# Achieving Emmetropia in Extremely Short Eyes with Two Piggyback Posterior Chamber Intraocular Lenses

*Jack T. Holladay, MD,*[1] *James P. Gills, MD,*[2] *Jane Leidlein, MD,*[1]
*Myra Cherchio, COT*[2]

***Purpose:*** To examine the refractive results and limitations of current intraocular lens power formulas when implanting two posterior chamber lenses in-the-bag to achieve emmetropia in extremely short eyes.

***Methods:*** Preoperative measurements (corneal diameter, axial length, keratometry, anterior chamber depth, and lens thickness) and postoperative measurements (refraction, corneal vertex to iris depth, and iris to front anterior lens surface) were taken in six eyes from three patients, with axial lengths ranging from 15.09 to 19.95 mm. These data were used to calculate the prediction error for three current third-generation formulas (Holladay, Hoffer Q, SRK/T) and two older formulas (SRK2 and SRK1).

***Results:*** None of the formulas accurately predicted the refractions using the optimized lens constants for normal eyes. The third-generation formulas were not different ($P \geq 0.602$) and averaged 5 diopters (D) of absolute error (Hoffer Q = 4.64 ± 1.57 D; Holladay = 5.07 ± 1.28 D; SRK/T = 5.12 ± 1.43 D). The older formulas were significantly worse ($P = 0.0006$), with average mean absolute errors of 10.93 ± 5.09 D for the SRK2 and 13.33 ± 5.09 D for the SRK1. When the formulas were optimized for these six eyes, the mean absolute errors were Holladay = 1.33 ± 1.25 D; SRK/T = 2.10 ± 1.31 D; Hoffer Q = 4.54 ± 2.00 D; SRK2 = 4.71 ± 1.94 D; and SRK1 = 4.71 ± 1.94 D. The Holladay and SRK/T formulas were statistically better ($P = 0.0068$) than the Hoffer Q and the two older formulas.

***Conclusion:*** Current third-generation formulas are better than older formulas for extremely short eyes, but still are not acceptable for the desired clinical accuracy. Newer formulas that will use additional anterior segment measurements (corneal diameter, anterior chamber depth, and lens thickness) will be required for improved accuracy, because the anterior segment often is not proportional to the axial length.

*Ophthalmology 1996;103:1118–1123*

Achieving emmetropia in extremely short eyes (<20 mm) after cataract removal is a difficult challenge clinically for several reasons. First, ultrasound axiometers are calibrated with average velocities for normal-length eyes (23.5 mm) that are incorrect for short eyes causing significant measurement errors.[1–8] Second, any measurement error in the axial length of a short eye will have a much greater effect on the final refraction, because a given measurement error is a much larger percentage of the axial length in a short eye.[9–12] Third, the current third-generation intraocular lens calculation formulas are not consistently accurate in

---

Originally received: November 7, 1995.
Revision accepted: March 15, 1996.

[1] Department of Ophthalmology, University of Texas Medical School, Houston.

[2] Department of Ophthalmology, University of South Florida, Tampa.

Dr. Holladay is author of the Holladay Formula and provides consultation for A-scan companies that use his formula.

Presented as a paper at the American Academy of Ophthalmology Annual Meeting, Atlanta, November 1995.

Reprint requests to Jack T. Holladay, MD, Houston Eye Associates Bldg, 2855 Gramercy, Houston, TX 77025.

short eyes.[13-27] And fourth, lenses above 34 diopters (D) are not readily available, must be custom manufactured, and require Food and Drug Administration approval with long-term monitoring.

We have analyzed the refractive results after cataract surgery of six eyes from three patients whose axial lengths ranged from 15.09 to 19.95 mm. Each of these patients had final refractions ranging from −0.12 to −3.37 D using two posterior chamber lenses in-the-bag to achieve the necessary dioptric intraocular lens power. In this study, we discuss the optical consequences of "piggyback" lenses and the limitations of our current intraocular lens power formulas.

