2 American History of IOL Power Calculation

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Introduction

Without the ability to accurately calculate its desired power, the intraocular lens (IOL) would never have become the revolution in eye surgery that it has. Many pioneers contributed to the development of accurate IOL power calculation, and I merely borrowed from most of them to arrive at methods and systems that would provide the greatest accuracy for my patients. My interest in teaching led me to share these procedures with my colleagues over this past half century. I have also enjoyed the challenge of trying to develop improvements and on occasion these endeavors have been fruitful. I will, therefore, present a personal history of these events as I remember them.

Prior to my first IOL implantation on April 22, 1974, I realized I needed to measure the axial length (AL) of the eye with ultrasound (US), measure the corneal power (K), and use an optical formula to obtain the IOL power needed for the patient.

Personal Ultrasound History

The first time I had ever heard of ultrasound in ophthalmology was from lectures given by Dr. Michael Weinstock during my residency at Kresge Eye Institute (Wayne State University) in Detroit (1969–1972), and I personally found the subject rather uninteresting. The next time the subject arose was in my first year of practice at an Eye Staff meeting at St. John's Hospital in Santa Monica in 1972. Robert Sinskey, the Chairman, asked the staff who would volunteer to fly to New York City and attend a course on how to use the new Sonometrics Coleman B-scan ultrasound diagnostic unit the hospital was purchasing. No one wanted to go and since I had relatives in New York, I volunteered. This decision changed my professional career.

The faculty at the 2-day course in Southampton consisted of Drs. Nathaniel Bronson, Jackson Coleman, and Karl Ossoinig (Fig. 2.1). Karl was a young A-scan pioneer and guru that Dr. Fred Blodi had brought from Vienna, Austria to Iowa City to teach at the university there. Karl gave a lecture on the techniques to accurately measure the axial length of the eye, and I distinctly remember wondering how often that would be of any clinical use and laughing about it with a fellow participant. That evening, the course sponsored a cocktail party at a local eatery and after dinner, Karl and I sampled at least five or six of their various brews. The conversation waxed until closing time, and a friendship started that night that has lasted all these years. What a totally fortuitous event!

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Fig. 2.1 Karl Ossoinig, MD (left), aided in the first ultrasound IOL power calculation in America; Gary G Hoffer, the author's brother

First American Ultrasound IOL Power Calculation

In early 1974, while planning my first IOL implantation on Mrs. Phoebe Miller (deceased), I had learned that Jan Worst (of Groningen, Holland) was using a little A-scan ultrasound unit to obtain an AL for IOL power calculation. I had remembered Ossoinig's lectures and called him for advice on the instrument I should use. Santa Monica Hospital (SMH) subsequently agreed to purchase the recommended Kretz 7200-MA unit (Fig. 2.2) from Austria along with a keratometer and provide a facility where I could perform the tests. They gave me the use of the hospital's old Intensive Care Unit, and I called the new facility the EyeLab. They soon hired a supervisor, Maryanne Hooper RN, and a photographer, Don Allen, who was to begin performing fluorescein angiograms.

I performed the first A-scan IOL power calculation with Dr. Ossoinig [Fig. 2.1] (on the phone from Iowa) talking me through the calibration of the Kretz unit and how to measure the Polaroid camera photographs using precision calipers. For his willingness to help me, I will be eternally grateful. It worked!

Prior to this time, American lens implanters used a standard 18.0 D IOL for all eyes, expecting the patient to be as myopic or hyperopic as they were before surgery. In the mid-70s, Dennis Shepard devised a nomogram (Fig. 2.3) based on the patient's preoperative refractive error. It was distributed in the syllabus to all those attending the SMH monthly lens implant courses that began in May 1974 and trained 2,600 surgeons over the ensuing years. After the word got out about our EyeLab, many colleagues sent their patients to us for IOL power calculations, including Henry Hirschman, who limousined his patients to Santa Monica from Long Beach. After months of performing the exam myself, I finally decided that I had to train a technician to do it. Our photographer, Don Allen, was the closest at hand and after 2 months he picked it up easily and became the first IOL power calculation technician in America and he trained many others to follow him. Don died 30 years ago and I honor him for his pioneering work.

