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BIOMETRY OF 7,500 CATARACTOUS EYES

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Previous studies by Sorsby[1] and others have provided estimates of the normal ranges of some of the clinical measurements of the eye's refractive status. These studies, however, were on patients without cataracts and with known refractions, so that correlations were possible. Oguchi and Van Balen[2] reported preoperative and postoperative measurements of 42 patients with intraocular lenses. They found steeper corneas after implant surgery and a 0.02-mm mean shortening in axial length (range, -0.7 to +0.9 mm); they also noted that shallow chambers deepened and deep chambers shallowed after intraocular lens surgery. Leonard,[3] in a series of 26 eyes, noted a 0.2-mm (0.6-diopter) mean decrease in axial length after intraocular lens surgery in 15 of 26 eyes. Yu and associates[4] used ultrasound to measure axial length in the eyes of 1,789 normal Chinese young adults (18 to 25 years old). They found a mean length of 23.74 mm (±1.24) and a average difference between fellow eyes of 0.42 mm.

My analysis of the biometric measurements of 7,500 eyes provides important new information and suggests that a revision of some commonly accepted figures and formulae is needed.

MATERIAL AND METHODS

I collected data on patients examined for cataract surgery with intraocular lens implantation between 1974 and 1979. Each patient had some form of cataractous change in one or both eyes. I measured axial length with various A-scan ophthalmic ultrasound devices (Kretz 7200MA, Sonometrics DBR-300, Xenotec, and Britt/DOC) and took keratometric readings. I measured anterior chamber depth with a pachymeter in 60% of the eyes and with A-scan ultrasound in the remaining 40%.

I examined exactly 7,500 eyes; from these, I selected a random series of 3,600 (1,800 patients) for a separate comparison of fellow eyes. An independent biostatistician performed the data analysis.

RESULTS

Of the 7,500 eyes, 6,950 were phakic, 400 were aphakic, and 150 were pseudophakic (Table 1). The mean age of the patients was 72 years (±10), with a range of 0.1 to 97 years (Fig. 1). The group with aphakic eyes was older than the groups with phakic or pseudophakic eyes by two years ($P<.002$ by Student's *t*-test).

The mean axial length (Table 1) of the 7,500 eyes was 23.65 mm (±1.35). Figure 2 shows the distribution. A comparison of the axial lengths of phakic (23.65 mm [±1.35]), aphakic (23.64 mm [±1.44]), and pseudophakic (23.64 mm [±1.45]) eyes shows no statistically significant difference. These data indicate that there is no significant shortening of the eye after cataract surgery, a finding which disagrees with those of other investigators used by Binkhorst[5] in his formula for lens calculation.

The mean average corneal power for this series was 43.81 diopters (±1.60). It is important to compare eyes that were operated upon with those that were not, since Binkhorst's formula takes into ac-

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TABLE 1

ANALYSIS OF 7,500 EYES

Measure	Eyes: Phakic (N=6,950) Mean	S.D.	Eyes: Aphakic (N=400) Mean	S.D.	Eyes: Pseudophakic (N=150) Mean	S.D.	Total of the Three Groups (N=7,500) Mean	S.D.
Age in years	72	±10	70	±10	72	±10	72	±10
Axial length (mm)	23.65	±1.35	23.64	±1.44	23.64	±1.45	23.65	±1.35
Keratometric reading (diopters)	43.81	±1.60	43.65	±1.60	43.78	±1.60	43.81	±1.60
Anterior chamber depth (mm)	3.24	±0.44	3.67	±0.48	3.32	±0.43	—	—
Astigmatism (diopters)	1.00	±1.00	1.50	±1.25	1.65	±1.25	—	—
Emmetropic IOL power (diopters)*	17.00	±4.50	18.00	±4.00	17.00	±4.00	17.00	±4.50
Central endothelial cell count	(N = 930)		(N = 50)		(N = 41)		(N = 1,021)	
(cells/mm^2)	2,538	±503	1,792	±680	1,737	±767	2,470	±570

*Prepupillary style.