## Materials and Methods

Preoperatively, the axial length, keratometry readings, horizontal and vertical white-to-white corneal diameters, anterior chamber depth, and crystalline lens thickness were obtained for each eye. Postoperatively, the power of the two implants, the stabilized refraction (4–6 weeks postoperatively), the distance from the corneal vertex to the iris and the distance from the iris to the anterior vertex of the front intraocular lens were recorded. These values are shown in Table 1.

All six pairs of lenses were in-the-bag with the haptics parallel to each other. The intraocular lenses were biconvex with 1:1 front-to-back surface powers (equiconvex) with personalized lens constants (for JPG) of A-constant = 119.0, anterior chamber depth = 5.37 mm and a Surgeon Factor of 1.81 mm. The personalized lens constants had been determined previously on 100 consecutive patients using the same surgery and intraocular lens. The data from each of the eyes were used to calculate the predicted refraction using the three current third-generation intraocular lens calculation formulas: Holladay,[17] SRK/T,[22] and the Hoffer Q,[25] and two earlier formulas the SRK2[18] and the SRK1.[28] The prediction error then was calculated as the difference between the predicted refraction from the formula and the actual postoperative refraction. The results are shown in Table 2. Each of the formula constants then were optimized for the six eyes to achieve zero average error, and the optimized values are shown in Table 3.

## Results

In Table 2, we see the prediction error and the absolute prediction error for each of the five intraocular lens formulas tested along with the average and standard deviation. The two best measures of a formula are the standard deviation of the prediction error and the average absolute prediction error, because prediction errors of opposite signs will not cancel out. The standard deviation weighs larger errors more heavily because it squares the error before averaging, whereas the average absolute error weighs all errors equally. Statistically, these are both valid measures, but the standard deviation may be more mean-

Table 1. Preoperative and Postoperative Measurements Used for Intraocular Lens Power Calculations

| | Preoperative Measurements | | | | | | | Postoperative Measurements | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Case No./ Eye | *Horizontal Corneal Diameter (mm)* | *Vertical Corneal Diameter (mm)* | *Average Keratometry Readings (D)* | *Axial Length (mm)* | *Anterior Chamber Depth (mm)* | *Lens Thickness (mm)* | *Anterior Segment Length (mm)* | *Total IOL Power (D)* | *Spheroequivalent Refraction (D)* | *Corneal Vertex to Iris (mm)* | *Iris to Anterior Vertex IOL (mm)* |
| 1/OD | 11.5 | 11.0 | 43.10 | 19.95 | 2.6 | 5.5 | 8.1 | 42.0 | −0.12 | 4.3 | 1.5 |
| 1/OS | 11.5 | 11.0 | 43.17 | 19.69 | 2.6 | 5.2 | 7.8 | 42.0 | −0.50 | 4.1 | 1.5 |
| 2/OD | 11.0 | 10.0 | 44.40 | 19.13 | 4.1 | 3.3 | 7.4 | 46.0 | −1.00 | 3.8 | 0.5 |
| 2/OS | 11.0 | 10.0 | 44.65 | 19.00 | 3.5 | 4.2 | 7.7 | 43.0 | −0.12 | 3.8 | 0.6 |
| 3/OD | 9.5 | 9.5 | 52.72 | 15.09 | 2.9 | 4.6 | 7.5 | 61.5 | −3.37 | 2.2 | 0.1 |
| 3/OS | 9.5 | 9.5 | 53.03 | 15.31 | 2.9 | 4.6 | 7.5 | 61.5 | −1.75 | 2.8 | 0.1 |
| Mean ± SD | 10.67 ± 0.85 | 10.17 ± 0.62 | 46.85 ± 4.30 | 18.03 ± 2.03 | 3.10 ± 0.54 | 4.57 ± 0.71 | 7.67 ± 0.24 | 49.33 ± 8.71 | −1.15 ± 1.14 | 3.50 ± 0.75 | 0.72 ± 0.58 |

D = diopters; IOL = intraocular lens; OD = right eye; OS = left eye; SD = standard deviation.

