-9] as well as education level.[9-11] Age, sex, stature, and education are all interrelated (eg, older adults are more likely to be shorter and less likely to be highly educated). Axial length in particular is an important determinant of refraction,[4,12,13] which has shown to have strong relationships with age and education.[2,13-19]

Although there have been studies that have assessed the interrelationships of ocular biometry measures with age, sex, stature, and education, most of these studies have been confined to Asian and Hispanic populations.[1,2] Some of these studies have found that AL is shorter in older people and women,[2,6] while others have reported relationships of height and education with various biometry measures.[5-7,20-22] However, there is very little understanding about the complex interrelationships of age, sex, height, and education with ocular biometry measurements in older white adults. Further understanding of such relationships may provide insight into observed trends and patterns of myopia.[13-19]

In the Beaver Dam Eye Study, a population-based cohort study of age-related eye diseases, we had the opportunity to add measurements of ocular dimensions at the fourth examination. In this primary report on these measures, we describe the relationships of ocular biometry components with age, sex, height, and education in this white adult population.

METHODS

STUDY POPULATION

Ocular dimensions were measured during the fourth examination of the Beaver Dam Eye Study cohort. The study began in 1988 with a private census of the population of Beaver Dam, Wisconsin. All individuals (N = 5924) between the ages of 43 and 84 years were identified and invited for a baseline examination from 1988 through 1990. Follow-up examinations were performed every 5 years after, with the fourth examination occurring from May 2003 to May 2005. At each examination, participation rates were over 80%, with the primary reason for nonparticipation being death. At each examination, living nonparticipants were older, less educated, had poorer vision, had higher blood

Author Affiliations: Department of Ophthalmology and Visual Sciences, University of Wisconsin School of Medicine and Public Health, Madison (Ms Lee and Drs B. E. K. Klein and R. Klein); Department of Epidemiology, San Diego State University, San Diego, California (Ms Quandt); and Centre for Eye Research Australia, University of Melbourne, Melbourne (Dr Wong). Ms Quandt is now with the University California–Berkeley/University of California–San Francisco Joint Medical Program, Berkeley.

Table 1. Comparison of Participants at Fourth Examination Phase of the Beaver Dam Eye Study

	Total Study Population		Axial Length			Corneal Curvature Radius			Anterior Chamber Depth		
Characteristic	No. of Participants	Mean (SD)	No. of Participants	Mean (SD)	*P* Value[a]	No. of Participants	Mean (SD)	*P* Value[a]	No. of Participants	Mean (SD)	*P* Value[a]
Age, y	2375	71.9 (9.1)	1967	70.3 (8.0)	<.001	1962	70.3 (8.0)	<.001	1675	69.1 (7.4)	<.001
Male sex, %	2375	41.3	1967	42.7	.25	1962	42.9	.13	1675	44.4	.008
Education, y	2365	12.7 (2.7)	1962	12.9 (2.6)	.75	1957	12.9 (2.6)	.52	1671	12.9 (2.7)	.70
Income, ×$1000	2358	55.0 (20.3)	1965	54.6 (19.2)	<.001	1961	54.5 (19.3)	<.001	1674	54.9 (18.7)	<.001
Height, cm	2336	164.5 (9.8)	1961	164.7 (9.7)	.003	1956	164.7 (9.6)	.02	1671	165.2 (9.6)	.99
Weight, kg	2350	80.3 (18.8)	1960	81.3 (18.7)	.61	1955	81.4 (18.7)	.38	1670	82.2 (18.6)	.16
Current smoker, %	2368	8.7	1967	9.4	.92	1962	9.4	.85	1675	9.8	.63
Hypertension, %	2323	65.6	1965	63.7	.12	1960	63.7	.14	1675	63.2	.82
Diabetes, %	2233	15.8	1949	14.2	<.001	1945	14.3	<.001	1659	13.4	<.001
Spherical equivalent, D	1819	0.38 (2.4)	1670	0.33 (2.3)	.52	1666	0.33 (2.3)	.53	1654	0.32 (2.3)	.46
IOP, mm Hg	2189	15.1 (3.3)	1952	15.1 (3.3)	.07	1948	15.1 (3.3)	.15	1663	15.2 (3.3)	<.001
Any cataract, %	1694	35.0	1604	32.9	.03	1601	32.7	.01	1588	32.6	.004
Early AMD, %	2111	13.6	1859	11.9	.22	1858	12.0	.24	1595	10.5	.19
Late AMD, %	2205	2.8	1895	1.3	<.001	1891	1.3	<.001	1618	0.9	<.001

