7 Demographics of Biometry

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Introduction

The accurate prediction of refraction after cataract surgery refraction depends on the quality of the biometric measurements of the eye obtained preoperatively. These critical measurements typically include anterior chamber depth, lens thickness, axial length, and corneal curvature (expressed as radius of curvature or keratometry values) although recent biometry devices have introduced the use of additional values such as central corneal thickness and horizontal corneal diameter (aka white-to-white dimension). As several reports have shown, these parameters often are correlated and may vary by patient sex, race, and age [1–14]. To further explore these relationships, we analyzed a large dataset of biometry values obtained with modern biometry equipment and compared these measurements to those obtained in prior studies.

Methods

Kaiser Permanente Northern California (KPNC) is a large medical system providing comprehensive health care services to a diverse population of over 4.4 million patients. KPNC standardized biometry measurements using an optical low coherence reflectometry device (Lenstar 900, Haig-Streit, Köniz, Switzerland) platform across 25 eye care clinics in 2014. The export function of the biometry device was used to obtain and collate biometry values for 85,404 patients measured during the period from 2014 to 2019. An illustrative tracing of the biometry signals with component labels is shown in Fig. 7.1. The KPNC electronic medical record (Epic Systems, Verona, USA) was queried to capture race, sex, age, and diagnoses for these patients. Those with a prior history of keratorefractive surgery (N = 4360, 5.4%) or a diagnosis of keratoconus (N = 295, 0.3%) were excluded, leaving a study population of 80,479 eyes. Statistical analyses were performed only on right eye data using Stata 15.1 (StataCorp, College Station, TX). Because of the large sample size, even clinically small differences between average values were statistically significant, and thus percentage differences between means were typically calculated.

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J. Aramberri et al. (eds.), *Intraocular Lens Calculations*, Essentials in Ophthalmology,
https://doi.org/10.1007/978-3-031-50666-6_7

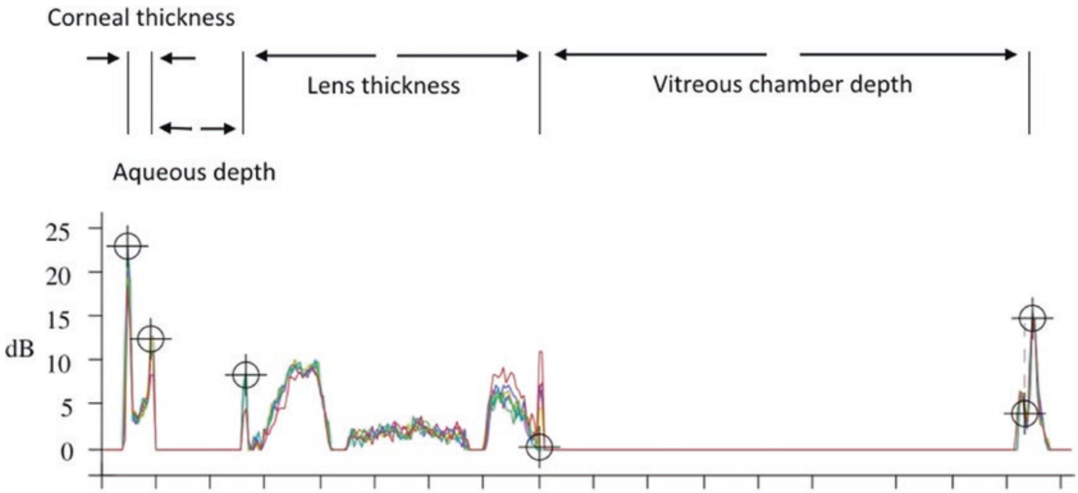

Fig. 7.1 An example optical low coherence reflectometry tracing of key biometric values

Results

Patients included in the study ranged in age from 21 to 102 (mean of 69.9, SD of 9.6). A diverse mix of racial/ethnic groups was represented including 14,768 Asian (18.4%), 5406 Black (6.7%), 7187 Hispanic (8.9%), 50,957 White (63.3%), and 2161 other race (2.7%) patients. As in many cataract-related studies, women ($N = 47{,}309$, 58.8%) outnumbered men ($N = 33{,}170$, 41.2%). Summary statistics of the biometry values are presented in Table 7.1. Using the Shapiro-Wilk test of normality on a random subcohort of 1000 patients, a normal distribution of values was found for aqueous depth and lens thickness but not for central corneal thickness, anterior corneal curvature, horizontal corneal diameter, or vitreous chamber depth. Skew and kurtosis values are also displayed in Table 7.1.

