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Refractive Lens Surgery

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Axial length measurement remains an indispensable technique for intraocular lens (IOL) power calculation. Recently, partial coherence interferometry has emerged as a new modality for biometry [1]. The postoperative results achieved with this modality have been considered analogous to those achieved with the ultrasound immersion technique [2]. Although reportedly "user-friendly" and less dependent on technician expertise than are ultrasound methods, noncontact optical biometry is limited by dense media such as posterior subcapsular cataract. A second limitation of the optical method is the lack of a lens thickness measurement, which is a required variable in the Holladay II IOL power calculation software, version 2.30.9705. According to Holladay, the lens thickness can be estimated by the formula, 4.0 + (age/100). Also, optical biometry can provide keratometry measurements, obviating the need for a second instrument.

Immersion ultrasound has long been recognized as an accurate method of axial length measurement and is generally considered superior to applanation ultrasound techniques [3,4]. The absence of corneal depression as a confounding factor in measurement reduces the risk of intertechnician variability in technique. In addition to having a short learning curve, immersion ultrasound has no limitations in terms of media density and measurement capability. On the other hand, optical biometry may be superior in eyes with posterior staphyloma because of more precise localization of the fovea.

The authors have compared axial length measurements obtained by optical biometry using the IOLMaster (Zeiss Humphrey Systems, Jena, Germany) with measurements obtained by immersion ultrasound using the Axis II (Quantel Medical, Clermont-Ferrand, France). The postoperative refractions of patients undergoing cataract extraction with posterior chamber IOL implantation were also examined to determine the accuracy of the immersion ultrasound technique.

Fifty cataractous eyes underwent preoperative axial length measurement with both the Axis II and IOLMaster. For the Axis II immersion technique, the Praeger shell was employed. Patients were placed in a sitting position in an examination room chair with the head reclined gently against the headrest. The average "Total Length" reported by the unit was entered into the Holladay II IOL power calculation formula. For the IOLMaster, the selected axial length with the highest signal-to-noise ratio was used as the basis for comparison. The measured axial lengths were plotted and a linear regression trendline fit to the data. The Pearson correlation coefficient was determined to assess the relationship between the immersion and the optical measurements according to the formula, $\rho = 1/(1 - n) \sum ((x - \mu)/s)((y - \mu)/s)$.

Keratometry was performed with the IOLMaster. The three reported sets of values were compared for consistency and were correlated with the axis and magnitude of the eye's preoperative astigmatism. An averaged value of three measurements or of the two closest measurements (in case one measurement appeared to be an outlier) was entered into the formula. In selected cases, autokeratometry (HARK 599, Zeiss Humphrey Systems) or computerized corneal topography (EyeSys Technologies, Houston, Texas) was used to better delineate the preoperative keratometry. The corneal white-to-white diameter was determined with the Holladay-Godwin Corneal Gauge.

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One surgeon (IHF) performed all of the surgery. The Holladay II IOL power calculation formula was used to select the IOL for implantation in each case. This program automatically personalized the surgeon's A-constant during the course of the study. To provide uniform results, the Collamer IOL (CC4204BF, Staar Surgical, Monrovia, California) was implanted in all 50 eyes. The surgical technique has been described previously [5]. Briefly, a temporal clear corneal incision is followed by continuous curvilinear capsulorrhexis, cortical cleaving hydrodissection and hydrodelineation, and nuclear disassembly using horizontal chopping with high vacuum and flow but low levels of ultrasound energy. The IOL is inserted into the capsular bag via an injection device.

All patients underwent autorefractometry (HARK 599) and subjective manifest refraction 2 to 3 weeks postoperatively. Only eyes obtaining 20/30 or better best-corrected visual acuity were included in the study. The postoperative refraction was then entered into the Holladay IOL Consultant (Holladay Consulting, Bellaire, Texas). Using the Surgical Outcomes Assessment Program (SOAP), the spherical equivalent prediction error was measured and analyzed.

Axial length measurements

The axial length measurements obtained with the Axis II and the IOLMaster correlated highly (Pearson correlation coefficient, 0.996) (Fig. 1). The mean of the axial lengths measured by immersion was 23.40 mm (range, 21.03 to 25.42 mm), whereas the mean of the optically measured axial lengths was 23.41 mm (range, 21.13 to 25.26 mm). Technicians noted that immersion measurements required 5 minutes, whereas optical measurements required about 1 minute.