Table 2. Prediction Errors (diopters) for the Five Formulas Using the Personalized Lens Constant for Normal Eyes

| Case No./ Eye | Holladay | Holladay (absolute) | SRK/T | SRK/T (absolute) | HOFFER Q | HOFFER Q (absolute) | SRK2 | SRK2 (absolute) | SRK1 | SRK1 (absolute) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1/OD | −5.56 | 5.56 | −6.28 | 6.28 | −4.78 | 4.78 | −7.19 | 7.19 | −9.59 | 9.59 |
| 1/OS | −4.24 | 4.24 | −4.99 | 4.99 | −3.38 | 3.38 | −6.35 | 6.35 | −8.75 | 8.75 |
| 2/OD | −6.06 | 6.06 | −6.81 | 6.81 | −4.76 | 4.76 | −8.83 | 8.83 | −11.23 | 11.23 |
| 2/OS | −4.01 | 4.01 | −4.68 | 4.68 | −2.78 | 2.78 | −7.23 | 7.23 | −9.63 | 9.63 |
| 3/OD | −3.45 | 3.45 | −2.37 | 2.37 | 7.75 | 7.75 | −16.84 | 16.84 | −19.24 | 19.24 |
| 3/OS | −7.11 | 7.11 | −5.61 | 5.61 | 4.4 | 4.4 | −19.14 | 19.14 | −21.54 | 21.54 |
| Mean ± SD | −5.07 ± 1.28 | 5.07 ± 1.28 | −5.12 ± 1.43 | 5.12 ± 1.43 | −0.59 ± 4.86 | 4.64 ± 1.57 | −10.93 ± 5.09 | 10.93 ± 5.09 | −13.33 ± 5.09 | 13.33 ± 5.09 |

D = diopters; OD = right eye; OS = left eye; SD = standard deviation.

Table 3. Prediction Errors (diopters) for the Five Formulas Using the Optimized Lens Constant for Six Eyes

| Case No./ Eye | Holladay | Holladay (absolute) | SRK/T | SRK/T (absolute) | HOFFER Q | HOFFER Q (absolute) | SRK2 | SRK2 (absolute) | SRK1 | SRK1 (absolute) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1/OD | −1.77 | 1.77 | −2.35 | 2.35 | −4.28 | 4.28 | 3.74 | 3.74 | 3.74 | 3.74 |
| 1/OS | −0.48 | 0.48 | −1.08 | 1.08 | −2.89 | 2.89 | 4.58 | 4.58 | 4.58 | 4.58 |
| 2/OD | −1.63 | 1.63 | −2.23 | 2.23 | −4.19 | 4.19 | 2.10 | 2.10 | 2.10 | 2.10 |
| 2/OS | −0.09 | 0.09 | −0.62 | 0.62 | −2.27 | 2.27 | 3.70 | 3.70 | 3.70 | 3.70 |
| 3/OD | 3.71 | 3.71 | 4.69 | 4.69 | 8.48 | 8.48 | −5.91 | 5.91 | −5.91 | 5.91 |
| 3/OS | 0.27 | 0.27 | 1.60 | 1.60 | 5.15 | 5.15 | −8.21 | 8.21 | −8.21 | 8.21 |
| Mean ± SD | 0.00 ± 1.82 | 1.33 ± 1.25 | 0.00 ± 2.47 | 2.10 ± 1.31 | 0.00 ± 4.96 | 4.54 ± 2.00 | 0.00 ± 5.09 | 4.71 ± 1.94 | 0.00 ± 5.09 | 4.71 ± 1.94 |

D = diopters; OD = right eye; OS = left eye; SD = standard deviation.

ingful clinically, because the larger prediction errors are much more problematic and deserve a greater weight than the smaller errors. All *P* values for our statistical analysis were determined using the Duncan multiple-range test.[29]

The standard deviation for the three third-generation formulas ranged from a low of 1.28 D for the Holladay formula to 1.43 D for the Hoffer Q formula. The standard deviation of the SRK1 and SRK2 regression formulas were 5.09 D, more than three times greater. The mean absolute prediction errors were also not significantly different for the third-generation formulas ($P \geq 0.60$), with the Hoffer Q having the smallest of 4.64 D and the SRK/T the largest of 5.12 D. The SRK2 and SRK1 had mean absolute prediction errors that were significantly worse ($P = 0.0006$) at 10.93 and 13.33 D, respectively. Although the third-generation formulas were two to three times better, they are still clinically unacceptable with errors from the desired refraction, averaging 5 D.