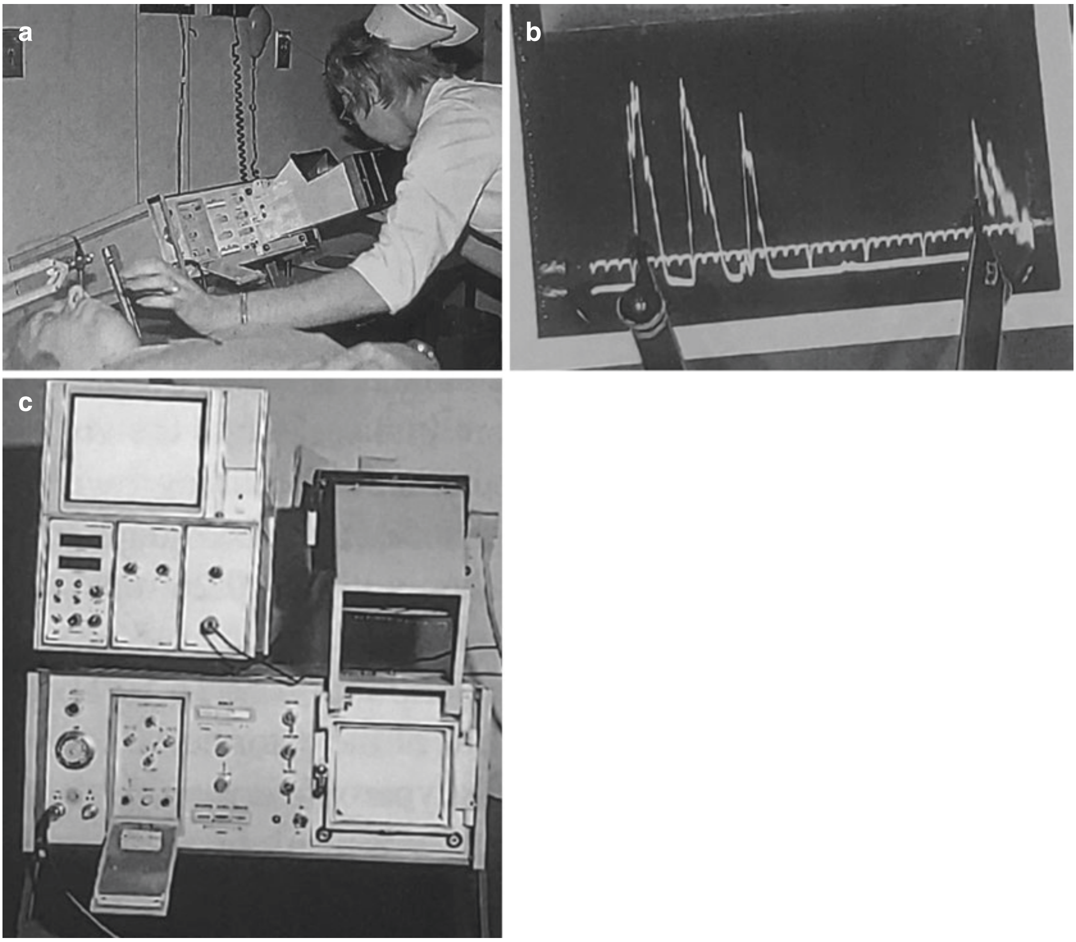

Fig. 2.2 A Kretz 7200-MA A-scan ultrasound unit used for the first IOL power calculation in America 1974. (**a**) Performing an immersion exam on Gary Hoffer (deceased). (**b**) Caliper measurement of the axial length on a Polaroid photograph of the A-scan. (**c**) A Kretz instrument (below) with its Xenotec replacement on top of it.

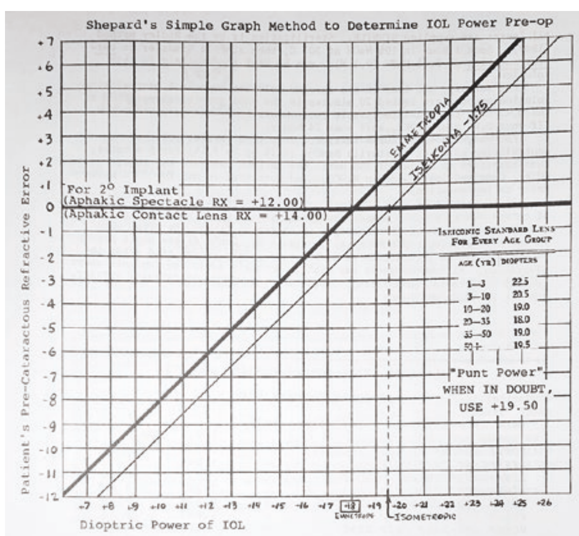

Fig. 2.3 A Dennis Shepard IOL power prediction nomogram distributed at all early Santa Monica Hospital IOL courses

Personal Formula History

See Chapter 43 on Hoffer Formula History.

Earliest Calculators and Computers

At first, I used my new Hoffer formula in longhand with paper and pencil for each patient, which was quite tedious. By July 1974, my brother Gary (patient in Fig. 2.1), who was a computer programmer before there were personal computers, now deceased) convinced me to let him program the formula on the mainframe computer he used at his work (TransAmerica Insurance Co., Los Angeles). The biometric data from each exam was phoned in to him by our nurse, Maryanne, and Gary would later call back with the IOL power result. Often, however, the computer would be tied up and we would have to wait for hours or until the next day for the results. Gary also helped make history by recommending in 1974 that I have the membership list of my fledgling American Intra-Ocular Implant Society (now ASCRS) programmed on a micro computer (years before PCs) making ASCRS the first medical society to do so.

For many years, SMH implant courses usually had from 25 to 40 attendees. Dr. Shepard would implant an intracapsular IOL in three to four cases, and I would do one case of phacoemulsification using a Binkhorst two-loop iridocapsular lens placed in the bag. Most surgeons wanting to learn lens implantation were not using phacoemulsification. During the didactic sessions, I always gave a talk on IOL power calculation and afterward we would give the attendees a tour of the EyeLab. In August of 1974, an attendee from Oklahoma, Dr. Ralph Dahlstrom, after seeing what I was doing, suggested that I get a Hewlett Packard programmable calculator for the formula. The HP-65 (Fig. 2.4) was one of the first handheld programmable consumer calculators, and it was expensive at $880 ($5,653 in 2024). Because it was the only one I knew available at the time, the hospital was willing to buy it for me. It was soon followed by the more affordable Texas Instruments unit at $250 ($1,517 in 2024). It took days and nights for me to learn its programming language, then program the formula, correct the bugs and finally have a working program which we published [2] so others could use it. Now, we were free of the mainframe computer and the delays. We were on our way, thanks to Ralph Dahlstrom.