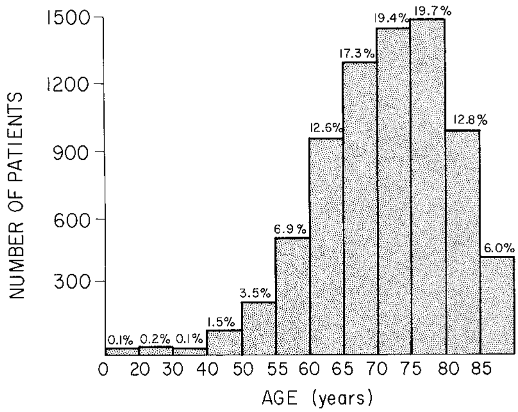

Fig. 1 (Hoffer). Age distribution.

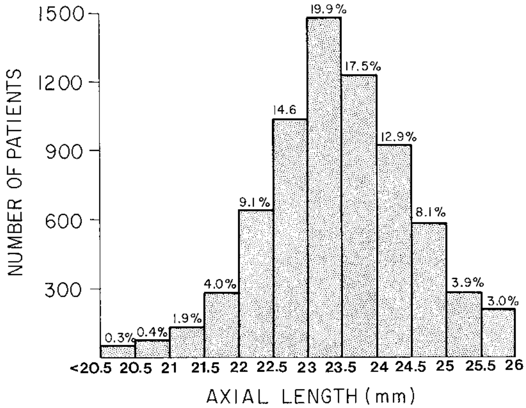

Fig. 2 (Hoffer). Axial length distribution.

count a flattening of the cornea after cataract surgery based on Floyd's[6] report of 42 eyes. Binkhorst used 1.3333 rather than the accepted 1.3375 as the refractive index of the cornea. Phakic eyes had an average keratometric reading of 43.81 diopters (±1.60), aphakic eyes, 43.65 diopters (±1.60), and pseudophakic eyes, 43.78 diopters (±1.60) (Fig. 3). Patients with aphakia do show a statistically significant flattening ($P<.006$) but it amounts to only 0.16 diopter. A comparison of the phakic eyes to the combined aphakic and pseudophakic groups is less significant ($P<.01$) and the flattening amounts to only 0.13 diopter. Most importantly, there is no significant flattening of the cornea in pseudophakic eyes compared to phakic eyes. These data indicate that a definite, but minor, flattening of the cornea occurs in aphakic eyes, but further studies are needed to document a more significant flattening in pseudophakic eyes after surgery.

Figure 4 shows the distribution of anterior chamber depth for the entire series. The mean anterior chamber depth in the phakic eyes was 3.24 mm (±0.44). The depth in aphakic eyes, as expected, was significantly greater ($P<.002$) at 3.67 mm (±0.48), as was the depth

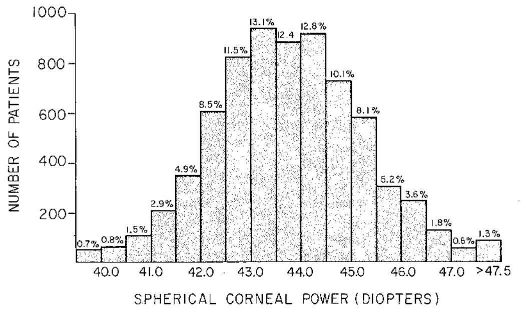

Fig. 3 (Hoffer). Average keratometric distribution for the entire series.