Optimizing each of the five formulas for these six eyes is accomplished by determining the constant that forces the mean prediction error to zero. In Table 3, we see that the mean prediction error for each of the five formulas is zero, with the corresponding standard deviations and mean absolute prediction errors. The standard deviations, using the optimized constant for the five formulas, ranged from a low of 1.82 D for the Holladay formula to a high of 5.09 D for the SRK2 and SRK1. The mean absolute prediction error was 1.33 D for the Holladay, 2.10 D for the SRK/T, 4.54 D for the Hoffer Q, and 4.71 D for the SRK2 and SRK1. The mean absolute errors for the Holladay and SRK/T were not different ($P = 0.363$), but were better than the Hoffer Q, SRK2, and SRK1 ($P \leq 0.0068$). Although these values are superior to the nonoptimized values in Table 2, they are still unacceptable clinically, with the smallest average formula error of 1.33 D for the Holladay formula and the largest formula error for a single eye ranging from 3.71 D for the Holladay to 8.48 D for the Hoffer Q in the right eye of case 3.

## Discussion

Implanting two posterior chamber lenses to achieve emmetropia in nanophthalmic eyes was first performed by Gayton,[30] in 1993. He used the SRK/T for his intraocular lens calculation, which required a 46-D lens. Based on these calculations, a 25-D lens was placed posteriorly and a 20-D lens was placed anteriorly in the capsular bag, for a total of 45 D. Similar to our results, he had an 8-D hyperopic surprise requiring replacement of the anterior lens with a 30-D lens, which still left the patient with a +2.25 spheroequivalent refraction.

As with many new developments, necessity was the mother of invention. Because Gayton was unable to get any of the lens manufacturers to make a 46-D lens, his only choice was to implant two lenses. Although Gayton was unaware at the time, using two lenses to achieve these high dioptric powers is superior optically to a single lens of the same total power if the two lenses are optically aligned (optical centers aligned).[31] The reason for the superior optical quality of the piggyback lenses is due to less spherical aberration than a single lens at these high dioptric powers. This factor is one of the reasons manufacturers chose 34 D as the upper limit of their available lens powers. Lenses that are significantly stronger required such steep radii that the lens begins to look more like a sphere than a lens. For a 3-mm pupil, the manufacturers could not pass the current resolution requirements for lenses above 44 D.[32] Clinically, it is similar to looking through a sphere where the image quality is severely distorted, such as a fish-eye lens or glass sphere.

Our results, as with those of Gayton, were achieved empirically by the surgeon (JPG). Similarly, the initial case required lens exchange because of a significant hyperopic surprise. In analyzing these three patients, we see that cases 1 and 2 have normal anterior segment dimensions for the corneal diameters, keratometry, and anterior segment length (anterior chamber depth + lens thickness). The only apparent abnormality is the foreshortened axial length, which is totally due to the shortened posterior segment. In contrast, case 3 truly has nanophthalmic eyes with corneal diameters, K-readings, and anterior chamber depth that indicate a very small anterior segment, as well as a very short posterior segment, which is almost proportional to the front. Only case 3 has symmetrically "small" eyes and cases 1 and 2 have asymmetrically "small" eyes, with normal anterior segments and short posterior segments.

Since all of the third-generation formulas shorten the expected anterior chamber depth to the lens as a function of the axial length, they would all predict the position of the lens to be too far anterior, which results in a hyperopic error. The Holladay and SRK/T formulas made a hyperopic error in all six of the eyes, ranging from 2.37 to 7.11 D. The Hoffer Q formula attenuates the scaling of the predicted anterior chamber depth by approximately one half of the Holladay and SRK/T formulas. Therefore, the Hoffer Q formula made slightly smaller hyperopic errors on cases 1 and 2, but actually made significant myopic errors on case 3 by predicting a much larger anterior chamber depth in this nanophthalmic eye.