Fig. 2.4 An HP-65-programmed calculator with the first Hoffer formula for IOL power calculation in America 1974

In 1978, I started the EyeLab, Inc. to provide accurate lens power calculation for my colleagues and their patients in Southern California since SMH had no interest in doing so. The idea came to me from the old expression "If you can't bring Mohammed to the mountain, bring the mountain to Mohammed." We needed to set up offices in various locations throughout the area (Sherman Oaks, Hollywood, Long Beach, Garden Grove, and a Mobile unit) and would need to equip and staff them. In doing so, we had to find a less expensive method to allow each of the five units to have their own calculator. I discovered the new Casio 4000P unit costing only about $100 ($607 in 2024) and learned its language and programmed the Hoffer formula on it. Over the years, I would update to more powerful Casio units as they came out, including the fx-8500G (Fig. 2.5) which allowed an optional printout using a module and finally the fx-9700GE. These latter units had enough memory to allow me to subsequently program the Holladay 1, the SRK/T and in 1993, the new Hoffer Q formula as well as add their individual personalization programs. I would not be able to program one of these calculators today; I have no idea how I did it. Holladay later came out with his own calculators with the Holladay formula on them which were available for purchase. Due to physician requests, we sold the programmed calculators through the EyeLab under the name "Hoffer® Programs" for many years.

In 1993, due to a colleague's request, I had the Hoffer® Programs (Fig. 2.6) system programmed

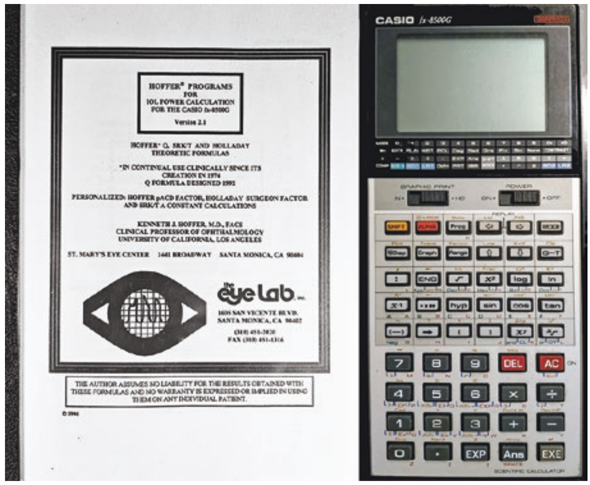

Fig. 2.5 Hoffer® Programs on a Casio fx-8500G with a user manual

Fig. 2.6 Hoffer® Programs on floppy disks and CDs for Windows, DOS, MAC, Palm, and Casio fx-8500G and fx-9700GE calculators

for personal computer use which became the first IOL power calculation program for use on any personal or office computer. First on Microsoft DOS and Windows-based computers and later on Macs and even the Palm handheld PDA phone. It was first on floppy disks and later on CDs. It was used by thousands of ophthalmologists but due to the very high expense to maintain the upgrades for each new rendition of the Windows operating system and the fact that most formulas were becoming available on ultrasound units and optical biometers, Hoffer® Programs ceased in the early 2000s.

The First Dedicated IOL Power A-Scan: The Invention of the Applanation Method

In 1974, because we were the only facility in California using the Coleman water bath ophthalmic diagnostic B-scan, patients were being referred to my St. John's Clinic from all over Southern California. I soon realized that I did not enjoy doing the time-consuming, tedious water-bath procedures and I did not feel particularly secure with my findings. I could not get out of the job until I trained someone else to do it. Gratefully, Dr. Jerry Pierce took it off my hands.

But before that, in late 1974, I decided that it would be wise if we had an aluminum calibration rod for the Coleman unit. I called the manufacturer, Sonometrics, in New York and reached its president, Mr. Lou Katz. After ordering the rod, I told him of the difficulties I was having with the Kretz 7200 A-scan unit for AL. I mentioned how tedious it was calibrating the unit for each exam, taking the screen Polaroid photographs and most of all, measuring the A-scan Polaroid photos with calipers. I brought up some ideas I had and asked him if his company would consider developing a dedicated A-scan instrument specifically for AL measurement. I told him the new instrument would need to use an immersion method with a water back-off of the probe from the cornea and that it might be more accurate if the patient could sit up rather than lying supine. My theory was that the eye and internal structures might measure differently in the two positions: the upright being more physiologic. Katz suggested using gates to allow the unit to automatically read out the axial length, which I thought would be fantastic. This would eliminate the measuring of photographs of the oscilloscope screen. I also suggested a red fixation light located at the center of the probe to make it easier for the patient to fixate and obtain axiality (which really never worked).

Katz was extremely doubtful about the commercial success of such a device because he had heard that lens implants were "going nowhere." I strenuously argued that implants would someday be routine and that every ophthalmologist would need a dedicated A-scan unit even though I was not sure of that statement. I was willing to say anything to convince him to consider my idea. He said he needed to check with his colleagues in New York and with Dr. Coleman, his chief consultant. I pestered him for months and finally he told me that they were planning to proceed with the development of such a device. I was on the phone with him constantly as production proceeded.