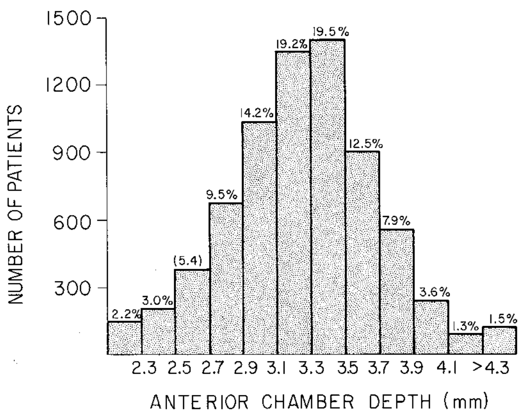

Fig. 4 (Hoffer). Anterior chamber depth distribution.

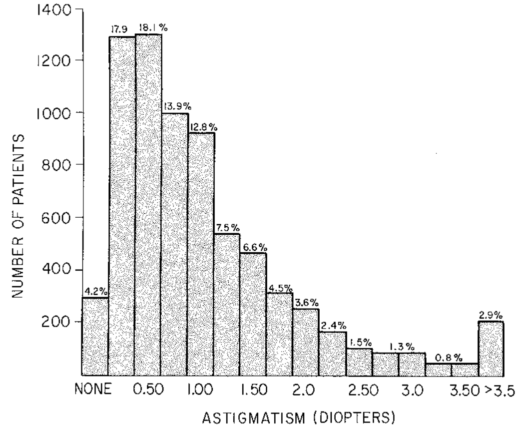

Fig. 5 (Hoffer). Astigmatism distribution.

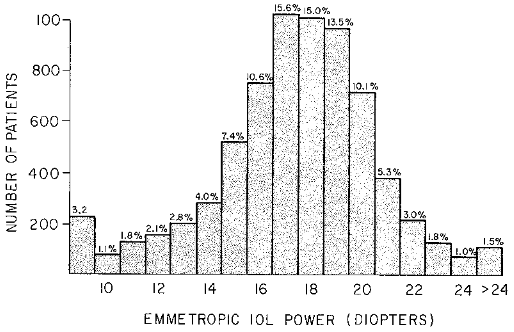

Fig. 6 (Hoffer). Distribution of prepupillary intraocular lens powers for emmetropia.

in pseudophakic eyes, 3.32 mm (±0.43) rather than the 3.50 mm usually quoted. I did not, however, define lens type in analyzing the pseudophakic eyes.

Figure 5 shows the distribution of corneal astigmatism in all 7,500 eyes. The mean astigmatism of the phakic eyes was 1.0 diopter (±1.0). The aphakic group showed an increase in astigmatism that was statistically significant ($P<.002$) but amounted to only 0.5 diopter. There was a significant increase in astigmatism in pseudophakic compared to aphakic eyes, but it amounted to only 0.13 diopter. These data do not substantiate the expected increase in astigmatism in aphakic and pseudophakic eyes.

The mean intraocular lens power, using my data and Collenbrander's[7] formula, was 17.0 diopters (±4.5). Figure 6 shows the bell-shaped curve distribution of powers for emmetropia. Of the lens powers that can be used clinically (eliminating powers under 14.0 diopters), 64% are between 17.0 and 20.0 diopters, 22% are less than 17.0 diopters, and 14% over 20.0 diopters (Fig. 7).

I performed random endothelial cell counts on 1,021 of the 6,950 phakic eyes with a specular microscope (Heyer-Schulte HS-CEM-3). The mean phakic central count was 2,538 cells/mm^2 (±503), which is in agreement with previous studies.[8] Figure 8 shows this distribution. There is no statistical significance in the

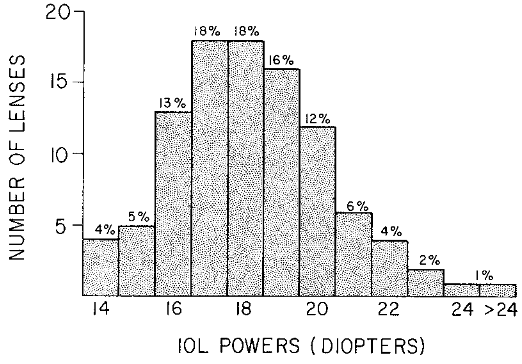

Fig. 7 (Hoffer). Percentages of prepupillary lens powers for clinical use.