Abbreviations: AMD, age-related macular degeneration; D, diopters; IOP, intraocular pressure.
[a] Comparison between those in the analysis with those not in the analysis (age-adjusted).

Table 2. Age and Sex Distribution of Ocular Biometry in Right Eyes

		Women			Men				All Participants		
Measure	Age, y	No. of Participants	Mean (SD), mm	*P* Value	No. of Participants	Mean (SD), mm	*P* Value	*P* Value[a]	No. of Participants	Mean (SD), mm	*P* Value
AL	<65	314	23.69 (1.25)		262	24.06 (1.06)			576	23.86 (1.18)	
	65-74	447	23.49 (1.21)	.001	343	23.88 (1.14)	.06		790	23.66 (1.19)	<.001
	≥75	366	23.37 (1.02)	<.001	235	23.83 (1.08)	.02		601	23.55 (1.06)	<.001
	Total	1127	23.51 (1.17)		840	23.92 (1.10)		<.001	1967	23.69 (1.16)	
CR	<65	313	7.67 (0.25)		263	7.77 (0.26)			576	7.72 (0.26)	
	65-74	443	7.66 (0.25)	.36	343	7.77 (0.27)	.73		786	7.71 (0.26)	.55
	≥75	365	7.63 (0.26)	.02	235	7.76 (0.27)	.58		600	7.68 (0.27)	.01
	Total	1121	7.65 (0.25)		841	7.77 (0.27)		<.001	1962	7.70 (0.26)	
ACD	<65	297	3.17 (0.32)		256	3.22 (0.36)			553	3.19 (0.34)	
	65-74	397	3.11 (0.35)	.02	314	3.12 (0.38)	<.001		711	3.11 (0.36)	<.001
	≥75	237	2.95 (0.37)	<.001	174	3.05 (0.40)	<.001		411	2.99 (0.39)	<.001
	Total	931	3.09 (0.36)		744	3.14 (0.38)		.004	1675	3.11 (0.37)	

Abbreviations: ACD, anterior chamber depth; AL, axial length; CR, corneal curvature radius.
[a] Comparison between men and women.

pressure, and smoked more than participants.[23-26] Informed consent was obtained at each examination with institutional review board approval. Tenets of the Declaration of Helsinki were followed. Similar protocols were followed during each examination. Using the National Institutes of Health classification of race, we identified 99% of the population as white.

MEASUREMENTS

Ocular biometry measures were added for the fourth examination, and those data are used in this article. The relevant portions of this examination, summarized herein, include standardized noncycloplegic refraction using an automated refractor (Humphrey, San Leandro, California) with further modification if resulting visual acuity was 20/40 or worse[27]; ocular biometry using partial coherence laser interferometry (IOL Master; Carl Zeiss, Jena, Germany) for AL, ACD, and CR; measurements of height and weight; questions about education; and assessment of lens status using standardized lens photography and grading.[28]

Weight was measured to the nearest quarter pound and converted to kilograms by multiplying by 0.4536. Height was measured to the nearest quarter inch and converted to centimeters by multiplying by 2.54. If we were unable to measure height or weight (3% of population), self-reported measurements were used. Education was assessed with the question: "What was the highest year of school or college you completed?" During slit-lamp examination, the examiner assessed lens status.

