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Age, Stature, and Education Associations with Ocular Dimensions in an Older White Population

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Abstract

Purpose—To describe ocular biometry relationships in older white adults.

Methods—Ocular dimensions were measured with partial coherence laser interferometry (IOL Master, Carl Zeiss, Germany) in 1968 persons (ages 58–100 years, 59% female) seen at the fourth examination of the Beaver Dam Eye Study. Generalized estimating equations modeled age, gender, height, and education associations with ocular dimensions: axial length (AL), corneal curvature radius (CR), anterior chamber depth (ACD).

Results—The mean AL was 23.69mm, CR 7.70mm, and ACD 3.11mm. Participants younger than 65 years had larger eyes (longer AL, greater CR, and deeper ACD) than persons 75 years and older. AL was 23.86mm, 23.66mm, and 23.55mm in people younger than 65 years, 65 to 74 years, and 75 years or older, respectively. Generally larger eyes were observed for men (vs women), for taller (> 178 cm vs ≤ 158 cm) and for more educated (16+ vs < 12 years) persons. Adjustment for height accounted for all gender differences. Age differences in AL were attenuated ($P=0.06$) after adjustment for both height and education.

Conclusions—In this older white population, age and gender variation in ocular dimensions is partially explained by differences in stature and education.

Keywords

axial length; corneal curvature; aging; education; stature

Biometric measurements of the globe, such as axial length, corneal curvature, and anterior chamber depth, have been found to differ by gender and age from childhood through adulthood.^{1–5} These measures also differ by stature^{5–9} as well as education level.^{9–11} Age, gender, stature, and education are all interrelated (e.g. 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 strong relationships to age and education.^{2,13–19}

Although there have been studies that have assessed the inter-relationships of ocular biometry measures with age, gender, stature, and education, the majority of these studies have been confined to Asian and Hispanic populations.^{1,2} Some of these studies have found that axial

length is shorter in older people and in women,^{2,6} while others have reported height and education relationships with various biometry measures.^{5-7,20-22} However, there is very little understanding about the complex inter-relationships among age, gender, height, and education with ocular biometry measurements in older white adults. Further understanding of such relationships may provide insight into trends and patterns of myopia¹³⁻¹⁹ that have been observed.

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 between ocular biometry components with age, gender, height, and education in this Caucasian adult population.

Methods

Study Population

The Beaver Dam Eye Study is a population-based cohort study of eye disease in adults. Ocular dimensions were measured during the fourth examination of the cohort. The study began in 1988 with a private census of the population of Beaver Dam, WI. All individuals (5924) between the ages of 43 and 84 years were identified and invited for a baseline examination from 1988–1990. Follow-up examinations were performed every 5 years after this with the fourth examination occurring from May 2003 to May 2005. At each examination, participation rates were over 80% with the primary reason for non-participation being death. At each examination, living non-participants were older, less educated, had poorer vision, higher blood 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 NIH classification of race, 99% of the population was classified as “white”.

Measurements

Ocular biometry measures were added for the fourth examination, and those data are used in this report. The relevant portions of this examination, summarized here, include: standardized non-cycloplegic refraction using an automated refractor (Humphrey, San Leandro CA) with further modification if resulting visual acuity was 20/40 or worse;²⁷ ocular biometry using partial coherence laser interferometry (IOL Master, Carl Zeiss, Germany) for axial length (AL), anterior chamber depth (ACD), and radius of corneal curvature (CR); measurements of height and weight; questions about education; and assessment of lens status using standardized lens photography and grading.²⁸

Height and weight were measured on a Health-O-Meter scale after participant had removed shoes, keys, wallets, etc. Weight was measured to nearest quarter pound and converted to kilograms by multiplying by 0.4536. Height was measured to nearest quarter inch and converted to centimeters by multiplying by 2.54. If unable to measure (3% of population), self-reported height and weight 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 on 1976 (83%) participants prior to pupillary dilation (1962 both eyes, 6 right eye only, 8 left eye only). Reasons for not measuring ocular biometry (right eye) included: off-site exams (n=243), physical limitations (n=41), not enough time (n=56), and other/unspecified/refusal/inability (n=67). The average of the two corneal curvature meridians was used for analysis of CR. ACD measurements were not included in the analyses in persons without a lens or with an intraocular

lens ($n=269$). Comparison of characteristics of those included for various analyses is shown in Table 1. In general, those included in analyses were younger and after age adjustment were less likely to have diabetes, were taller, and were less likely to have cataract and age-related macular degeneration. There were no differences in education or refraction (spherical equivalent).