I obviously waited with great anticipation to finally see the device and try it out. Because of this, I lifted the rule I had established for our upcoming first "ASCRS" meeting and allowed Katz to demonstrate the prototype unit just outside the doorway of the first Scientific Meeting of the American Intra-Ocular Implant Society (AIOIS, now ASCRS) at the Statler Hilton Hotel in Dallas, TX, on September 21, 1975 (Fig. 2.7). I had organized and chaired this first meeting and had not made any plans for exhibits by commercial interests. But this was just too exciting for ophthalmology (and for me). During that meeting, I gave a presentation [3] on IOL power calculation and told the attendees about this new instrument I had persuaded Sonometrics to create and that it could be viewed in the hallway after the meeting. At the end of the meeting, I eagerly went out to see the new Sonometrics DBR-100 (Digital Biometric Ruler) instrument (Fig. 2.8) for the first time and proudly demonstrate it to my colleagues. As I approached it, there was a huge crowd surrounding it. I soon noticed that it was being demonstrated by a gentleman I did not

Fig. 2.7 A program for the very first ASCRS meeting in Dallas TX, September 21, 1975

recognize. He was also demonstrating his new IOL power formula which was programmed on a $250 Texas Instruments programmable calculator. Katz then introduced me to Richard D. Binkhorst of New York (brother of the well-known Cornelius Binkhorst of Holland), and, the rest, as they say, is history. If anyone bought the instrument, they would be persuaded to buy the calculator with the Binkhorst formula and that became the world standard for the next decade.

I was obviously put off by this sudden switch without any fore-warning and let my feelings be known to Katz. I asked when the instrument would be delivered to Santa Monica so that I could test it out, and I was told it was first going to Florida for evaluation by Dr. Norman Jaffe (second ASCRS President). This was an excellent scientific, political, and marketing decision but not a fair one. I was never given the opportunity to work with it, evaluate it, or comment on it until it was well on the open market. I would have many occasions to mention my displeasure on how I was treated by Sonometrics to anyone who would listen, including Jaffe. As the major force behind my fledgling "Implant Society" (ASCRS), Jaffe had many occasions to converse with me since I was the Past-President and now the Secretary. He got so sick of hearing about it that he finally contacted Sonometrics and asked them to show me the DBR-100 and "get things straight with me." He also told me that the unit that I had designed was "not especially useful" and that the changes he had recommended made the unit

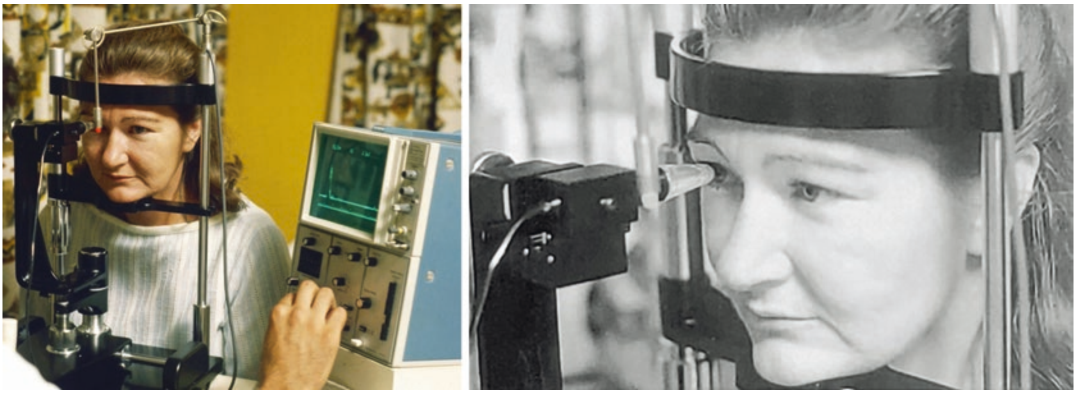

Fig. 2.8 A Sonometrics DBR-100 A-scan applanation ultrasound unit in 1975

functional, even though I told him that I had nothing to do with those negative aspects.

Because of Jaffe, Katz flew to SMH with a DBR-100 unit. He was accompanied by the son of Charles Schepens (Boston), who was president of Medical Instrument Research Associates (MIRA), the company that marketed all Sonometrics products worldwide at the time. After I asked for an explanation as to why I had been treated as I had, Mr. Schepens came clean and explained that it was "purely business." He told me my name was unknown at the time and because of his famous brother, Richard Binkhorst (of NY City) would promote the unit more successfully. I also got the impression that Coleman was happier with that arrangement as well. Regardless of what I said about fairness, it made little difference to them. They had no plans to acknowledge my development of the DBR-100, but, to "shut me up," they offered to give me a unit for free if I would keep quiet. I refused the offer on principle but did recommend they could donate the unit to SMH, which they did. I never agreed to keep quiet. To this day, I have never received any credit for any involvement in the development of the first dedicated IOL power A-scan instrument. Many years later, while negotiating a Sonometrics license for the Hoffer® Q formula, Katz (now deceased) specifically promised that he would make a public notice of my invention of the unit but that never happened. He stayed true to form. This may be a lesson to young naïve ophthalmologists with new ideas.

Early IOL Power Studies

In those first 2 years (1974–1976), we had been performing several studies of our results and I realized that it was not at all clinically useful to report the mean error for IOL power prediction because a +10 D error would cancel out a −10 D error giving a mean error result of 0 while hiding two clinical disasters. I recommended (in a publication [4]) that all future IOL power study results should consist of the following factors: the mean absolute error (MAE) (preventing plus and minus errors from canceling each other out), the percentage of eyes within ±1.00 and ±2.00 D of prediction, and the range of errors from the highest plus to the highest minus. It took several years to catch on, but this became the way most early studies were reported. As accuracy became more precise, I added the reporting of ±0.50 D errors. Today, we are down to reporting ±0.25 D and perhaps soon even ±0.13 D.