Ocular biometry was measured following manufacturer's recommendations in 1976 participants (83%) before pupillary dilation (both eyes in 1962 participants, right eye only in 6, left eye only in 8). Reasons for not measuring ocular biometry (right eye) included the following: examinations conducted off site (n=243), physical limitations (n=41), not enough time (n=56), and other/unspecified/refusal/inability (n=67). The average of the 2 corneal curvature meridians was used for analysis of CR. Anterior chamber depth measurements were not included in the analyses in persons without a lens or with an intraocular lens (n=269). Comparison of characteristics in those included for various analyses is presented in **Table 1**. In general, those included in analyses were younger, taller, and, after age adjustment, less likely to have diabetes, cataract, or age-related macular degeneration. There were no differences in education or refraction (spherical equivalent).

STATISTICAL ANALYSIS

For all analyses, SAS, version 9.1 (SAS Institute Inc, Cary, North Carolina), was used. Normality of each ocular biometry mea-

sure (AL, CR, and ACD) was assessed. Mean ocular dimensions were calculated for each eye separately and are reported for the right eye, as analyses for left eyes were similar (data not shown). However, both eyes were included in analysis of variance models with the generalized estimating equations approach to adjust for correlation between the eyes. All adjustments were done for the continuous version of the variables. Models were assessed using appropriate contrast statements.

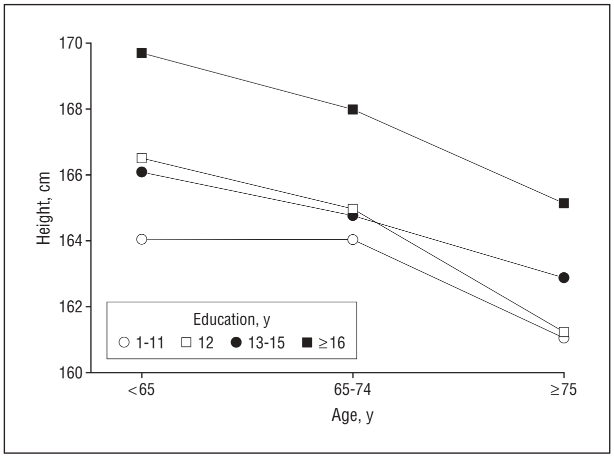

Figure 1. Distribution of height by age and educational level.

RESULTS

The associations of age and sex with the ocular dimensions and refractions are presented in **Table 2**. Men and younger persons had longer AL, greater (flatter) CR, and deeper ACD than women and older individuals, respectively. Persons younger than 65 years of age had a mean AL of 23.86 mm, a mean CR of 7.72 mm, and a mean ACD of 3.19 mm. Persons who were aged 75 years or older had a mean AL of 23.55 mm, a mean CR of 7.68 mm, and a mean ACD of 2.99 mm.

Both height and education decreased with increasing age. Persons younger than 65 years had a mean height of 167.1 cm (standard deviation [SD], 9.9 cm) and had completed a mean of 13.6 years (SD, 2.6 years) of school. On average, persons aged 75 years or older were 162.0 cm (SD, 9.6 cm) tall and had completed 12.1 years (SD, 2.9 years) of school. The age trends were similar within sex, and women were shorter (mean [SD], 158.6 [6.6] vs 172.9 [7.2] cm) and had completed less schooling (mean [SD], 12.5 [2.3] vs 13.1 [3.2] years) than men. Within each age category, persons with more education were taller (**Figure 1**). The same trends were observed within each sex (data not shown).