Statistical Methods

SAS version 9.1²⁹ was used for all analyses. Normality of each ocular biometry measure (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 (GEE) 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.

Results

The relationships of age and gender to the ocular dimensions and refractions are shown in Table 2. Men and younger persons had longer AL, greater (flatter) CR, and deeper ACD than women and older individuals. Persons who were < 65 years of age had a mean AL of 23.86 mm, a CR of 7.72 mm, and an ACD of 3.19 mm. Persons who were ≥ 75 years of age had a mean AL of 23.55 mm, a CR of 7.68 mm, and an ACD of 2.99 mm.

Both height and education decreased with increasing age. Persons younger than 65 years had a mean \pm standard deviation height of 167.1 ± 9.9 cm (65.8 ± 3.9 inches) and had completed 13.6 ± 2.6 years of school. Persons ≥ 75 years were 162.0 ± 9.6 cm (63.8 ± 3.8 inches) tall and had completed 12.1 ± 2.9 years of school. The age trends were similar within genders and women were shorter (158.6 ± 6.6 cm vs 172.9 ± 7.2 cm; 62.5 ± 2.6 vs 68.1 ± 2.8 inches) and had completed less schooling (12.5 ± 2.3 vs 13.1 ± 3.2 years) than men. Within an age category, persons with more education were taller (Figure 1). The same trends were observed within each gender (data not shown).

Ocular dimensions varied with height and education and were similar in men and women (Table 3). Taller individuals generally had larger eyes. In the full population, AL increased from 23.36 mm in those < 158 cm (62 inches) tall to 24.20 mm in those > 178 cm (70 inches) tall ($\beta = .31$, $P < .001$ per 10 cm). Similarly, CR increased from 7.60 mm to 7.84 mm ($\beta = .08$, $P < .001$) and ACD increased from 3.04 mm 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 (versus those with 1–11 years). Additional adjustment for height attenuated the relationships, but they remained statistically significant (not shown).

To further explore whether height differences may explain the age, gender, and education relationships to the biometry measures, we plotted AL by height for age (Figure 2a), gender (Figure 2b), and education (Figure 2c) categories. 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 persons with the same height, younger persons had deeper ACD and those with ≥ 16 years of education had greater (flatter) CR and deeper ACD.

In models adjusting for height and education (Table 4), the age and gender relationships to the ocular components were attenuated. Importantly, the age relationship to AL was non-

significant after adjustment for both height and education ($P = .06$). The age relationship to CR was no longer significant after adjustment for height. Education did not add information beyond height for CR. Both height and education add to the model for ACD and the age relationship remained significant. The gender relationships to AL, ACD, and CR were no longer significant after adjustment for height.

Discussion

In this study, we report on the distribution of ocular biometry measures in an older Caucasian population. We found that younger people, men, 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 used in the other studies,^{1,2} our Caucasian population had, on average, longer AL and greater CR than the Asian and Hispanic populations (K. Lee, unpublished data 2007). In 60–69 year old women, the mean AL was 23.7 mm in BDES, 22.7 mm in Tanjong Pagar, 23.2 mm in Mongolia, and 23.1 mm in Los Angeles Latino Eye Study. These differences may be influenced by differing methods (IOL master compared to ultrasound) used to obtain biometry measures. Additionally our population is slightly older, taller, had more years of education, and had a spherical equivalent between the Asian and Hispanic population.^{1,2}

The age and gender differences observed for AL, CR, and ACD may be related to the fact that older persons and women have smaller stature and thus smaller eyes. In our population, height decreased by 1.3 cm (0.5 inches) for every 5 year increase in age and women were on average 14 cm (5 inches) 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 ratio of AL to CR (K. Lee, unpublished data 2007), supporting the notion that the AL and CR remained in similar proportions for taller and shorter persons. Adjustment for height attenuated the age and gender relationships to the ocular biometry measures. The gender 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 larger in younger persons (K. Lee, unpublished data 2007), even after adjustment for height, suggesting that these persons have proportionately longer AL given the CR than older persons.