Surgical outcomes assessment

The Holladay IOL Consultant report reflected a personalized A-constant of 119.365 (ACD, 5.512) compared with the manufacturer's suggested constant of 119.0 (ACD, 5.55). The frequency distribution of the postoperative spherical equivalent prediction error revealed that 48% of eyes precisely achieved the targeted refraction. The cumulative distribution graph demonstrated that 92% of eyes measured within ±0.5 D of the targeted refraction and 100% of eyes measured within ±1.00 D of the targeted refraction (Fig. 2). The mean absolute error measured 0.215 D, whereas the mean error of −0.105 reflected the trend toward myopia.

The near perfect correlation of immersion ultrasound and optical coherence biometry measurement techniques indicates the high level of accuracy of both of these methodologies. The high rate of achieving the targeted refraction by using immersion ultrasound measurements and the Holladay II formula compares favorably with previously reported results. For example, Haigis achieved accurate prediction within ±1.00 D in 85.7% of eyes by using immer-

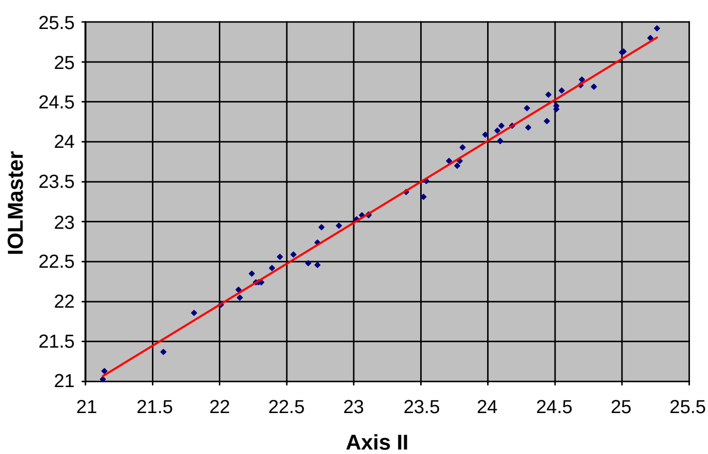
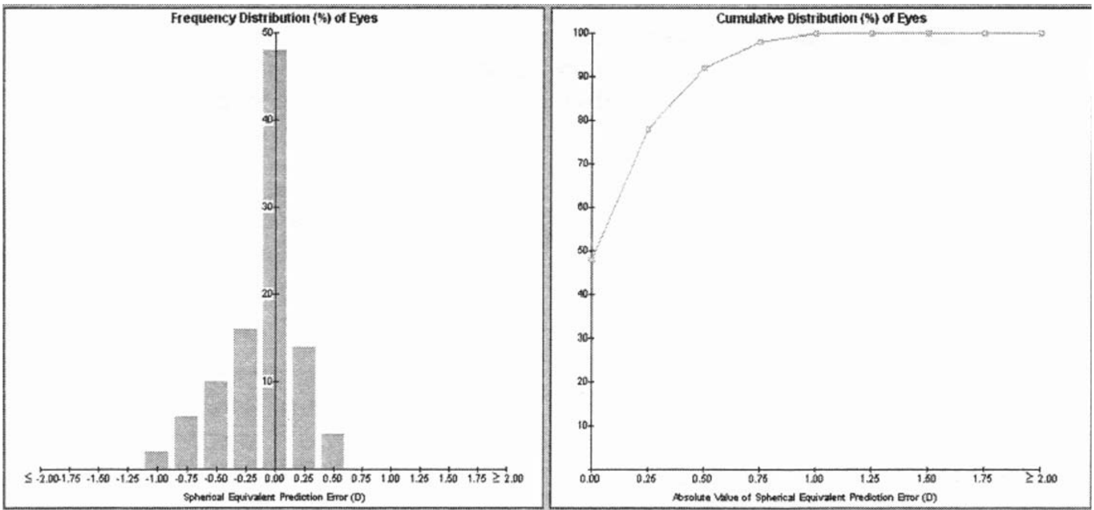


Fig. 1. Comparison of axial length measurements with immersion ultrasound (abscissa) and optical coherence interferometry (ordinate). The linear regression trendline reflects the high correlation between the two sets of values.