Table 3. Association of Height and Education With Ocular Biometry in Right Eyes

Measure	Women		Men		All Participants	
	No. of Participants	Mean (SD)	No. of Participants	Mean (SD)	No. of Participants	Mean (SD)
Axial Length						
Height, cm						
≤158	495	23.35 (1.18)	15	23.57 (1.26)	510	23.36 (1.18)
159-168	562	23.59 (1.12)	189	23.66 (1.08)	751	23.61 (1.11)
169-178	70	23.98 (1.27)	453	23.93 (1.10)	523	23.94 (1.13)
>178	0		183	24.20 (1.03)	183	24.20 (1.03)
Education, y						
1-11	153	23.23 (1.44)	128	23.54 (0.85)	281	23.37 (1.22)
12	593	23.47 (1.09)	385	23.86 (1.15)	978	23.62 (1.13)
13-15	214	23.61 (1.21)	124	24.01 (1.03)	338	23.76 (1.16)
≥16	165	23.77 (1.00)	200	24.25 (1.09)	365	24.03 (1.07)
Corneal Curvature Radius						
Height, cm						
≤158	491	7.60 (0.25)	15	7.65 (0.23)	506	7.60 (0.25)
159-168	560	7.69 (0.24)	189	7.69 (0.27)	749	7.69 (0.25)
169-178	70	7.74 (0.27)	454	7.78 (0.26)	524	7.77 (0.26)
>178	0		183	7.84 (0.26)	183	7.84 (0.26)
Education, y						
1-11	150	7.63 (0.25)	128	7.73 (0.25)	278	7.68 (0.26)
12	591	7.64 (0.25)	386	7.78 (0.27)	977	7.70 (0.27)
13-15	213	7.66 (0.24)	124	7.75 (0.24)	337	7.69 (0.24)
≥16	165	7.70 (0.25)	200	7.79 (0.27)	365	7.75 (0.27)
Anterior Chamber Depth						
Height, cm						
≤158	392	3.04 (0.36)	11	3.17 (0.42)	403	3.04 (0.36)
159-168	479	3.11 (0.35)	163	3.07 (0.38)	642	3.10 (0.36)
169-178	60	3.22 (0.37)	402	3.13 (0.38)	462	3.15 (0.38)
>178	0		168	3.21 (0.37)	168	3.21 (0.37)
Education, y						
1-11	120	2.95 (0.35)	109	3.00 (0.34)	229	2.97 (0.34)
12	493	3.09 (0.36)	336	3.13 (0.37)	829	3.11 (0.36)
13-15	178	3.11 (0.33)	112	3.14 (0.38)	290	3.12 (0.35)
≥16	138	3.16 (0.36)	185	3.22 (0.41)	323	3.20 (0.39)

Ocular dimensions varied with height and education and were similar in men and women (**Table 3**). Taller individuals generally had larger eyes. In all participants, mean AL was 23.36 mm in those shorter than 158 cm and 24.20 mm in those taller than 178 cm ($\beta = .31$, $P < .001$ per 10 cm). Similarly, CR increased from 7.60 to 7.84 mm ($\beta = .08$, $P < .001$), and ACD increased from 3.04 to 3.21 mm ($\beta = .05$, $P < .001$). Persons with more education had longer AL ($\beta = .08$, $P < .001$ per year), greater (flatter) CR ($\beta = .009$, $P < .001$), and deeper ACD ($\beta = .02$, $P < .001$). When comparing CR by categories of education, only those with 16 or more years of education had significantly higher CR (vs those with 1-11 years of education). Additional adjustment for height attenuated the associations, but they remained statistically significant (not shown).

To further explore whether height differences may explain associations of age, sex, and education with the biometry measures, we plotted AL by height for age (**Figure 2**A), sex (Figure 2B), and education (Figure 2C). For persons of the same height, those younger than 65 years and those with more education appeared to have longer AL. Similar figures for CR and ACD (not shown) also suggested that among those with the same height, younger persons had deeper ACD and those with 16 or more years of education had greater (flatter) CR and deeper ACD.

In models adjusting for height and education (**Table 4**), associations of age and sex with the ocular components were attenuated. Importantly, the association of age with AL was nonsignificant after adjustment for both height and education ($P = .06$). The association of age with CR was no longer significant after adjustment for height. Education did not add information beyond height for CR. When both height and education were added to the model for ACD, the age association remained significant. The associations of sex with AL, ACD, and CR were no longer significant after adjustment for height.