Sex-Related Differences

Differences in biometry values by sex are summarized in Table 7.2. In general, all values were larger in male patients, though in the case of central corneal thickness and lens thickness the differences were less than 1%. The most dramatic difference between the sexes is found in aqueous depth, where males had on average a 4.7% deeper dimension than females (mean ± SD: 2.69 ± 0.41 vs. 2.57 ± 0.40, respectively).

Racial Differences

There are modest differences among the biometric measurements by race. Table 7.3 summarizes the key values for Asian, Black, Hispanic, White, and Others categories of race. Corneas are thinnest in Black patients and thickest in Whites. In general, Whites had the largest values in each measurement category, except for vitreous chamber depth and axial length, which were greatest in Asian patients, and radius of the anterior cornea, which was greatest in Blacks and Hispanics.

Age-Related Trends

The aqueous depth (Fig. 7.2) decreases with age due to thickening of the lens (Fig. 7.3). The vitreous chamber depth also decreases with age due to thickening of the lens, but the magnitude of this effect is difficult to ascertain in the current study population as myopic patients with deeper vitreous chamber depths tended to present at an earlier age for cataract surgery. The measured horizontal corneal diameter (aka White-to-White)

Table 7.1 Demographics and biometry measure summary statistics ($N = 80{,}479$). (All numbers represent millimeters unless otherwise indicated and are from right eye measurements only)

Measure	Mean	Median	SD	Minimum	Maximum	Skew	Kurtosis
Central corneal thickness	544.3 μ	543.9 μ	35.4 μ	356 μ	750 μ	0.10	0.35
Radius anterior cornea	7.69	7.69	0.27	6.31	9.47	0.14	3.30
Aqueous depth	2.62	2.61	0.41	1.25	4.83	0.14	0.01
Anterior chamber depth	3.17	3.16	0.41	1.76	5.40	0.14	0.01
Lens thickness	4.57	4.57	0.45	2.53	6.35	0.11	−0.12
Vitreous chamber depth	16.27	16.08	1.31	11.25	25.16	1.08	2.58
Axial length	24.00	23.80	1.38	18.60	33.25	1.05	2.39
Horizontal corneal diameter[a]	11.98	11.99	0.49	7.09	14.66	−0.83	4.41

[a]Also known as White-to-White (WTW)

Table 7.2 Sex differences in key biometry measures (all numbers represent millimeters unless otherwise indicated and are from right eye measurements only)

Measure	Female *N* (%)	Male *N* (%)	Difference of means	Percentage difference of means
Sex	47,309 (58.8%)	33,170 (41.2%)	–	–
	Mean ± SD	**Mean ± SD**		
Age at measurement (years)	70.0	69.8	0.2	0.2%
Central corneal thickness	543.1 μ ± 34.7	546.2 μ ± 36.3	3.1 μ	0.6%
Radius anterior cornea	7.65 ± 0.26	7.76 ± 0.27	0.11	1.5%
Aqueous depth	2.57 ± 0.40	2.69 ± 0.41	0.12	4.7%
Anterior chamber depth	3.11 ± 0.40	3.24 ± 0.41	0.13	4.0%
Lens thickness	4.56 ± 0.44	4.58 ± 0.47	0.02	0.6%
Vitreous chamber depth	16.11 ± 1.30	16.49 ± 1.29	0.38	2.4%
Axial length	23.78 ± 1.36	24.32 ± 1.38	0.54	2.2%
Horizontal corneal diameter[a]	11.90 ± 0.47	12.07 ± 0.51	0.17	1.4%

[a]Also known as White-to-White (WTW)

Table 7.3 Racial differences in the mean values of key biometry measures. The race with the minimum values for a given measure are shown in *italics* and maximum values in **bold** (all numbers represent millimeters unless otherwise indicated and are from right eye measurements only)