Formula	Number of Cases	Personalized ACD (mm)	Eqv. Form. Constant	Current Form. Constant	Mean Rx Err (D)	Mean Abs Rx Err (D)	Std Dev of Rx Err (D)	Max Rx Err (D)	% cases > +/- 2 D Rx
Holladay2	50	5.512 +/-0.040	ACD: 5.512	5.512	-0.105	0.215	0.306	-0.91	0.0%
Holladay1	50	5.765 +/-0.049	SF: 2.000	2.000	-0.118	0.222	0.336	-0.97	0.0%
HofferQ	50	5.763 +/-0.048	ACD: 5.763	5.763	-0.017	0.160	0.252	-0.86	0.0%
SRKT	50	5.817 +/-0.048	ACst 119.365	119.365	-0.091	0.260	0.341	-0.93	0.0%
HolladayR	50				0.000	0.000	0.000	0.00	0.0%

Fig. 2. Holladay IOL Consultant, Surgical Outcomes Assessment Program.

sion ultrasound [2]. Additionally, Sanders and coworkers [6] have indicated that achievement of about 90% of eyes within ±1.00 D of the targeted refraction and a mean absolute error of approximately 0.5 D represents an acceptable outcome.

Technicians report that the immersion ultrasound method with the Praeger shell is well tolerated by patients and relatively easy to learn. Its applicability to all types of cataracts and its ability to generate a phakic lens thickness represent significant advantages, especially for surgeons who use the Holladay II calculation formula.

Keratometry after keratorefractive surgery

IOL power calculations for cataract and refractive lens exchange surgery have become more precise with the current theoretical generation of formulas and newer biometry devices [7]. Nevertheless, IOL power calculation remains a challenge in eyes with prior keratorefractive surgery. The difficulty in these cases lies in determining accurately the corneal refractive power [8–10].

In a normal cornea, standard keratometry and computed corneal topography are accurate in measuring four sample points to determine the steepest and flattest meridians of the cornea, yielding accurate values for the central corneal power. In irregular corneas, such as those having undergone radial keratotomy, laser thermal keratoplasty, hexagonal keratotomy, penetrating keratoplasty, photorefractive keratectomy, or laser in site keratomileusis (LASIK), the four sample points are not sufficient to provide an accurate estimate of the center corneal refractive power [11]. Traditionally, three methods have been used to calculate the corneal refractive in these eyes [12]. These approaches include the historical method, the hard contact lens method, and values derived from standard keratometry or corneal topography. The historical method remains limited by its reliance on the availability of refractive data before the keratorefractive surgery. The contact lens method is not applicable in patients with significantly reduced visual acuity [13]. Use of simulated or actual keratometry values almost invariably leads to a hyperopic refractive surprise [14].

It has been suggested that using the average central corneal power rather than topography-derived keratometry may offer improved accuracy in IOL power calculation following corneal refractive surgery [15]. The Effective Refractive Power (Eff RP) (Holladay Diagnostic Summary, EyeSys Topographer, Tracey Technologies, Houston, Texas) is the refractive power of the corneal surface within the central 3-mm pupil zone, taking into account the Stiles-Crawford effect. This value is commonly known as the spheroequivalent power of the cornea within the 3-mm pupil zone. The Eff RP differs from simulated keratometry values given by topographers. The simulated K-readings that the standard topography map gives are the points along the 3-mm pupil perimeter, not the entire zone. As is true for standard keratometry, these two meridians are forced to be 90 degrees apart. The higher the discrepancy between the mean simulated K-readings and the Eff RP, the higher the degree of variability in the results of IOL calculations [3].

Aramberri [16] recently reported the advantages of using a "double K" method in calculating IOL power in eyes post keratorefractive surgery. Holladay recognized this concept and implemented it in the Holladay IOL Consultant in 1996 [17]. The Holladay II IOL power calculation formula (Holladay IOL Consultant, Jack Holladay, Houston, Texas) uses the corneal power value in two ways: (1) in a vergence formula to calculate the refractive power of the eye, and (2) to aid in determination of the effective lens position (ELP). The formula uses a total of seven variables to estimate the ELP, including keratometry, axial length, horizontal white-to-white measurement, anterior chamber depth, phakic lens thickness, patient age, and current refraction.

The Holladay II program permits the use of the Eff RP as an alternative to keratometry (Alt K) for the vergence calculation. For the ELP calculation, the program uses either the K-value entered as the Pre-Refractive Surgery K or, if it is unknown, 43.86, the mean of the human population (personal communication, Jack Holladay, February 3, 2004).