The relationship 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 socio-economic status and better nutrition associated with more educated groups. Indeed, we found that among persons the same age, persons with more education tended to be taller. We also observed that among persons 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 relationships remained despite adjustment for age and height (data not shown). Thus, height differences associated with education do not explain the longer AL in persons with more education.

The major limitation in this and other reported population-based studies is that they were cross-sectional, which does not allow evaluation of change of 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 axial length, 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, where survivors may be more educated and taller. However, we did not observe large differences in baseline height or education level among participants in this analysis compared to all participants in the baseline examination phase.

An important observation in our study was that adjustment for both education and height attenuated the relationship between age and axial length. Younger persons had more education and were taller. Among persons with a similar height, those with ≥ 16 years of education had longer AL. Our finding that age variations in axial length, 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 that is now recognized in many different populations with diverse racial/ethnic groups.

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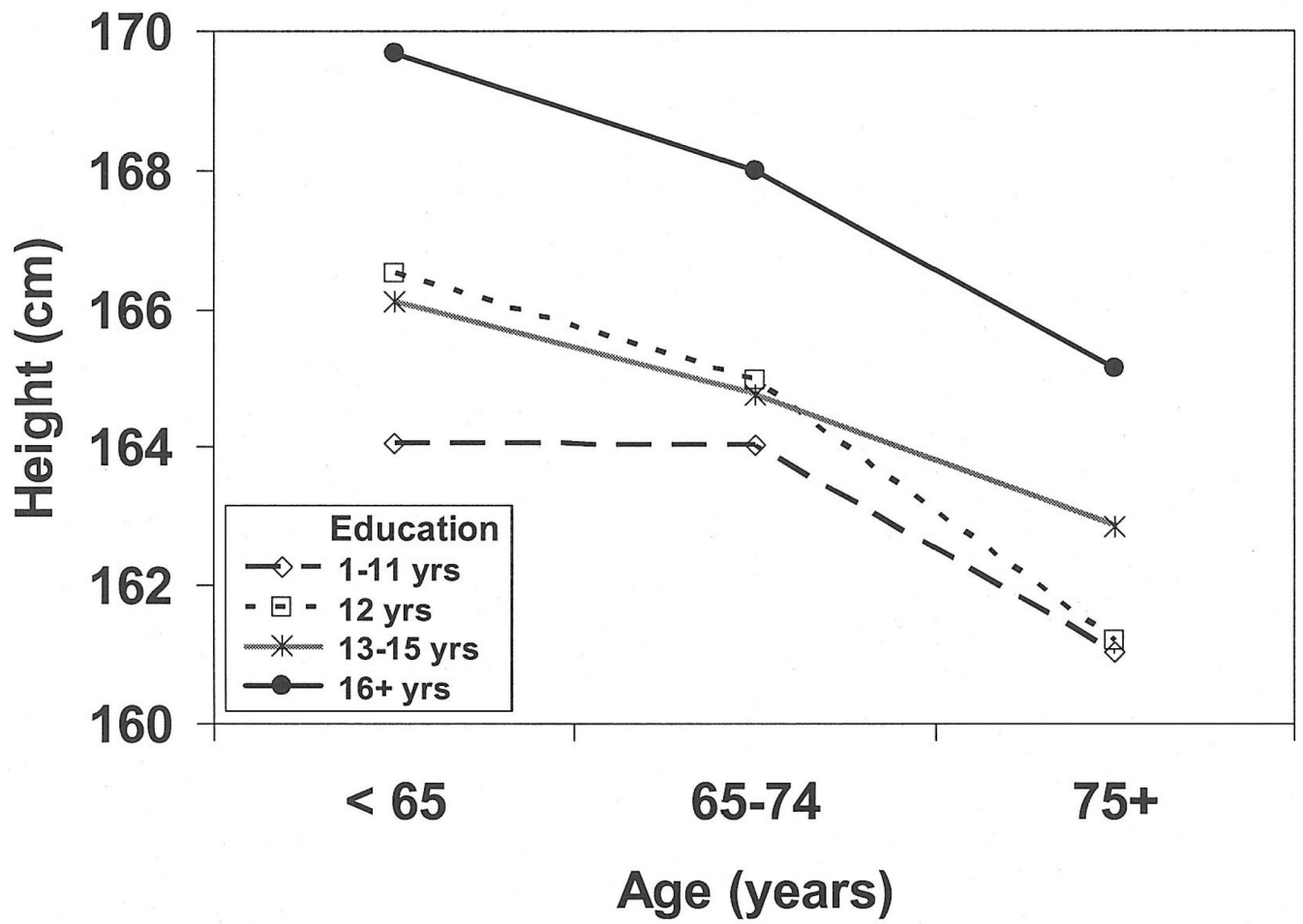
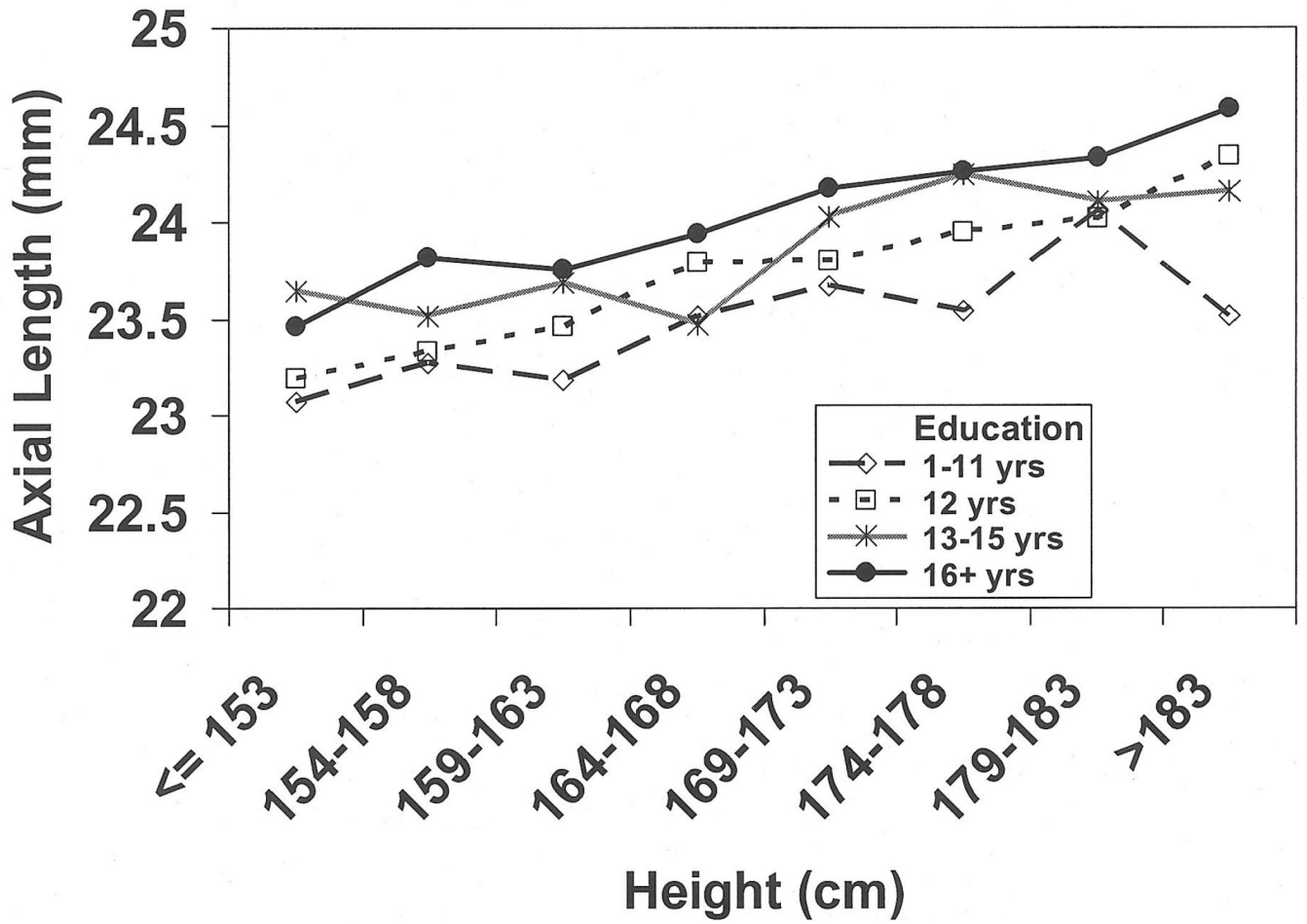
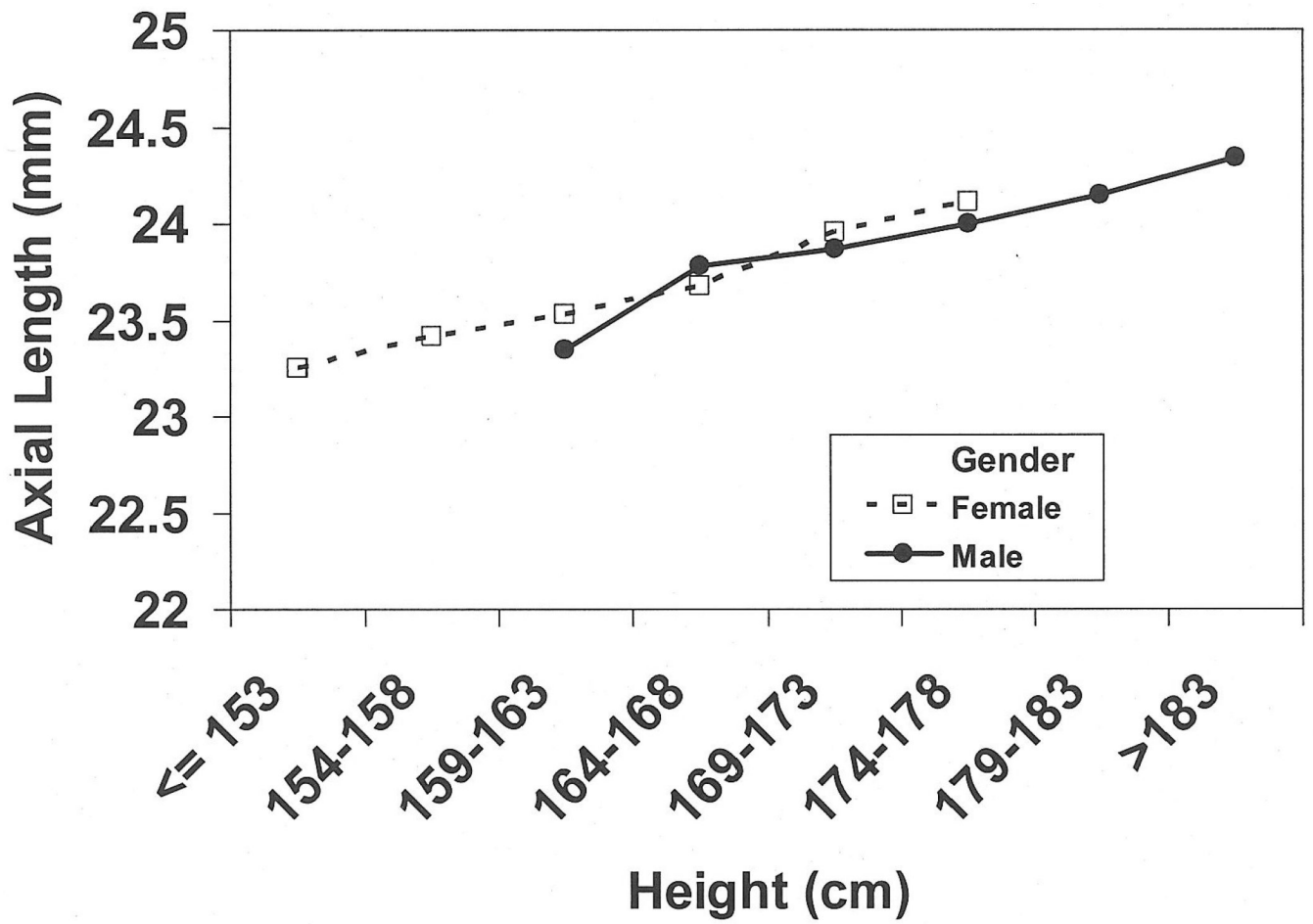