Another factor that caused the hyperopic errors is the actual position of the piggyback lenses in-the-bag. Before measuring the distance from the iris to the anterior intraocular lens vertex, it was expected that the anterior intraocular lens would be more anterior in the posterior chamber than a single lens. Our measurements demonstrated that the anterior lens was in the normal position and the posterior lens was one lens thickness deeper than normal. In retrospect, we should have predicted this because the elasticity of the posterior capsular bag easily can accommodate another lens that is only approximately 1-mm thick. The lens thickness before cataract extraction averages 4.8 mm in the cataract age group.[33–35] In fact, we now have one patient (JPG) who has four standard intraocular lenses in the capsular bag.

If we are to achieve results that are comparable to normal eyes in these extremely short eyes, we first must determine the size of the anterior segment using the horizontal white-to-white corneal diameter, anterior chamber

Table 4. Clinical Conditions Demonstrating Independence of Anterior Segment Size and Axial Length

| Anterior Segment Size | Axial Length | | |
|---|---|---|---|
| | *Short* | *Normal* | *Long* |
| Small | Small eye nanophthalmia | Microcornea | Microcornea + axial myopia |
| Normal | Axial hyperopia | Normal | Axial myopia |
| Large | Megalocornea + axial hyperopia | Megalocornea | Large eye buphthalmos<br>Megalocornea + axial myopia |

depth, and lens thickness as well as the K-readings and axial length, i.e., determine whether the eye is nanophthalmic (symmetrically small anterior and posterior segment) or simply a short posterior segment with a normal anterior segment. This is analogous to measuring the height of two very short people—one pituitary dwarf (symmetric dwarf=+) and one achondroplastic dwarf (asymmetric dwarf=+).[36] The pituitary dwarf is comparable to nanophthalmia, where the all of the body parts are proportionately small (short crown-to-rump and short limbs). In the achondroplasic dwarf, however, the trunk and head are normal, only the limbs are short (normal crown-to-rump with short limbs). The independence of the anterior segment size and the axial length can be seen by the clinical conditions shown in Table 4.

With these additional measurements of the anterior segment (horizontal white-to-white, anterior chamber depth, and lens thickness), newer intraocular lens formulas can use these dimensions to distinguish between the different types of short eyes, making a better prediction of the actual position of the intraocular lens within the anterior segment of the eye and resulting in much smaller prediction errors. Distinguishing between these types of short eyes is also important surgically, because intraocular procedures in the nanophthalmic eye with the small anterior segment frequently are complicated by choroidal effusion, nonrhegmatogenous retinal detachment, and angle-closure glaucoma.[37,38]