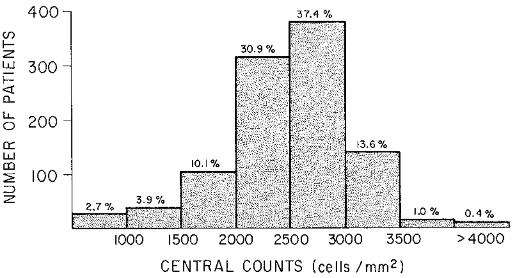

Fig. 8 (Hoffer). Central endothelial cell count distribution (cells/mm^2).

mean postoperative cell counts of aphakic (1,792 cells/mm^2 [±680]) and pseudophakic (1,737 cells/mm^2 [±767]) eyes (Table 1).

It is possible to compare other biometric variables for eyes defined as having axial myopia, emmetropia, or hyperopia (Table 2). I defined axial emmetropia as 23.65 mm with a tolerance of ±0.75 diopter, that is, 23.4 to 23.9 mm. I defined axial myopia as more than 23.9 mm and axial hyperopia as less than 23.4 mm. Of this series, 47% had hyperopia, 33% myopia, and 20% emmetropia. Because of cataract formation, correlation with refractive error was not possible. Age analyses (Table 2) showed that the group with hyperopia was older than the group with emmetropia by one year, while the group with emmetropia was older than the group with myopia by two years. Both figures are significant to $P<.002$. Myopic eyes may be prone to cataract formation at an earlier age.

Anterior chamber depth, based on axial length analysis, showed that shorter eyes have shallower anterior chambers, 3.11 mm (±0.45), and that longer eyes have deeper anterior chambers, 3.46 mm (±0.41). Emmetropic eyes were halfway between the other two groups, 3.28 mm (±0.42). These differences were significant to $P<.002$. It is disturbing that the range of anterior chamber depths based on axial length is small. It can be seen from Table 2 that the minimum depth is less in hyperopia (1.0 mm) but equal in emmetropia and myopia (2.0 mm), while

TABLE 2

ANALYSIS BASED ON AXIAL LENGTH

Measure	Eyes		
	Hyperopic	Emmetropic	Myopic
Axial length by ultrasound (mm)	<23.40	23.40-23.90	>23.90
No.	3,600	1,400	2,500
%	47	20	33
Age in years			
Mean	73	72	70
S.D.	±10	±10	±10
Anterior chamber depth (mm)			
Mean	3.11	3.28	3.46
S.D.	±0.45	±0.42	±0.41
Range	1.0-6.0	2.0-6.0	2.0-7.0
Average keratometric reading (diopters)			
Mean	44.43	43.58	43.13
S.D.	±1.56	±1.23	±1.52
Astigmatism (diopters)			
Mean	1.00	0.92	1.00
S.D.	±1.06	±0.88	±1.00
Range	9.50	6.30	9.50
Emmetropic IOL power (diopters)*			
Mean	19.00	17.00	14.50
S.D.	±2.7	±2.0	±5.6
Central endothelial cell count (cells/mm^2)	N = 475	N = 207	N = 339
Mean	2,423	2,485	2,525
S.D.	±627	±482	±530

*Prepupillary style.

the maximum is higher in myopia (7.0 mm) but equal in emmetropia and hyperopia (6.0 mm). This does not provide great security in using refractive error (for example, axial length) to estimate anterior chamber depth, leaving it a rather unpredictable variable.

Analysis of the average keratometric values for these groups demonstrates the so-called emmetropizing relationship between axial length and keratometric reading (Table 2). Hyperopic eyes had stronger or steeper corneas (44.43 diopters [±1.56]) than emmetropic eyes (43.58 diopters [±1.23]), a difference of 0.85 diopter. It is interesting to note that the difference in mean keratometric values between emmetopic and hyperopic eyes is twice as much as that between emmetropic and myopic eyes (0.45 diopters).