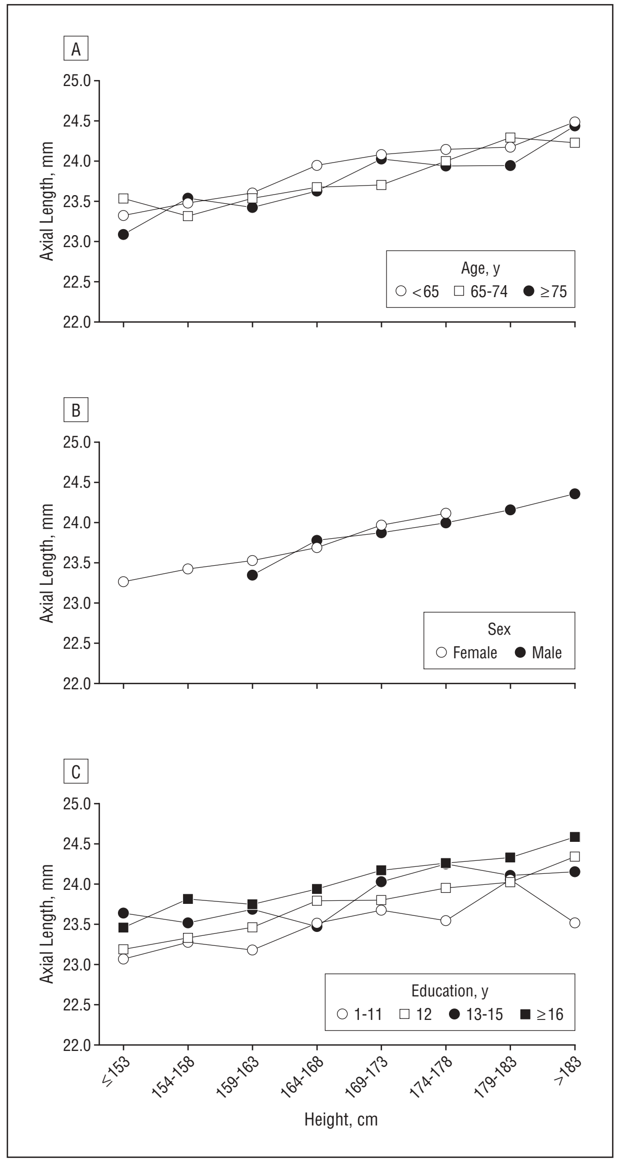

Figure 2. Distribution of axial length (right eyes) by height and age (A), sex (B), and education (C) in the Beaver Dam Eye Study.

COMMENT

In this study, we report on the distribution of ocular biometry measures in an older white population. We found that men and younger, taller, and more educated people had generally longer AL and larger eyes. We found that height explained most of the variations in the measures between men and women as well as the variation in CR between younger and older people. Adjustment for education in addition to height explained some of the variation in AL between younger and older people.

As in previous studies in Asian and Hispanic populations, we found that younger persons had longer AL, greater (flatter) CR, and deeper ACD than older persons. In a separate analysis in which we used age groups similar to those in other studies,[1,2] this white population had, on average, longer AL and greater CR than Asian and Hispanic populations (K.E.L., unpublished data, 2007). In women aged 60 to 69 years, the mean AL was 23.7 mm in the Beaver Dam Eye Study, 22.7 mm in the Tanjong Pagar Survey,[1] 23.2 mm in Mongolia,[29] and 23.1 mm in the Los Angeles Latino Eye Study.[2] These differences may be influenced by differing methods used to obtain biometry measures (the IOL Master compared with ultrasonography). Additionally, our population was slightly older and taller, had more years of education, and had a spherical equivalent between that of the Asian and Hispanic populations.[1,2]

The age and sex differences observed for AL, CR, and ACD may be associated with older persons and women having smaller statures and thus smaller eyes. In our population, height decreased by 1.3 cm for every 5-year increase in age, and women were on average 14 cm shorter than men. In addition, shorter persons had significantly shorter AL, shorter CR, and shallower ACD, which is consistent with observations in Asian populations.[5,6] Height was not related to the AL:CR ratio (K.E.L., unpublished data, 2007), supporting the notion that AL and CR remained in similar proportions for taller and shorter persons. Adjustment for height attenuated the associations