Using these principles, I determined that my early results on the very first 127 eyes using the Kretz immersion A-scan done by me personally were 70% (±1.00 D) and 96% (±2.00 D) with a range from +2.50 to −3.80 (6.20 D). A later study using the DOC attachment to the Kretz unit (which used gates to automatically measure the AL) performed by Don Allen on 239 eyes resulted in 72% (±1.00 D) and 98% (±2.00 D) with a range from +2.00 to −3.00 (5.0 D)—not dramatic but an improvement. When we switched to the newer Storz Compuscan 20/20 immersion unit, we saw a definite increase in accuracy. In 63 eyes, we obtained 81% (±1.00 D) and 100% (±2.00 D) with a range from +1.87 to −1.76 (3.63 D)—a dramatic improvement.

In 1974, I attempted to determine whether adding a retinal thickness factor (RTF) to the AL as recommended in the 1973 paper by Colenbrander [5] (but was not a part of his written formula) would improve my prediction accuracy. After reviewing several ophthalmic anatomy sources, I concluded that the thickness of the retina in the fovea was best estimated as 0.26 mm. The theory is that the ultrasound wave bounces off the internal limiting membrane of the retina, whereas the light needs to travel that distance as well as the additional distance from the retinal surface to the visual receptors at the pigment epithelial layer. I analyzed my prediction accuracy without the RTF [70% (±1.00 D), 96% (±2.00 D) range +2.50 to −3.80 (6.20 D)] and then with the 0.26-mm RTF added to each of the ALs. The latter results [45% (±1.00 D), 83% (±2.00 D) range +2.00 to −4.50 (6.50 D)] were much worse and caused a definite shift of the error curve to the hyperopic side (85% hyperopic errors). If the AL is made longer, it will result in a lower power IOL which if incorrect will result in hyperopia, the least desired error. Since it did not improve the accuracy but only created more hyperopia, I have never used an RTF. Richard Binkhorst used an RTF (he said to make up for the corneal flattening that he felt occurred after cataract surgery). I later proved that corneal flattening does not occur and I theorized he may have offset the AL shortening caused by the applanation method.

We also compared the difference between using the measured preoperative ACD [70% (±1.00 D), 96% (±2.00 D) range +2.50 to −3.80 (6.20 D)] and using a standard 3.5-mm ACD for all eyes as recommended by Cornelius Binkhorst [63% (±1.00 D), 90% (±2.00 D) range +3.00 to −4.50 (6.50 D)]. Thus, we were the first to prove that using the preoperative measured ACD with phacoemulsification and an iridocapsular lens fixed in the capsule was more accurate than using a standard ACD value for all eyes. This was ultimately substantiated by Olsen, Haigis, and Holladay. Unfortunately, I was so busy with running ASCRS, the ASCRS meeting, the *JCRS* journal and my practice, I never published any of these results. So here they are now.

Not to ignore the Richard Binkhorst formula [6], in 1976, I performed a study to analyze the difference in results between the R. Binkhorst, Hoffer, and other formulas. I found that the R Binkhorst always recommended a power 0.50 D stronger compared to all the other theoretic formulas. After analyzing his formula, I understood why. He artificially changed the refractive index of the cornea from 1.375 to 4/3 (1.333…) to correct for what he erroneously believed was a flattening of the cornea that occurs after "all cataract surgery." We proved that this flattening was not true [7]. He based this on a small study of less than 100 eyes that had large incision intracapsular surgery. I felt that this was not very scientific for the following reasons: no definite studies showed that corneas uniformly flatten a specific amount after all types of cataract surgery, and even if it were the case, it would be far better to simply subtract 0.50 D (or the average flattening, X) from all ALs input to the formula rather than changing the refractive index of the cornea which theoretically is a known constant. I warned about this error in publications [8, 9] in 1981 and was severely criticized for it in print [10] in four pages by Katz, R Binkhorst ("The more than 2,000 users of the Binkhorst IOL Power Module should not be misled by Hoffer's false conclusions.") and Coleman ("It is disappointing that the Archives would support Hoffer's unsubstantiated endorsement by including the article in its pages"). I responded accordingly [10–12]. It is interesting to look back 40 years ago.

When we finally received the Sonometrics DBR-100 in the SMH's EyeLab (Fig. 2.8), we performed a study with it. We found it very easy to use the gates rather than measuring photographs but much more difficult to get a measurement without compressing the cornea. In the early 1980s, we did the first study to compare applanation to immersion. We used the same eyes, the same technician, and the same A-scan and probe, leaving the only difference the method of the exam. Our results on 20 eyes showed an average 0.33-mm shortening of the AL using the applanation method. I never found time to publish the results, but when Shammas repeated our study on a larger series of 180 eyes, he found a resultant shortening of 0.25 mm with applanation and included the results of our study in his excellent paper [13]. Several studies since have corroborated this effect. The problem is not that a shortening occurs since, if it were consistent in every case, it could be easily corrected by merely adding that factor to the AL result or by personalizing the formula. The problem is that it occurs sporadically, i.e., not shortening some eyes and extensively shortening others. It is not possible for the examiner to tell which eyes are or are not being shortened. The disatisfaction caused by these errors as well as those due to the R. Binkhorst formula led to the development of regression formulas to improve results.