## References

1. Kanki K, Yoshimoto M, Uesugi T, Kimura T. Measurement of the axial length of the eye by the application of ultrasonic waves. Acta Soc Ophthalmol Japan 1961;65:1877.
2. Jansson F, Kock E. Determination of the velocity of ultrasound in the human lens and vitreous. Acta Ophthalmol 1962;40:420–33.
3. Binkhorst RD. The accuracy of ultrasonic measurement of the axial length of the eye. Ophthalmic Surg 1981;12:363–5.
4. Hillman JS, de Dombal FT. Sources of error in the calculation of intraocular lens power. In: Thijssen JM, Verbeek AM, eds. Ultrasonography in Ophthalmology. Proceedings of the 8th Siduo Congress, The Hague, Dr. W Junk Publ (Doc Ophthalmol Proc Ser.) 1981;29:225.
5. Hoffer KJ. Intraocular lens calculation: the problem of the short eye. Ophthalmic Surg 1981;12:269–72.
6. Shammas HJF. Axial length measurement and its relation to intraocular lens power calculation. American Intraocular Implant Soc J 1982;8:346.
7. Richards SC, Olson RJ, Richards WL. Factors associated with poor predictability by intraocular lens calculation formulas. Arch Ophthalmol 1985;103:515–8.
8. McEwan JR, Massengill RK, Friedel SD. Effect of keratometer and axial length measurement errors on primary implant power calculations. J Cataract Refract Surg 1990;16:61–70.
9. Holladay JT, Prager TC, Ruiz RS, Lewis JW. Improving the predictability of intraocular lens power calculations. Arch Ophthalmol 1986;104:539–41.
10. Drews RC. Results in patients with high and low power intraocular lenses. J Cataract Refract Surg 1986;12:154–7.
11. Drews RC. Reliability of lens implant power formulas in hyperopes and myopes. Ophthalmic Surg 1988;19:11–5.
12. Hoffer KJ. Ultrasound velocities for axial eye length measurement. J Cataract Refract Surg 1994;20:554–62.
13. Sanders DR, Retzlaff J, Kraff MC. Comparison of empirically derived and theoretical aphakic refraction formulas. Arch Ophthalmol 1983;101:965–7.
14. Binkhorst RD. Intraocular lens power calculation manual. A guide to the author's TI CC-40 programs. 3rd ed, New York, Richard D Binkhorst, 1984.
15. Hoffer KJ. The effect of axial length on posterior chamber lenses and posterior capsule position. Current Concepts in Ophthalmic Surgery 1984;1(1):20–2.
16. Richards SC, Olson RJ, Richards WL, et al. Clinical evaluation of six intraocular lens calculation formulas. Am Intraocular Implant Soc J 1985;11:153–8.
17. Holladay JT, Prager TC, Chandler TY, Musgrove KH, Lewis JW, Ruiz RS. A three-part system for refining intraocular lens power calculations. J Cataract Refract Surg 1988;14:17–24.
18. Sanders DR, Retzlaff J, Kraff MC. Comparison of the SRK2 formula and other second generation formulas. J Cataract Refract Surg 1988;14:136–41.
19. Naeser K, Boberg-Ans J, Bargum R. Biometry of the posterior lens capsule: A new method to predict pseudophakic anterior chamber depth. J Cataract Refract Surg 1990;16:202–6.
20. Olsen T, Olesen H, Thim K, Corydon L. Prediction of postoperative intraocular lens chamber depth. J Cataract Refract Surg 1990;16:587–90.
21. Olsen T, Thim K, Corydon L. Theoretical versus SRK1 and SRK2 calculation of intraocular lens power. J Cataract Refract Surg 1990;16:217–25.
22. Retzlaff JA, Sanders DR, Kraff MC. Development of the SRK/T intraocular lens implant power calculation formula. J Cataract Refract Surg 1990;16:333–40.

23. Sanders DR, Retzlaff J, Kraff M, et al. Comparison of the SRK/T formula and other theoretical and regression formulas. J Cataract Refract Surg 1990;16:341–6.
24. Olsen T, Thim K, Corydon L. Accuracy of the newer generation intraocular lens power calculation formulas in long and short eyes. J Cataract Refract Surg 1991;17:187–93.
25. Hoffer KJ. The Hoffer Q formula: a comparison of theoretic and regression formulas. J Cataract Refract Surg 1993;19:700–12.
26. Kalogeropoulos C, Aspiotis M, Stefaniotou M, Psiles K. Factors influencing the accuracy of the SRK formula in the intraocular less power calculation. Doc Ophthalmol 1994;85:223–42.
27. Niederer W. Analysis of parameters for calculating the intraocular lens. Klin Monatsbl Augenheilkd 1994;204:435–7.
28. Sander D, Retzlaff J, Kraff M, et al. Comparison of the accuracy of the Binkhorst, Colenbrander, and SRK1 implant power prediction formulas. Am Intra-Ocular Implant Soc J 1981;7:337–40.
29. Duncan DB. t-Tests and Intervals for Comparisons Suggested by the Data Biometrics 1975;31:339–59.
30. Gayton JL. Implanting two Posterior Chamber Intraocular Lenses in Microphthalmos. Ocular Surgery News 1994;64–5.
31. Smith WJ. Modern Optical Engineering. The Design of Optical Systems. New York: McGraw Hill Book Co, 1966;50–2.
32. American National Standard for Ophthalmics-Intraocular Lenses-Optical and Physical Requirements, ANSI Z80.7-1994, American National Standards Institute, New York, 1994.
33. Bellows JG. Cataract and Anomalies of the Lens. St. Louis: C. V. Mosby, 1944;64–72.
34. Fontana ST, Brubaker RF. Volume and depth of the anterior chamber in the normal aging human eye. Arch Ophthalmol 1980;98:1803–8.
35. Assia EI, Legler UFC, Apple DJ. The capsular bag after short- and long-term fixation of intraocular lenses. Ophthalmology 1995;102:1151–7.
36. Robbins S, Cotran RS. Pathologic Basis of Disease, 2nd ed. Philadelphia: WB Saunders, 1979;1341, 1481.
37. Brockhurst RJ. Nanophthalmos with uveal effusion. Arch Ophthalmol 1975;93:1289.
38. Kimbrough RL, Trempe CS, Brockhurst RJ, Simmons RJ. Angle-closure glaucoma in nanophthalmos. Am J Ophthalmol 1979;88:572.