The authors performed a retrospective analysis of all patients in their practice who underwent cataract or refractive lens exchange surgery after incisional or thermal keratorefractive surgery in whom the Eff RP and Holladay II IOL calculation formula were used for IOL power determination. Between February 23, 2000 and October 28, 2002, a total of 20 eyes met these criteria. Fourteen eyes had undergone radial keratotomy, three eyes hexagonal keratotomy, and three eyes laser thermokeratoplasty with the Sunrise Sun1000 laser (Sunrise Technologies, Fremont, California).

Preoperative evaluation included a complete ophthalmic examination. Axial length measurements were performed with the IOL Master (Carl Zeiss Meditec, Dublin, California). The protocol for axial length measurements with the IOL Master allowed up to 0.15 mm of variation within 10 measurements of one eye and up to 0.20 mm of variation between the two eyes, unless explained by anisometropia. The signal-to-noise ratio was required to read 1.6 or better, and a tall sharp "Chrysler Building" shaped peak was preferred. If any of these criteria were not met, the measurements were repeated with immersion ultrasonography (Axis II, Quantel Medical, Bozeman, Montana).

The corneal white-to-white distance was measured with a Holladay-Godwin Gauge in the initial 14 eyes and with the newly available frame grabber software on the IOL Master in the final 6 eyes. The phakic lens thickness was estimated as 4 plus the patient's age divided by 100 (eg, a 67-year-old patient's lens thickness was estimated as 4.67) or determined by immersion ultrasonography. The Holladay II formula was used for all IOL power calculations (Holladay IOL Consultant). "Previous RK" was set to "Yes," and the Eff RP value from the Holladay Diagnostic Summary of the EyeSys Corneal Analysis System was input in the "Alt K" area. This procedure instructs the formula to use the Eff RP value in place of standard keratometry for the vergence calculation. In no case was the prerefractive surgery keratometry known; therefore, the formula used 43.86 as the default value to determine the ELP. The "Alt K" radio button was highlighted, and the Eff RP value was printed on the report as a confirmation that the formula had used it in the calculation. In every case, the targeted postoperative refraction was emmetropia.

Preoperative astigmatism was addressed at the time of cataract or lens exchange surgery by means of limbal relaxing incisions performed with the Force blade (Mastel Precision Surgical Instruments, Rapid City, South Dakota) as described by Gills and Gayton [18] and Nichamin [19]. In general, with-the-rule corneal astigmatism equal to or greater than 1.00 D and against-the-rule corneal astigmatism equal to or greater than 0.75 D were considered appropriate for correction.

The surgical technique, including clear corneal cataract extraction with topical anesthesia and the use of power modulations in phacoemulsification, has been described previously [20]. Eight eyes in five patients received the Array SA 40 multifocal IOL (AMO, Santa Ana, California), five eyes in three patients received the AQ2010V (STAAR Surgical, Monrovia, California), both eyes of one patient received the CLRFLXB (AMO), both eyes of one patient received the SI 40 (AMO), and one eye of one patient each received the CeeOn Edge 911A (Pfizer, New York, New York), the Tecnis Z9000 (Pfizer), and the Collamer CC4204BF (STAAR Surgical). The deviation of the achieved postoperative spherical equivalent from the desired postoperative goal for each eye was determined. Each group of kerato-refractive patients was also analyzed separately. The differences between the Eff RP value and the corneal refractive power derived from the corneal topographer and autokeratometer were also analyzed. All data were placed in an Excel spreadsheet, and statistical analyses were performed.

In the radial keratotomy group, the number of radial incisions ranged from 4 to 20, with the majority having 8 incisions. Fifty percent of these patients had astigmatic keratotomy performed in addition to radial keratotomy. For all eyes, the mean duration from IOL surgery to the last postoperative refraction was 6.73 months (range, 1 to 24 months). The radial keratotomy group had the longest follow-up, averaging 9.25 months (range, 2.5 to 24 months).

The mean deviation from the calculated postoperative refractive goal for all patients was 0.13 ± 0.62 D (range, −1.49 to 1.03 D). The difference from the postoperative refractive goal for each group of keratorefractive eyes was 0.27 ± 0.51 D for the radial keratotomy group, −0.07 ± 0.44 D for the laser thermal keratoplasty group, and −0.32 ± 1.10 D for the hexagonal keratotomy group. The targeted versus achieved spherical equivalent correction is shown in Fig. 3. A linear regression equation fitted to the data, that is, Achieved Correction = 0.9266 (Targeted Correction) + 0.1233 D, demonstrates the slightly hyperopic trend in achieved spherical equivalent correction. All eyes achieved a postoperative refraction within 1.5 D of emmetropia, and 80% were within 0.50 D of emmetropia (Fig. 4).