I warned the ophthalmic community of these drawbacks in courses and publications, but they were little heeded. Clinicians did not want to purchase the more cumbersome and expensive Kretz unit using the "messier" immersion method and the more expensive HP-65 calculator with the Hoffer formula. The DBR, using applanation, combined with the R Binkhorst formula on the TI calculator, became the standard in America and ultimately around the world. Incidentally, the red light I had invented in the DBR's probe was totally useless because the patient could not really see it at such a close distance compounded by the cataract and the probe on the cornea. Our side-by-side study was the first to show the DBR to be clinically less accurate due to probe-compression causing artificial AL shortening.

We therefore continued to use the Kretz immersion unit, which was later aided by a "black box" attachment called the DOC (Digital Ocular Computer) that added gates and an automatic measuring device that would give an AL readout. It was made for us by John McAdams of Instruments for Medicine. Several years went by before competition to the DBR was achieved by the introduction of the Storz Compuscan and the Xenotec Ultrscan. It was then I met John Weymouth of Xenotec who became a major force in convincing ophthalmologists to use the immersion method. What is paradoxical is that I helped invent the DBR and spent most of my career lecturing against its use.

For years, we did side-by-side comparisons of various A-scans as they were introduced and reported our results to the profession [14]. Unfortunately, it was soon obvious to the manufacturers that I would truthfully report if the results were not optimal (as in the case of the Storz Echo-Oculometer) and soon no one asked us to evaluate their equipment—a negative aspect of being publicly honest.

In 1978, Dr. Leo Bores of Detroit asked me to start doing radial keratotomy (RK) so that I could study the effect of RK on AL and endothelial cell counts. I did the first RK on the West Coast in November 1979 and instigated the UCLA Myopia Study with the approval of Bradley Straatsma, the UCLA Stein Eye Institute Chairman. I reported our results at the 1980 American Academy of Ophthalmology (AAO) meeting (first corneal refractive surgery presentation at the AAO), and we published the first RK paper [15] in the American literature. We found an average 0.15 mm shortening of the AL from 25.45 to 25.30 mm after a 16-incision metal-blade RK which could be due to flattening of the cornea, but the change was not consistent or statistically significant.

During my 1982 invention of the first multifocal IOL (the Hoffer Split Bifocal [the U.S. FDA just approved the Lenstec version in 2022]), I devised the method to calculate the exact power needed for the additional power in the near vision optic. This was first published in Maxwell and Nordan's textbook on Multifocal IOLs [16], and later in a 1992 AJO publication [17] by Holladay and I as well as in Jorge Alio's textbook *Multifocal Intraocular Lenses* [18]. It was also included in a Focal Points issue [19] the AAO asked me to write on the subject of IOL power calculation in 1995.

For many years, I have stressed the importance of early (24 hour) IOL exchange to correct IOL power errors [20]. In 2008, we performed the first precision study of the improved accuracy of exact-power-labeled IOLs (made by TechnoMed, Germany) with the US Food and Drug Administration (FDA) proving there was an improvement in IOL Power prediction using them [21]. This was scoffed at as inconsequential by Lindstrom in print.

The EyeLab

In 1978, I started the EyeLab, Inc. to provide accurate lens power calculation for my colleagues and their patients in Southern California. This was done with the help of our technicians Greg Phillippi, Larry Margules, and Dee Zigmund. At that time, Medicare had not approved the examination for reimbursement because very few were being done. I spent 4 months making daily phone calls to the federal officials in the Medicare Administration until we finally received notice that it had been approved with a fee higher than we had requested at that time, i.e., \$350 per eye (\$2,124 in 2024). This was a feat for which I was personally quite proud. This meant that ultrasound lens power calculation would now be more readily available to the American public. I later successfully fought with them to pay for both eyes being done rather than only the eye being operated on, It is a shame that later, in the 1990s, the valiant attempts by the American Society of Cataract & Refractive Surgery (ASCRS) to prevent Medicare decreases in cataract surgery reimbursement led Stephen Obstbaum and the leaders of ASCRS to offer them instead a reduction in IOL power calculation fees as a compromise. Medicare responded by not only lowering cataract fees but in addition, slashing the power calculation fee drastically.

Over the years, the EyeLab examined well over 10,000 eyes. In 1979, I asked William Link, then president of Heyer-Schulte (later AMO, now J&J), if we could be able to get our data analyzed using their mainframe computers. He agreed and with the help of Ginger Silva, the biometry of 7,500 eyes were entered and analyzed. These results were published in the *American Journal of Ophthalmology* [7] in 1980, the first such large series on human eye biometry. We showed that the average AL of the human cataractous eye by immersion ultrasound was 23.65 mm (±1.35) and the average K reading was 43.81 D (±1.60). We also showed the average cylinder in this cataract age group was 1.00 D (±1.00) and that only 10% of eyes had a cylinder of 2.00 D or greater. We reported that the mean difference between the two eyes of a given patient was 0.34 mm (±0.70) for AL, 0.87 D (±0.83) for K, and 0.23 mm (±0.27) for ACD. This study resulted in my definition of Short Eyes as <22 mm; Medium Long Eyes as 24.5–26 mm; Very Long Eyes as >26 mm and Normal Length Eyes as 22–24.5 mm. These definitions have been used by many ever since. The data was later used by Holladay in the development of his second formula (unpublished) as well as his recommendations for when to recheck biometry results. This study was also the first to statistically prove that myopic eyes develop cataracts at an earlier age than hyperopes ($p < 0.002$).