---

## Centennial Advertisement

From the *Textbook of Ophthalmology*, by Dr. Ernest Fuchs. New York: D. Appleton and Company, 1896. Anatomy of the Eyeball.*

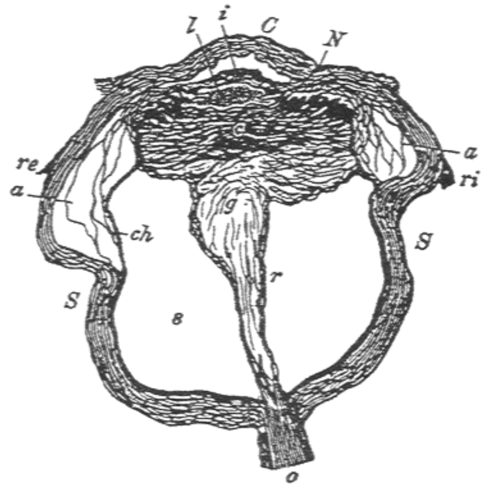

FIG. 62.—ATROPHY OF THE EYEBALL. IN PART AFTER WEDL-BOCK.

The eye is smaller and of irregular shape, chiefly from the folding of the sclera behind the points of attachment of the ocular muscles, the rectus internus, *ri*, and the rectus externus, *re*. The cornea, *C*, is diminished in size, flattened, and folded especially on its posterior surface. At its inner border it bears the depressed cicatrix, *N*, which was produced by the injury. The anterior chamber is shallow; the iris, *i*, is thickened and forms an unbroken surface, because the pupil is closed by exudate. Behind the iris lies the shrunken lens, *l*, and behind this is the great shell of cyclitic membrane, *c*, the shrinking of which is the cause of the atrophy of the eyeball. By reason of this shrinking, the ciliary processes, the pigment-layer of which has markedly proliferated, are drawn in toward the center, and, together with the adjacent chorioid, *ch*, are detached from the sclera; between the two structures are seen the disjoined lamellæ of the suprachorioid membrane, *a*. The retina, *r*, is detached and folded in the form of a funnel, which incloses the remains of the degenerated vitreous. The subretinal space, *s*, is filled with a fluid rich in albumin. The optic nerve, *o*, is thinner than usual and atrophic.

* Centennial advertisment provided courtesy of the Museum of Ophthalmology, Foundation of the American Academy of Ophthalmology, San Francisco, California