It is obvious that there is an inverse relationship between axial length and emmetropic prepupillary intraocular lens power. Patients with hyperopia required, on the average, 19.0-diopter (±2.7) lenses to achieve emmetropia; patients with emmetropia required 17.0-diopter (±2.0) lenses; those with myopia required 14.5-diopter (±5.6) lenses. The standard deviation is significantly larger in the group with myopia, indicating a greater potential for error when using clinical history to assess myopic eyes. Some individuals with myopia, for example, required 20-diopter lenses.

An analysis, based on axial length, of astigmatism (Table 2) shows that emmetropic eyes (0.92 diopter [±0.88]) have less mean astigmatism than myopic (1.0 diopters [±1.0]) or hyperopic (1.0 diopter [1.06]) eyes, a difference of 0.08 diopter ($P<.005$). Hyperopic eyes were equal to myopic eyes in regard to astigmatism. The maximum range of astigmatism was 6.3 diopters for emmetropic eyes and 9.5 diopters for both myopic and hyperopic eyes.

I also analyzed endothelial cell counts on the basis of axial length. There is a direct relationship between axial length and central endothelial cell counts. Hyperopic eyes with the the shortest axial lengths had the lowest mean cell count (2,423 cells/mm^2 [±627]) compared to emmetropic eyes which demonstrated a mean of 2,485 cells/mm^2 (±482). This is significant to $P<.002$, even though the difference amounted to only 62 cells/mm^2 (2.5%). The emmetropic mean count was lower than that seen in myopic eyes (2,525 cells/mm^2 [±530]) by 40 cells/mm^2 (1.6% less). The myopic mean cell count was 6.5% higher than the hyperopic mean count. These correlations were all significant to $P<.002$.

I compared the biometric values of both eyes for 1,800 randomly selected patients in this series (Table 3) to determine the need to measure the axial length of the fellow eye in order to

TABLE 3

DIFFERENCES BETWEEN FELLOW EYES*

Measure	Mean Difference	S.D.	Range
Axial length by ultrasound (mm)	0.34	±0.70	0-11.02
Average keratometric value (diopters)	0.87	±0.83	0-9.65
Anterior chamber depth (mm)	0.23	±0.27	0-2.94

*No. =3,600 (1,800 patients).

calculate intraocular lens power for one eye and to determine the consistency of these measurements between fellow eyes. The mean of the difference in axial length between fellow eyes was 0.34 mm, which is very similar to the 0.42 mm found by Yu and associates.[4] However, the standard deviation of 0.7 mm indicates that there is no predictable trend in axial-length symmetry between fellow eyes. The minimum difference was 0 mm and the maximum difference was 11.02 mm.

Comparison of the average keratometric values for fellow eyes disclosed a mean difference of 0.87 diopter (±0.83). This indicates that 66% of the patients showed a difference in average keratometric values of 0 to 1.7 diopters, while 34% showed a greater difference. The minimum difference was 0 diopters, while the maximum was 8.65 diopters. The anterior chamber differences revealed an average of 0.23 mm (±0.27), with a minimum of 0 mm and a maximum of 2.94 mm. Sixty-six percent showed anterior chamber depth differences of 0 to 0.5 mm.

There was no central tendency or predictability in any of the variables of axial length, average keratometric value, or anterior chamber depth between fellow eyes of these 1,800 patients. Therefore, it is imperative to obtain measurements of both eyes when selecting intraocular lens power for the first eye.

It should be noted that analysis of the data showed no statistically significant relationship between steepness of the cornea (average keratometric value) and astigmatism, anterior chamber depth, central endothelial cell count, or age, or between age and astigmatism or anterior chamber depth.

Analysis of the graphic distribution of the data for each factor is summarized in Table 4.