Measure	Asian	Black	Hispanic	White	Others	Difference[a]	Percentage difference
N (%)	14,768 (18.4%)	5406 (6.7%)	7187 (8.9%)	50,957 (63.3%)	2161 (2.7%)	–	–
Age at measurement (years)	*67.4*	68.9	67.9	**71.1**	*67.4*	3.7	5.5%
Central corneal thickness	540 μ	*524 μ*	539 μ	**549 μ**	540 μ	24.5	4.7%
Radius anterior cornea	7.68	**7.73**	**7.73**	7.69	7.71	0.05	0.6%
Aqueous depth	*2.57*	2.63	*2.57*	**2.64**	2.63	0.07	2.9%
Anterior chamber depth	*3.11*	3.15	*3.11*	**3.19**	3.17	0.08	2.7%
Lens thickness	4.55	*4.47*	4.55	**4.59**	4.51	0.12	2.7%
Vitreous chamber depth	**16.60**	16.36	*16.09*	16.19	16.26	0.51	3.2%
Axial length	**24.26**	23.98	*23.75*	23.97	23.94	0.52	2.2%
Horizontal corneal diameter	*11.73*	11.97	11.87	**12.06**	11.94	0.33	2.8%

[a]Absolute difference between the minimum and maximum values for measure row

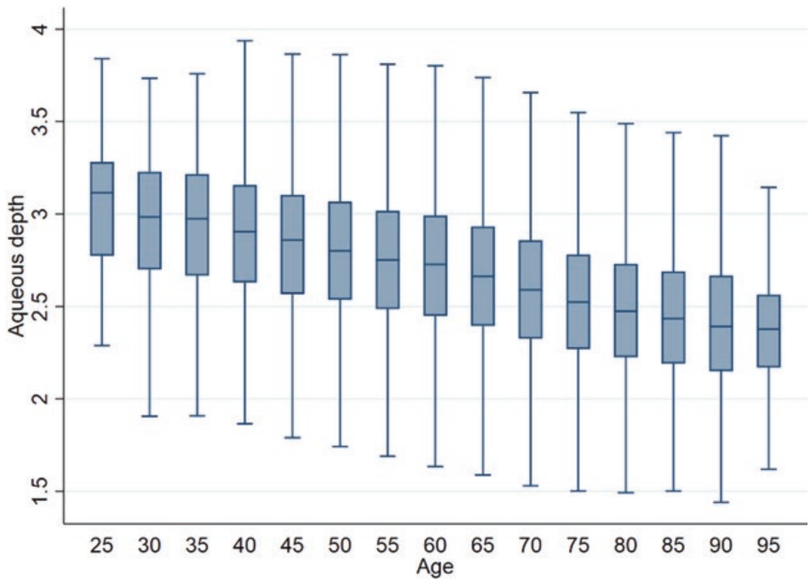

Fig. 7.2 Decrease in aqueous depth with age. The change is approximated by the linear regression equation: aqueous $depth_{mm} = (-0.011*age) + 3.36$. The central line within the box represents the median value for that age group; the box edges represent the 25th and 75th percentiles (Q1 and Q3) and the whiskers show the lower and upper extremes as calculated by Q1 – (1.5*(Q3 – Q1)) and Q3 + (1.5*(Q3 – Q1)), respectively

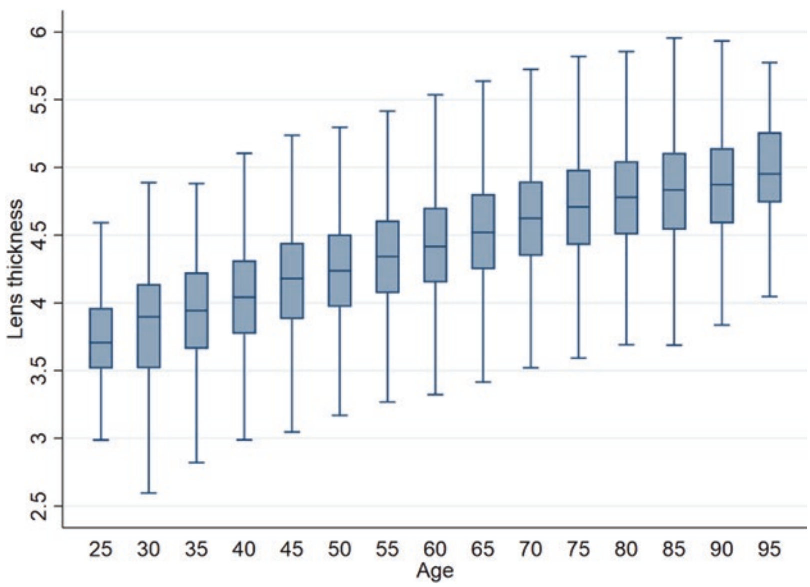

Fig. 7.3 Increase in lens thickness with age. The increase is approximated by the linear regression equation: lens $thickness_{mm} = (0.017*age) + 3.37$

decreases slightly with age (Fig. 7.4), while central corneal thickness remains relatively stable (Fig. 7.5).