Table 4. Generalized Estimating Equation Models for Ocular Dimensions With Age, Sex, Height, and Education

Measure	Model 1[a] β (95% CI)	Model 1[a] *P* Value[c]	Model 2[b] β (95% CI)	Model 2[b] *P* Value[c]
Axial Length				
Male vs female	0.41 (0.32 to 0.50)	<.001	0.02 (−0.13 to 0.16)	.80
Age, per 5 y	−0.08 (−0.11 to −0.05)	<.001	−0.03 (−0.07 to 0.001)	.06
Height, per 10 cm			0.20 (0.14 to 0.26)	<.001
Education, per 4 y			0.24 (0.16 to 0.31)	<.001
Corneal Curvature Radius				
Male vs female	0.12 (0.10 to 0.14)	<.001	0.002 (−0.03 to 0.04)	.88
Age, per 5 y	−0.01 (−0.02 to −0.003)	.005	0.001 (−0.01 to 0.01)	.74
Height, per 10 cm			0.06 (0.05 to 0.08)	<.001
Education, per 4 y			0.01 (0.00 to 0.03)	.11
Anterior Chamber Depth				
Male vs female	0.04 (0.01 to 0.08)	.01	−0.01 (−0.06 to 0.04)	.69
Age, per 5 y	−0.06 (−0.07 to −0.05)	<.001	−0.05 (−0.06 to −0.04)	<.001
Height, per 10 cm			0.03 (0.01 to 0.05)	.01
Education, per 4 y			0.06 (0.03 to 0.08)	<.001

Abbreviation: CI, confidence interval.
[a]Adjusted for age and sex.
[b]Adjusted for age, sex, height, and education.
[c]Analogous to type III sums of squares.

of age and sex with the ocular biometry measures. The sex differences for all measures were no longer significant after height adjustment. However, despite some attenuation, older individuals still had shorter AL and shallower ACD, but there were no significant differences in CR after adjustment for height. The AL:CR ratio was greater in younger persons (K.E.L., unpublished data, 2007) even after adjustment for height, suggesting that these persons have proportionately longer AL, given the CR, than older persons.

The association between education and AL has not been widely studied.[30] It may reflect excessive AL growth associated with near work (use-abuse theory),[13] as supported by data from studies of medical students or microscopists that show an increase in AL with adult-onset myopia.[10,11,31] It may also reflect larger stature resulting from a higher socioeconomic status and better nutrition associated with more-educated groups. Indeed, we found that in persons of the same age, those with more education tended to be taller. We also observed that in persons of the same height, those with more education had longer AL. We found that more education was significantly associated with longer AL, greater (flatter) CR, and deeper ACD. With the exception of CR, these associations remained despite adjustment for age and height (data not shown). Thus, height differences associated with education do not explain longer AL in persons with more education.

The major limitation in this and other reported population-based studies is their cross-sectional design, which does not allow evaluation of change in these measures with age. To investigate a real effect of aging as opposed to a cohort effect, longitudinal data are needed. While such data are lacking for AL, data on myopia suggest that the aging process may explain age-related declines in myopia observed in many cross-sectional studies.[32] It is possible that some of these results may be affected by differential survival, in which survivors may be taller and more educated. However, we did not observe large differences in baseline height or education level in participants in this analysis compared with all participants in the baseline examination phase.

An important observation in our study was that adjustment for both education and height attenuated the association between age and AL. Younger persons had more education and were taller. In persons with a similar height, those with 16 or more years of education had longer AL. Our finding that age variation in AL, a key determinant of refraction, is largely explained by height and education may partially explain the cohort effect of more myopic refractions at younger ages.

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Correspondence: Kristine E. Lee, MS, Department of Ophthalmology and Visual Sciences, University of Wisconsin–Madison, 610 N Walnut St, 405 WARF Bldg, Madison, WI 53726-2336 (klee@epi.ophth.wisc.edu).
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