Figure 1.
Distribution of height by age and education level.





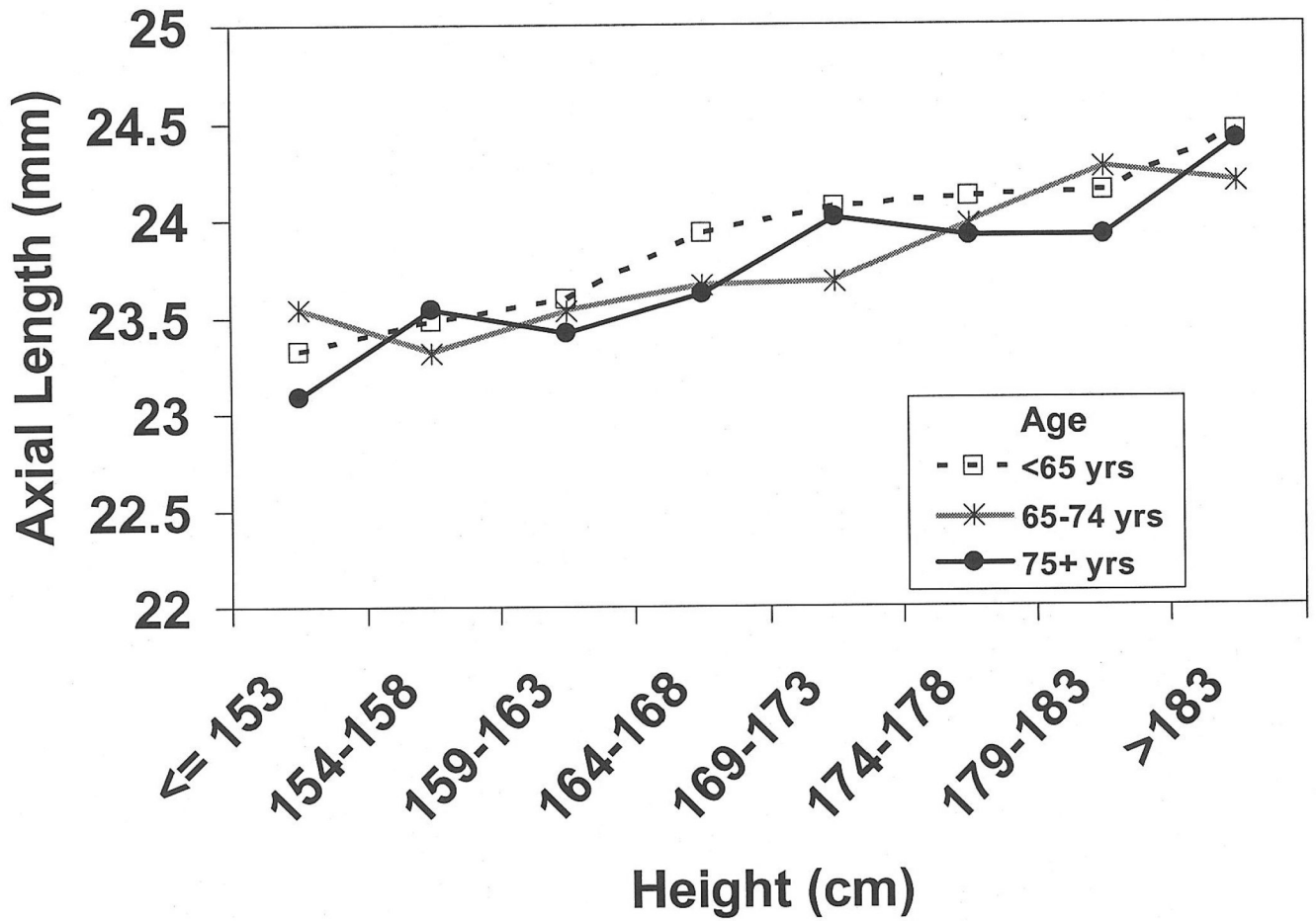


Figure 2. Distribution of axial length (right eyes) by height and a) age, b) gender, and c) education in the Beaver Dam Eye Study.

Table 1
Comparison of Participants at Fourth Exam Phase of Beaver Dam Eye Study to Those Included in Analyses.

Characteristic	Whole Population			With AL Measure			With CR Measure			With ACD Measure		
	N	Mean (SD) / %	P value ^a	N	Mean (SD) / %	P value ^a	N	Mean (SD) / %	P value ^a	N	Mean (SD) / %	P value ^a
Age (years)	2375	71.9 (9.1)	1967	70.3 (8.0)	***	1962	70.3 (8.0)	***	1675	69.1 (7.4)	***	
Sex (% male)	2375	41.3%	1967	42.7%	--	1962	42.9%	--	1675	44.4%	**	
Education (years)	2365	12.7 (2.7)	1962	12.9 (2.6)	--	1957	12.9 (2.6)	--	1671	12.9 (2.7)	--	
Income (\$1K)	2358	55.0 (20.3)	1965	54.6 (19.2)	***	1961	54.5 (19.3)	***	1674	54.9 (18.7)	***	
Height (cm)	2336	164.5 (9.8)	1961	164.7 (9.7)	**	1956	164.7 (9.6)	*	1671	165.2 (9.6)	--	
Weight (kg)	2350	80.3 (18.8)	1960	81.3 (18.7)	--	1955	81.4 (18.7)	--	1670	82.2 (18.6)	--	