Corneal Astigmatism

Corneal astigmatism also varies with age, with younger patients on average having greater with-the-rule cylinder (Fig. 7.6), middle-aged patients having a decrease in overall astigmatism (Fig. 7.7), and older patients having an increase in against-the-rule cylinder (Fig. 7.8). The vertical astigmatism component was calculated as $Vertical_{astigmatism} = Sine\ (Axis) * Cylinder_{diopters}$ and the horizontal astigmatism component as $Horizontal_{astigmatism} = Absolute\ (Cosine\ (Axis)) * Cylinder_{diopters}$.

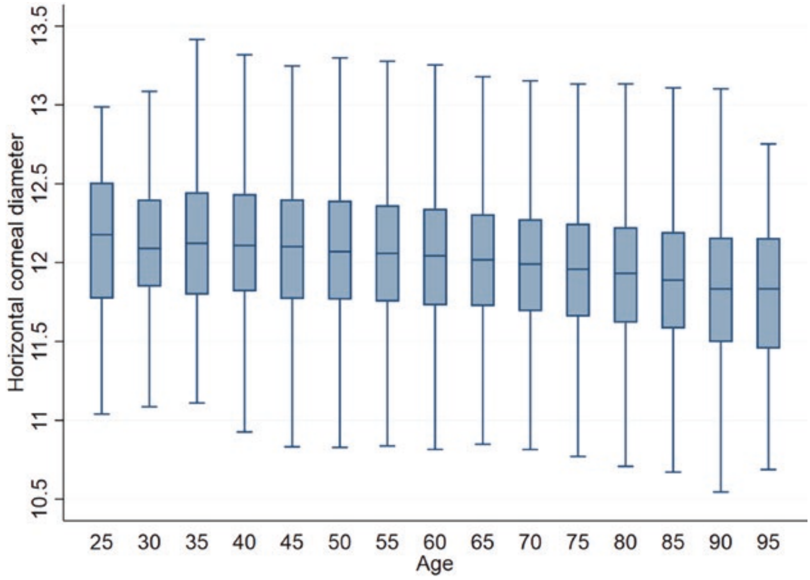

Fig. 7.4 Slight decrease in horizontal corneal diameter (aka White-to-White) with age

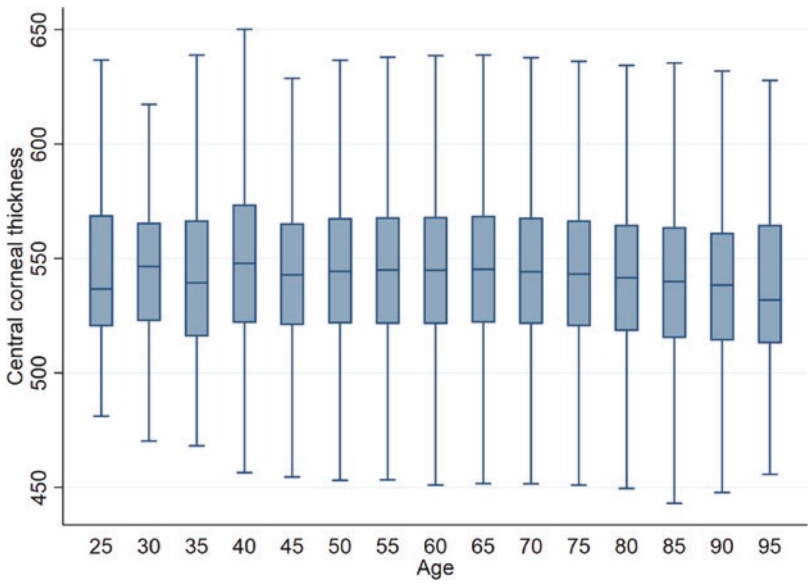

Fig. 7.5 Stable corneal thickness with age

Correlation Among Biometry Variables

The highest correlation among the biometry measures are the aqueous depth-lens thickness, the anterior corneal radius-horizontal corneal diameter, the vitreous chamber depth-aqueous depth and vitreous chamber depth-anterior corneal radius, and the vitreous chamber depth-horizontal corneal diameter. Corneal measures are largely independent of the lens thickness (Table 7.4).

Inter-Eye Variation

All biometry values were very highly correlated between the right and left eyes (Table 7.5).