To better access the thickness of the cataractous lens, I performed a study in 1993 on 600 eyes using a crystalline lens sound velocity of 1641 m/s which was published in the *Archives of Ophthalmology* [22] (now *JAMA Ophthalmology*). The mean thickness of the lens for the entire series was 4.63 mm (±0.68) with a range of 2.27–6.86 mm. We proved that the lens thickens with age (which makes sense), in that it measured an average of 3.78 mm (±0.21) in the third decade of life and 5.03 mm (±0.46) in the tenth decade. We showed hyperopic ALs (<22 mm) measured 5.03 mm (±0.63) while myopic ALs (>27 mm) measured 4.24 mm (±0.58). This proved that the shorter the eye, the thicker the lens. Younger eyes under age 65 ($n = 158$) had a mean AL of 24.08 mm (±1.53); ages 65–75 ($n = 252$) were 23.67 mm (±1.19), and older eyes over 75 ($n = 190$) were 23.26 mm (±1.03). This again statistically confirmed ($p > 0.0001$) that myopic eyes require cataract surgery at an earlier age than hyperopes.

In the mid-1980s, with the first declines in cataract reimbursement by Medicare, more ophthalmologists purchased an A-scan unit to help offset these decreases which ultimately led to the closure of the EyeLab offices. The EyeLab was revived as an entity in 1990 when the request for Hoffer® Programs calculators and later computer programs became evident and again in 2020 as a structure for the new Hoffer QST free website.

Ultrasound Velocities for Axial Length Measurement

In 1974, I needed to develop a more accurate average sound velocity for the human eye. To do this, I postulated an eye of a given AL of 23.50 mm, a corneal thickness of 0.50 mm, and a crystalline lens thickness of 5.00 mm. Knowing that the velocity of sound through both the cornea and lens was accepted to be 1641 m/s and using the velocity formula $V = d/t$ ($t = d/V$), I was able to calculate the time it took for the sound to travel through the solid parts of the eye (5.00 + 0.50 = 5.5; 5.5 mm/1.641 mm/s = 3.35 µs). Similarly, with the velocity of 1532 m/s through both aqueous and vitreous, the time to traverse the liquid parts of the eye could also be determined (23.50–5.50 = 18; 18 mm/1.532 mm/s = 11.75 µs). Adding the solid and liquid time spans yields the total time for the sound to traverse the entire eye (3.35 + 11.75 = 15.1 µs). Again, using the velocity formula, I simply divided the given 23.50-mm AL by the total time of 15.1 µs to arrive at an average velocity of 1556 m/s. When this process was repeated for an aphakic eye, the result was 1534 m/s. Unfortunately, I was never able to publish this information except in periodicals [23] but only discuss it in my many lectures and courses and thus it never changed the general use of 1550 m/s as the velocity for the average eye.

In 1994, I repeated this work [24] using a more correct 0.55 mm for corneal thickness and the 4.63 mm I obtained from my previous study of lens thickness and obtained an average velocity of 1555 m/s. This schema was repeated for 20- and 30-mm eyes, and we discovered that the longer the eye, the thinner the lens and the slower the average velocity (1550); the shorter the eye, the thicker the lens and the faster the average velocity (1560). I developed formulas to correct for this change in average velocity due to AL, but it is only clinically important in the very extremes of AL. Measuring an eye that contains an IOL (pseudophakic) creates a different situation depending on what material the implant is made of and how thick the IOL is. This concept was first brought to light by Albert Milauskas [25] of Palm Springs, when he discovered the errors obtained measuring eyes containing silicone implants. He proposed that the extremely low sound velocity through silicone was the reason. I used my previously described schema to determine average velocities through eyes with IOLs of PMMA, silicone, glass, acrylic, and collamer. Holladay proposed a different method he termed the CALF factor that may be more precise, but it requires knowing the thickness of the implant in the eye which is not always easy to obtain. In 2003, I published [20, 21] a method to measure the AL of phakic eyes which contain phakic IOLs (biphakic) when the material and thickness of the phakic IOL is known [26, 27].

Getting the Word Out

Once my colleagues heard about the EyeLab at SMH, I was asked to speak on the subject at the first American scientific meeting on lens implantation which was to be held on November 16, 1974 at the Long Beach Memorial Hospital by its organizer, Dr. Francis ("Red") Hertzog, Jr. Because I had never spoken before any group before, I was a little apprehensive and felt a need to gain "credibility," so I flew to Holland in early November to visit with Dr. Jan Worst and Prof. Colenbrander. I also visited Cornelius Binkhorst in Terneuzen, Holland, and Hermann Gernet in Münster, Germany, who had written several papers on iseikonic IOL power. They were all truly kind to me. Cornelius Binkhorst did excoriate me somewhat for forming this "American Implant Society," which he felt would someday usurp his International Implant Club (IIC, now IIIC). Months later at an ASCRS meeting, he kept on me about this quite emotionally and so to calm him down I recommended he get each EU country's implant society to join a broad European Implant Lens Council that he could preside over as President. I even contacted Leo Amar, the French society's founder and president (I had given him advice on forming it), to get him to agree. Later, Binkhorst did just that and it ultimately became the European Society of Cataract & Refractive Surgery (ESCRS).

In meeting with Prof. Colenbrander at his home for dinner, each and every time I tried to discuss his formula during dinner, he immediately changed the subject. This left me with the impression that perhaps he did not write it. My time with Worst was always hectic, but he was always very helpful to me. Gernet was very kind and showed me his voluminous printout reports from his huge mainframe computer. Because of its extreme complexity (meaning I could not figure out what he was doing), I realized that this would receive little interest in the United States.