Current smoker (%)	2368	8.7%	1967	9.4%	--	1962	9.4%	--	1675	9.8%	--	
Hypertensive (%)	2323	65.6%	1965	63.7%	--	1960	63.7%	--	1675	63.2%	--	
Diabetes (%)	2233	15.8%	1949	14.2%	***	1945	14.3%	***	1659	13.4%	***	
Spherical equivalent (diopters)	1819	.38 (2.4)	1670	.33 (2.3)	--	1666	.33 (2.3)	--	1654	.32 (2.3)	--	
IOP (mmHg)	2189	15.1 (3.3)	1952	15.1 (3.3)	+	1948	15.1 (3.3)	--	1663	15.2 (3.3)	***	
Any cataract (%)	1694	35.0%	1604	32.9%	*	1601	32.7%	*	1588	32.6%	**	
Early AMD (%)	2111	13.6%	1859	11.9%	--	1858	12.0%	--	1595	10.5%	--	
Late AMD (%)	2205	2.8%	1895	1.3%	***	1891	1.3%	***	1618	0.9%	***	

Definitions: AL=axial length; CR=radius of corneal curvature; ACD=anterior chamber depth; IOP=intraocular pressure; AMD=age-related macular degeneration.

^aCompare those in analysis to those not in analysis (age-adjusted).

Notes:

--=p value \geq 0.10

+ =p value \geq 0.05 and $<$ 0.10

*=p value \geq 0.01 and $<$ 0.05

**=p value \geq 0.001 and $<$ 0.01

***=p value $<$ 0.001

Table 2

Age and Gender Distribution of Ocular Biometry (right eyes).