The mean difference between standard automated keratometry readings (IOL Master) and the Eff RP values was 0.01 ± 0.66 D (range, −1.5 to 2.00 D). These results are shown in Fig. 5. Within the individual groups, the difference was 0.12 ± 0.65 D (range, 0.47 to 2.00 D) for the radial keratotomy eyes, 0.05 ± 0.29 D (range, −1.5 to 0.24 D) for the laser thermal keratoplasty eyes, and 0.48 ± 0.91 D (range, −0.26 to 0.28 D) for the hexagonal keratotomy group.

The mean difference between standard simulated keratometry readings from topography and Eff RP values was −0.85 ± 0.73 D (range, −2.28 to 0.31 D). Within the individual groups, the mean difference was −1.03 ± 0.74 D (range, −2.28 to −0.19 D) for the radial keratomy eyes, −0.01 ± 0.28 D (range, −1.08 to −0.5 D) for the laser thermal keratoplasty group, and −0.84 ± 0.30 D (range, −0.13 to 0.31 D) for the hexagonal keratotomy eyes. Axial lengths in all eyes averaged 24.78 ± 1.54 mm (range, 22.31–27.96 mm). In the radial keratotomy group, the mean axial length measured 25.38 ± 1.40 mm (range, 23.04–27.96 mm). In the laser thermal keratoplasty group, the mean axial length measured 23.21 ± 1.26 mm (range, 22.31–24.65 mm). In the hexagonal keratotomy group, the mean axial length measured 23.57 ± 0.43 mm (range, 23.08–23.82 mm). No significant correlation between axial length and postoperative spherical equivalent was found (Pearson correlation coefficient, 0.08).

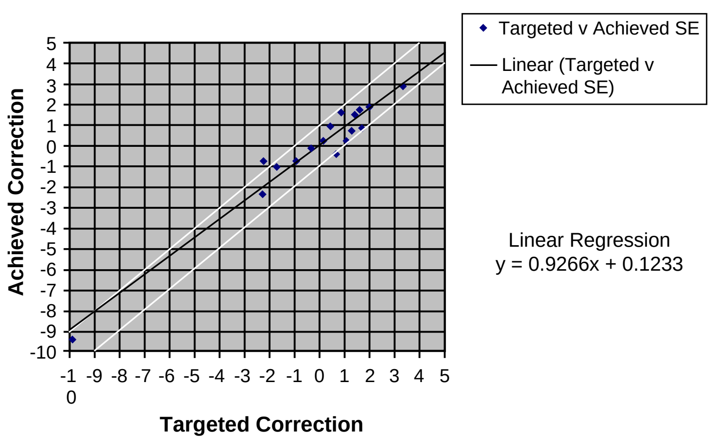


Fig. 3. Targeted correction in spherical equivalent calculated by the Holladay II formula compared with the achieved postoperative correction in spherical equivalent. Linear regression analysis (y = 0.9266x + 0.1233) demonstrated a slightly hyperopic trend.

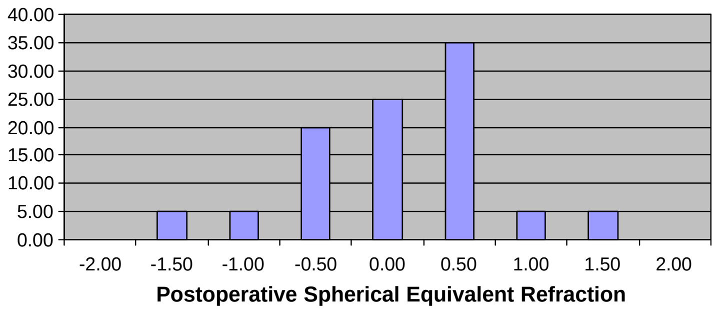


Fig. 4. The frequency distribution of eyes (%) determined by the postoperative spherical equivalent refractions.

The eye with −9.88 D preoperative spherical equivalent refraction deserves a brief comment because of its position as an outlier and because of the unusual features of the case. This patient presented 22 years after "failed" radial keratotomy in this eye. She had never proceeded with surgery on the fellow eye. No other history was available. The fellow unoperated eye had a spherical equivalent of −4.86 D, with keratometry of 42.82 × 44.34 @ 98 and an axial length of 25.13 mm. Her preoperative best-corrected acuity in the operated eye was 20/30 with a correction of −10.75 + 1.75 × 33. Keratometry in the operated eye was 41.31 × 42.67 @ 64, yielding an average K of 41.99. Simulated keratometry was 41.36 × 42.55 @ 70. The calculated Eff RP was 41.90 D, and the axial length was 26.59 mm. Examination revealed moderate nuclear sclerosis. The Holladay II Formula predicted a postoperative spherical equivalent refraction of −0.02 D. The eye achieved a final best-corrected visual acuity of 20/20 with a correction of +0.25 + 0.75 × 55, indicating a predictive error of 0.64 D.