23. Sanders DR, Retzlaff J, Kraff M, et al. Comparison of the SRK/T formula and other theoretical and regression formulas. J Cataract Refract Surg 1990;16:341–6.
24. Olsen T, Thim K, Corydon L. Accuracy of the newer generation intraocular lens power calculation formulas in long and short eyes. J Cataract Refract Surg 1991;17:187–93.
25. Hoffer KJ. The Hoffer Q formula: a comparison of theoretic and regression formulas. J Cataract Refract Surg 1993;19:700–12.
26. Kalogeropoulos C, Aspiotis M, Stefaniotou M, Psiles K. Factors influencing the accuracy of the SRK formula in the intraocular less power calculation. Doc Ophthalmol 1994;85:223–42.
27. Niederer W. Analysis of parameters for calculating the intraocular lens. Klin Monatsbl Augenheilkd 1994;204:435–7.
28. Sander D, Retzlaff J, Kraff M, et al. Comparison of the accuracy of the Binkhorst, Colenbrander, and SRK1 implant power prediction formulas. Am Intra-Ocular Implant Soc J 1981;7:337–40.
29. Duncan DB. t-Tests and Intervals for Comparisons Suggested by the Data Biometrics 1975;31:339–59.
30. Gayton JL. Implanting two Posterior Chamber Intraocular Lenses in Microphthalmos. Ocular Surgery News 1994;64–5.
31. Smith WJ. Modern Optical Engineering. The Design of Optical Systems. New York: McGraw Hill Book Co, 1966;50–2.
32. American National Standard for Ophthalmics-Intraocular Lenses-Optical and Physical Requirements, ANSI Z80.7-1994, American National Standards Institute, New York, 1994.
33. Bellows JG. Cataract and Anomalies of the Lens. St. Louis: C. V. Mosby, 1944;64–72.
34. Fontana ST, Brubaker RF. Volume and depth of the anterior chamber in the normal aging human eye. Arch Ophthalmol 1980;98:1803–8.
35. Assia EI, Legler UFC, Apple DJ. The capsular bag after short- and long-term fixation of intraocular lenses. Ophthalmology 1995;102:1151–7.
36. Robbins S, Cotran RS. Pathologic Basis of Disease, 2nd ed. Philadelphia: WB Saunders, 1979;1341, 1481.
37. Brockhurst RJ. Nanophthalmos with uveal effusion. Arch Ophthalmol 1975;93:1289.
38. Kimbrough RL, Trempe CS, Brockhurst RJ, Simmons RJ. Angle-closure glaucoma in nanophthalmos. Am J Ophthalmol 1979;88:572.

## Centennial Advertisement

From the *Textbook of Ophthalmology,* by Dr. Ernest Fuchs. New York: D. Appleton and Company, 1896. Anatomy of the Eyeball.*

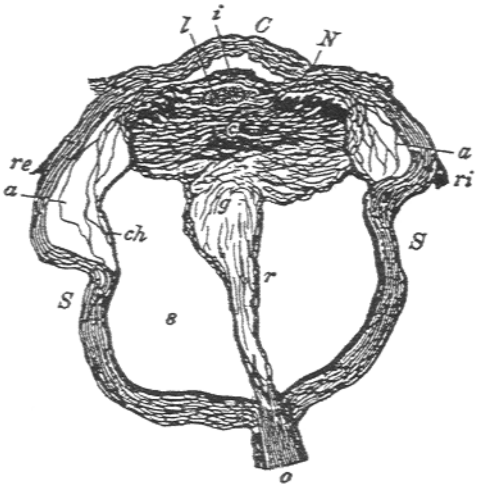

FIG. 62.—ATROPHY OF THE EYEBALL. IN PART AFTER WEDL-BOCK.

The eye is smaller and of irregular shape, chiefly from the folding of the sclera behind the points of attachment of the ocular muscles, the rectus internus, *ri*, and the rectus externus, *re*. The cornea, *C*, is diminished in size, flattened, and folded especially on its posterior surface. At its inner border it bears the depressed cicatrix, *N*, which was produced by the injury. The anterior chamber is shallow; the iris, *i*, is thickened and forms an unbroken surface, because the pupil is closed by exudate. Behind the iris lies the shrunken lens, *l*, and behind this is the great shell of cyclitic membrane, *c*, the shrinking of which is the cause of the atrophy of the eyeball. By reason of this shrinking, the ciliary processes, the pigment-layer of which has markedly proliferated, are drawn in toward the center, and, together with the adjacent chorioid, *ch*, are detached from the sclera; between the two structures are seen the disjoined lamellæ of the suprachorioid membrane, *a*. The retina, *r*, is detached and folded in the form of a funnel, which incloses the remains of the degenerated vitreous. The subretinal space, *s*, is filled with a fluid rich in albumin. The optic nerve, *o*, is thinner than usual and atrophic.

* Centennial advertisment provided courtesy of the Museum of Ophthalmology, Foundation of the American Academy of Ophthalmology, San Francisco, California