	Age (years)	Women			Men			Men vs Women			All Persons		
		N	Mean (SD)	P value	N	Mean (SD)	P value	N	Mean (SD)	P value	N	Mean (SD)	P value
AL	<65	314	23.69 (1.25)	referent	262	24.06 (1.06)	referent	576	23.86 (1.18)	referent	576	23.86 (1.18)	referent
	65-74	447	23.49 (1.21)	.001	343	23.88 (1.14)	.06	790	23.66 (1.19)	<.001	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	601	23.55 (1.06)	<.001
	Total	1127	23.51 (1.17)		840	23.92 (1.10)		1967	23.69 (1.16)		1967	23.69 (1.16)	
CR	<65	313	7.67 (0.25)	referent	263	7.77 (0.26)	referent	576	7.72 (0.26)	referent	576	7.72 (0.26)	referent
	65-74	443	7.66 (0.25)	.36	343	7.77 (0.27)	.73	786	7.71 (0.26)	.55	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	600	7.68 (0.27)	.01
	Total	1121	7.65 (0.25)		841	7.77 (0.27)		1962	7.70 (0.26)		1962	7.70 (0.26)	
ACD	<65	297	3.17 (0.32)	referent	256	3.22 (0.36)	referent	553	3.19 (0.34)	referent	553	3.19 (0.34)	referent
	65-74	397	3.11 (0.35)	.02	314	3.12 (0.38)	<.001	711	3.11 (0.36)	<.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	411	2.99 (0.39)	<.001
	Total	931	3.09 (0.36)		744	3.14 (0.38)		1675	3.11 (0.37)	.004	1675	3.11 (0.37)	

Definitions: SD=standard deviation; AL=axial length; CR=radius of corneal curvature; ACD=anterior chamber depth.

Table 3
Height and Education Relationship to Ocular Biometry (right eyes).

	Women		Men		All Persons	
	N	Mean (SD)	N	Mean (SD)	N	Mean (SD)
AL						
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 (years)						
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)
CR						
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 (years)						
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)
ACD						
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 (years)						
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)

Abbreviations: SD=standard deviation; AL=axial length; CR=radius of corneal curvature; ACD=anterior chamber depth

Note:

≤ 158 cm = ≤ 62 inches

159–168 cm = 63–66.00 inches

169–178 cm = 67–70 inches

>178 cm = > 70.1 inches

Table 4
Generalized Estimating Equation Models for Ocular Dimensions with Age, Gender, Height, and Education.

	Model 1 ^a		Model 2 ^b		P value ^c
	β (95% CI)	P value ^c	β (95% CI)	P value ^c	
AL					
Male vs Female	0.41 (0.32, 0.50)	<.001	0.02 (-0.13, 0.16)	.80	
Age (per 5 years)	-0.08 (-0.11, -0.05)	<.001	-0.03 (-0.07, 0.001)	.06	
Height (per 10 cm)	-	-	0.20 (0.14, 0.26)	<.001	
Education (per 4 years)	-	-	0.24 (0.16, 0.31)	<.001	
CR					
Male vs Female	0.12 (0.10, 0.14)	<.001	0.002 (-0.03, 0.04)	.88	
Age (per 5 years)	-0.01 (-0.02, -0.003)	.005	0.001 (-0.01, 0.01)	.74	
Height (per 10 cm)	-	-	0.06 (0.05, 0.08)	<.001	
Education (per 4 years)	-	-	0.01 (0.00, 0.03)	.11	
ACD					
Male vs Female	0.04 (0.01, 0.08)	.01	-0.01 (-0.06, 0.04)	.69	
Age (per 5 years)	-0.06 (-0.07, -0.05)	<.001	-0.05 (-0.06, -0.04)	<.001	
Height (per 10 cm)	-	-	0.03 (0.01, 0.05)	0.01	
Education (per 4 years)	-	-	0.06 (0.03, 0.08)	<.001	

Abbreviations: β =estimate of slope; CI=confidence interval; AL=axial length; CR=radius of corneal curvature; ACD=anterior chamber depth

^aModel 1 adjusted for age and gender

^bModel 2 adjusted for age, gender, height, and education

^cP value analogous to type III sums of squares