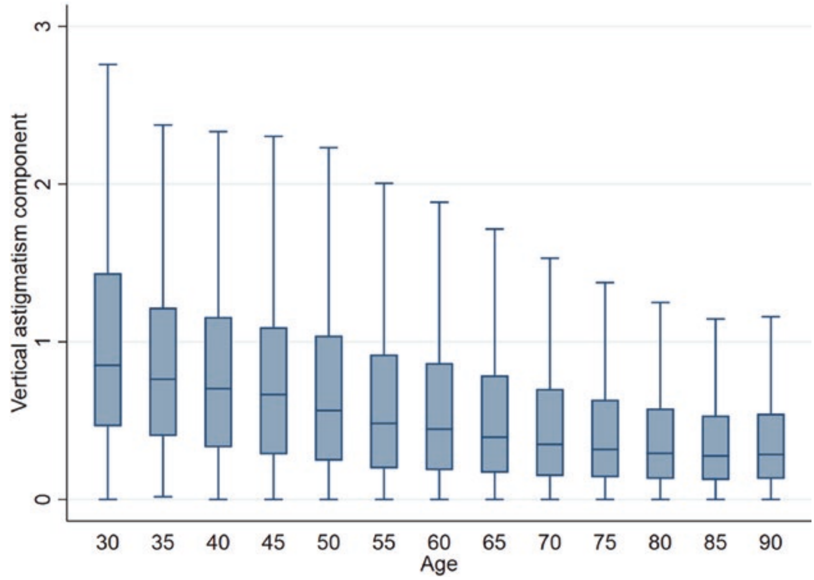

Fig. 7.6 Higher with-the-rule astigmatism in younger patients

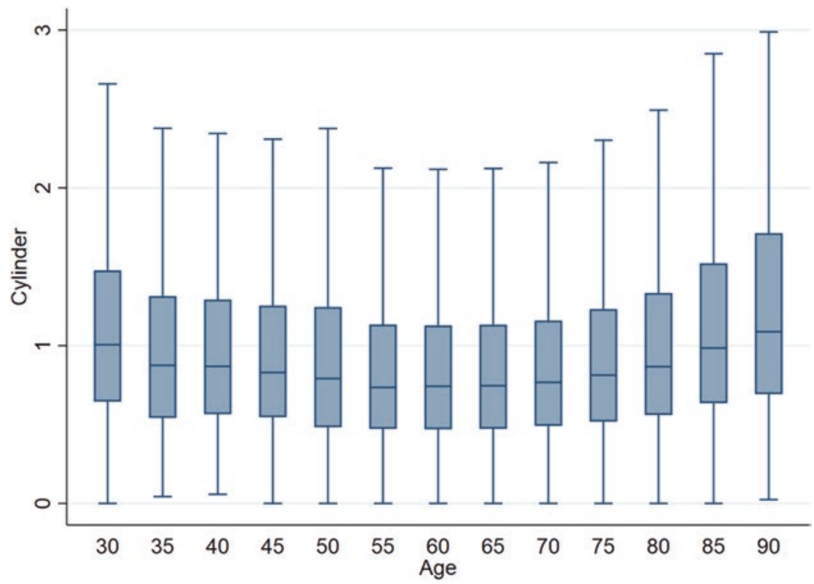

Fig. 7.7 Net astigmatism (cylinder) reaches a minimum near age 60

Conclusion

It is important for cataract surgeons to familiarize themselves with the normal ranges and correlations among biometry values in order to be able to quickly recognize outliers and possible measurement errors [15]. In addition, authors of intraocular lens calculation formulas should understand the variations in biometry values between the sexes [16, 17] and also how these measurements change with age. In particular, the continued increase in against-the-rule astigmatism late into life should be factored into toric intraocular implant selection. The decrease in horizontal corneal diameter seen with increased age may be an artifact of measurement as encroaching discoloration effects occur (such as from white limbal girdle of Vogt or arcus senilis).