TABLE 4

SUMMARY OF CLINICAL FINDINGS

Clinical Finding	% of Patients*
Age ≥ 70 years	58
Anterior chamber depth (mm)	
<3.3	54
3.5	32
>3.7	14
Keratometric value (diopters)	
±2.5 of mean	90
>2.50 more hyperopic than the mean	3
Emmetropic	12
Astigmatism (diopters)	
None	4
<0.5	40
0.5 to 2.0	50
>2.0	10
>3.5	3
Endothelial cell count (cells/mm^2)	
<2,000	17
2,000 to 3,000	68
>3,000	15

*Percentages are rounded off to nearest whole number.

DISCUSSION

In my use of oculometry for intraocular lens power calculations, I had assumed that the "emmetropic" axial length was 23.5 mm, the "emmetropic" average keratometric value was 43.5 mm, and the normal anterior chamber depth was 3.5 mm. Since the axial length, the average keratometric value, and the position and power of the crystalline lens interdependently produce the refractive status of the eye, how does one define an emmetropic axial length or average keratometric value? Is it one found in an emmetropic eye, one defined by schematic eye formulation, or the mean of the measurements on a large series of eyes such as this study provides? We do not have the answers to these questions.

It must be kept in mind that measuring axial length by ultrasound does not necessarily measure the true axial length, but is probably more accurate than histological measurements.

This study shows that several accepted values should be changed. The preoperative anterior chamber depth is 3.24 mm rather than 3.5 mm. There is no significant change in axial length or corneal curvation after cataract surgery. Formulas based on other assumptions should be reevaluated. Mean astigmatism changes little after cataract surgery. We found little difference in the postoperative endothelial cell counts of cataract patients with and without intraocular lenses. The aphakic eyes showed a 29% and pseudophakic eyes a 32% mean cell loss compared to the phakic eyes. The mean emmetropia-producing prepupillary intraocular lens power was 17.0 diopters rather than 18.0 diopters as is commonly held.

These data can be used to restructure the Gulstrand model of the eye and lead to more accurate theoretic formulae for intraocular lens power and other important calculations.

SUMMARY

This biometric analysis of 7,500 eyes of cataract patients gave a mean axial length of 23.65 mm, a mean average keratometric value of 43.81 diopters, a mean preoperative anterior chamber depth of 3.24 mm, and a mean central endothelial cell count of 2,470 cells/mm^2. There is a statistically significant but clinically insignificant 0.16-diopter flattening of the cornea after cataract surgery without an intraocular lens, but none with an intraocular lens. Pseudophakic eyes do not show a clinically significant increase in corneal flattening over aphakic eyes. Anterior chamber depth increases from 3.24 mm to 3.32 mm (±0.08) in pseudophakic eyes and to 3.67 mm (±0.43) in aphakic eyes. Astigmatism averaged 1.0 diopter in phakic eyes preoperatively, showing a mean increase of only 0.5 diopter in aphakic eyes and 0.65 diopter in pseudophakic eyes.

One third of the eyes in this series had axial myopia while slightly less than half had axial hyperopia; the remaining 20% were in the emmetropic range. Preoperative anterior chamber depths were lowest in eyes with short axial lengths and increased with axial length. However, deep (6 mm) and shallow (2 mm) anterior chamber depths were encountered in all three groups. Shorter eyes had steeper corneas than emmetropic eyes by less than 1.0 diopter while myopic eyes had weaker corneas than emmetropic eyes by about 0.5 diopter. Astigmatism was essentially the same in all three groups (1.0 diopter) except that emmetropic eyes showed a small (0.08 diopter) but statistically significant decrease in cylinder from the other groups, as well as a smaller range (6.3 vs. 9.5 diopters). There is a very small but extremely significant increase in endothelial cell count from hyperopic to myopic eyes. There is little correlation between fellow eyes for axial length, average keratometric value, or anterior chamber depth, indicating the need for bilateral examination in calculating intraocular lens power. All other possible correlations of these data were not statistically significant.

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