After visiting Zurich and Rome (for the very first time), I returned home and was prepared to give my very first lecture on IOL power calculation at the Long Beach meeting. I brought the Kretz 7200 A-scan unit with me to demonstrate it to those who might be interested to see it. The lecture went well and after the meeting, one local ophthalmologist (Ron Jensen of Glendale, CA) spent a lot of time with me learning how to perform the procedure. After months of turning down the many requests for newspaper interviews about our unique EyeLab from Jean Harris, the Public Relations director of SMH, I read the front-page headlines of the LA Herald Examiner to discover that the "first ultrasound IOL power calculations done in Southern California" were done by that same Ron Jensen I had taught that day in Long Beach. I learned early on that not every colleague plays fairly or honestly. Another lesson learned.

My next lectures were at the Southern California Section of the American College of Surgeons Meeting in Santa Barbara and then at the Mexican Ophthalmological Society in Mexicali, Mexico. I got over my shyness. I continued to give these presentations at our SMH courses, ASCRS courses, and Dr. Hirschman's IOL courses in Long Beach as well as at the IOL courses started by Bradley Straatsma, Murry Weber, and I at the UCLA Stein Eye Institute. After applying several times (but I think with the influence of Dr. Jaffe), my IOL power course was finally accepted by the AAO. In the early years, I did it alone, but as I saw others developing an interest in the subject, I invited them to join me. John Shammas of Los Angeles was the very first in 1975.

When I was invited to give a named lecture at the University of Oregon Ophthalmology Meeting in Portland in March 1979, I heard a presentation by a local ophthalmologist, John Retzlaff, on a regression formula he had developed. I was aware of the first regression formula that had been developed by Thomas Lloyd [28], a technician with James Gills in Florida. I pressured the shy and reluctant Retzlaff, to present his formula at my AAO course and at the next Annual ASCRS Meeting at the Century Plaza Hotel in Los Angeles. I also begged him to publish it in the *JCRS* Journal, all of which he ultimately did [29]. I had told him I was putting his name on the program and if he didn't show up I would present it as "my work." I had also invited Donald Sanders and Manus Kraff of Chicago who had also developed a regression formula [30]. They agreed and after all three of their presentations, collaboration developed between them that led to the amalgamation of their individual formulas into what they termed the SRK regression formula [31]. Over the years, because of its sheer simplicity, it became the formula used throughout the world. Why? Because it was so easy ($P = A - 2.5*\text{AL} - 0.9*K$, where A is the lens constant) and it could be done by hand.

In those same years, I met a young ophthalmologist from Houston, Texas, who had an engineering background, tons of enthusiasm, and agreed with me that theoretic formulas were superior to regression. Jack Holladay became a permanent member of my AAO and ASCRS course faculty joining Kraff, Retzlaff, Sanders, and Shammas. Many years later, after one of these courses, Kraff suggested that we were all tired of giving them and everyone who wanted to has probably already attended. Because of that, I stupidly dropped the course the next year. Soon after the next AAO Meeting I received so many irate phone calls from ophthalmologists and technicians who expected the course to be given that I reapplied with one speaker initially for 1 hour. It was soon increased to 2 hours, and I have been giving them ever since. My similar courses at ASCRS paralleled those at the Academy, always presenting the latest unbiased information. Since starting our 3-month European trips in 1997, I have given these courses at the ESCRS meetings in Europe as well. In the past 16 years, I have been joined by Giacomo Savini of Bologna, Italy to discuss toric calculations which I never had much interest in. By the latest count, I have lectured on IOL power over 500 times since that day in November 1974.

A life-altering event occurred in 1999 upon meeting Wolfgang Haigis (Fig. 2.9) for the first

Fig. 2.9 Wolfgang Haigis, PhD (left), with the author in 1999

time. Zeiss asked him to join the team that flew in to install the first American IOLMaster optical biometer in my office in Santa Monica. The company wanted my opinion on the instrument and to check the accuracy of their programming of the Hoffer Q formula in the biometer. I recommended that they change the corneal power readings from radius of curvature (r) to diopters (D) for an American consumer, which they did. Haigis was an expert in immersion ultrasound and had helped set the standards for their optical biometer and all the others that followed. He developed the Haigis formula in 2000 that replaced the K with the pre-op ACD in predicting the ELP, but it used three lens constants: a_0 (IOL constant), a_1 (based on AL), and a_2 (based on ACD), which required a more cumbersome triple optimization of the lens constants. In all studies, his formula was very accurate. We became very good friends over the years, especially during the 15 years of the IOL Power Club, and I deeply miss him since his passing in October 2019.

Many new optical biometers and corneal biometry measuring devices have been brought to the market since 2009 with the introduction by Haag-Streit of their Lenstar LS-900. Due to my receiving the first Lenstar in the U.S., Giacomo Savini, John Shammas, and I had the opportunity to test it and later compare the accuracy of most all of the new biometers as they appeared and have published our results [32–36]. We are presently testing the latest instruments: the German Heidelberg Anterion and the Optopol Revo NX from Poland and the Chinese Colombo II from Moptim. Many new formulas have been made available which show excellent results (see other Chapters).

Conclusion

The events recounted here are based on my personal vivid memory of them. They are not meant to offend anyone or ignore the work of those not mentioned. I am humbly grateful and appreciative of all those who have helped me in these endeavors. I have enjoyed working in this field for these 50 years and hope for a few more years to continue the effort to gain the ultimate goal we all seek; the elimination of all errors in predicting postoperative IOL refractive error.

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