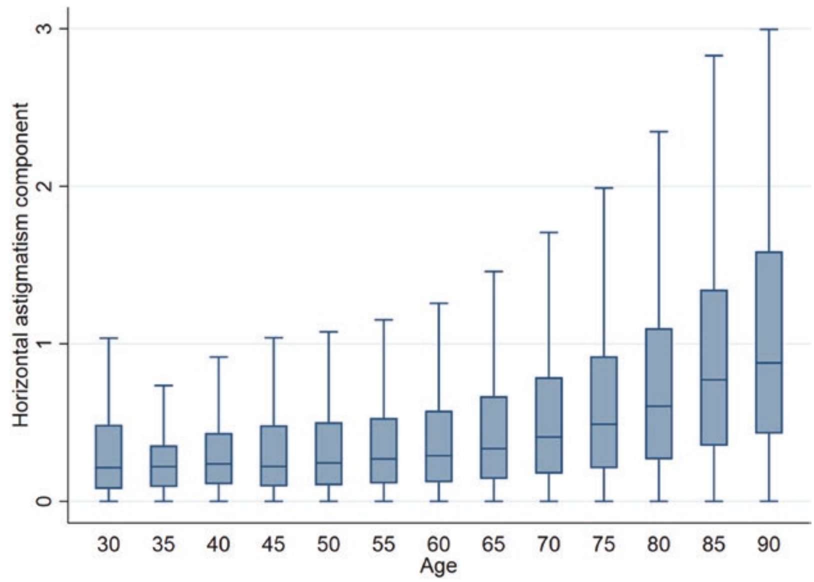

Fig. 7.8 Against-the-rule astigmatism continues to increase with age in older patients

Table 7.4 Correlation matrix of key biometry variables

	R_{ac}	HCD	CCT	AD	LT	VCD
Radius anterior cornea (R_{ac})	–					
Horizontal corneal diameter (HCD)	0.387	–				
Central corneal thickness (CCT)	0.133	0.001	–			
Aqueous depth (AD)	−0.025	0.355	−0.048	–		
Lens thickness (LT)	0.001	−0.074	0.023	−0.625	–	
Vitreous chamber depth (VCD)	0.359	0.240	0.042	0.385	−0.326	–

Table 7.5 Inter-eye variation. All numbers represent values in millimeters, except where noted

Measure	Mean difference	Median difference	SD	Mean absolute difference	Median absolute difference	SD absolute difference
Central corneal thickness (microns)	−0.25 μ	−0.36 μ	9.85 μ	6.46 μ	4.82 μ	7.44 μ
Radius anterior cornea	0.01	0.01	0.09	0.06	0.05	0.06
Aqueous depth	−0.01	−0.01	0.19	0.12	0.07	0.15
Anterior chamber depth	−0.01	−0.01	0.19	0.12	0.07	0.15
Lens thickness	0.01	0.00	0.30	0.20	0.11	0.23
Vitreous chamber depth	0.02	0.03	0.44	0.27	0.17	0.35
Axial length	0.02	0.02	0.40	0.22	0.13	0.34
Horizontal corneal diameter	0.01	0.00	0.66	0.15	0.09	0.24

Table 7.6 Summary of biometry studies comparing race and sex differences. Percent differences calculated as: $(\text{Value}_{male} - \text{Value}_{female})/\text{Value}_{female}$. Values are expressed in millimeters. N/A = Not available

Study (year)	*N*	Method	Race	ACD female	ACD male	ACD percentage difference	AL female	AL male	AL percentage difference
Melles (2021)	80,479	Optical low coherence reflectometry (OLCR)	Multiple	3.11	3.24	4.2%	23.78	24.32	2.3%
Huang (2018)	6933	Partial coherence laser interferometry (PCLI)	Chinese	3.01	3.16	5.0%	23.88	24.79	3.8%
Hoffer (2017)	83,830	Various	Multiple	2.99	3.15	5.4%	23.23	23.75	2.2%
Hashemi (2012)	4869	OLCR	Iranian	2.58	2.66	3.1%	22.95	23.41	2.0%
Foster (2010)	2519	PCLI	White	3.08	3.15	2.3%	23.29	23.80	2.2%
Fotedar (2010)	1952	PCLI	White	3.06	3.16	3.3%	23.19	23.76	2.5%
Jivrajka (2008)	750	Immersion ultrasound	N/A	2.90	3.05	5.2%	23.27	23.76	2.1%
Warrier (2008)	1498	A-scan ultrasound	Burmese	2.79	2.86	2.5%	22.54	23.12	2.6%
Olsen (2007)	723	A-scan ultrasound	White	3.08	3.20	3.9%	23.20	23.74	2.3%

Table 7.6 summarizes the results from other large biometry studies. The results reported here closely aligned with those of previous reports, although the axial lengths were greater, possibly because the population studied included almost 20% Asian patients. In addition, values generated by different biometry methods may vary significantly. We have found in particular that optical low coherence reflectometry may overestimate anterior chamber depth and underestimate lens thickness compared to immersion ultrasound, a finding previously reported by Savini et al. [18]

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