Determination of IOL power following keratorefractive surgery remains a challenge for the cataract and refractive surgeon. Using a combination of measured and calculated K-values with the historical

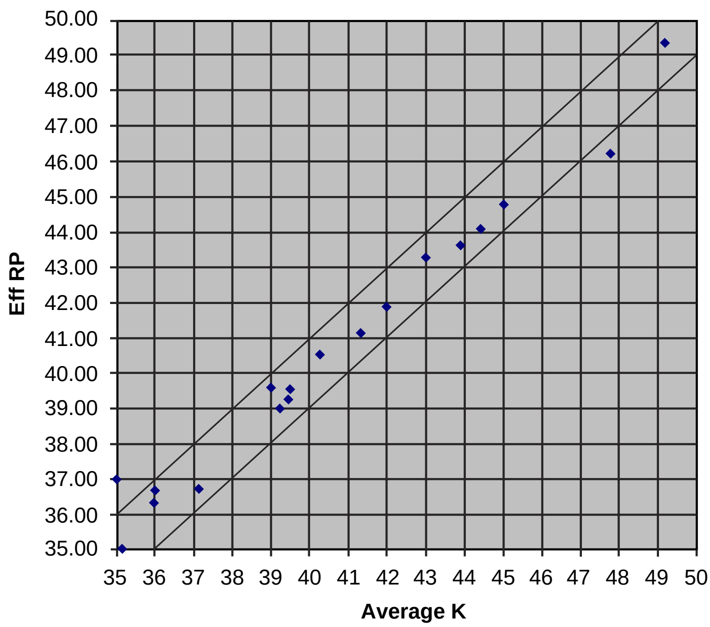


Fig. 5. The average keratometry reading (IOL Master) compared with the Eff RP determined by the Holladay Diagnostic Summary. Although the mean difference was small, the range of differences was broad (−1.50 to +2.00). Equivalency lines show the range ±1.0 D.

and contact lens methods, as well as a myopic target refraction, Chen and coworkers achieved a postoperative refractive outcome of 29.2% within ±0.50 D of emmetropia in a series of 24 eyes with a history of radial keratotomy [8]. They suggested ‘‘corneal power values that involve more central regions of the cornea, such as the effective refractive power in the Holladay diagnostic summary of the EyeSys Corneal Analysis System, would be more accurate K-readings in post-RK eyes.’’ The authors’ results would tend to support that conclusion.

Accurate biometry also has an important role in IOL power determination. The use of partial coherence interferometry (IOL Master) for axial length measurement improves the predictive value of postoperative refraction [21] and has been shown to be equivalent in accuracy to immersion ultrasound [22].

A smaller difference occurred between simulated keratometry and the Eff RP in the laser thermal keratoplasty group in a comparison with the incisional keratorefractive surgery groups. One possible explanation of this difference is that the laser thermal keratoplasty corneas had undergone regression from treatment and returned to a less distorted anatomy.

The IOL calculation formula has a critical role in obtaining improved outcomes. The Holladay II formula is designed to improve determination of the final ELP by taking into account disparities in the relative size of the anterior and posterior segments of the eye. To accomplish this goal, the formula incorporates the corneal white-to-white measurement and the phakic lens thickness and uses the keratometry (or Eff RP) values not only to determine corneal power but also to predict ELP. The authors have found that use of the Holladay II formula has increased the accuracy of IOL power calculations [23].

The authors’ studies have been limited to eyes that have undergone incisional and thermal keratorefractive surgery. Ongoing research will help to determine the most effective methods of calculating IOL power in eyes that have had lamellar keratorefractive surgery, such as photorefractive keratectomy or LASIK. It appears that further modification is necessary in these situations because of the inaccuracy of the standardized values of the index of refraction [24].

The authors continue to tell patients as part of the informed consent process that IOL calculations following keratorefractive surgery remain a challenge, and that refractive surprises do occur. It is explained that further surgery (eg, placement of a piggyback IOL) may be necessary in the future to enhance uncorrected visual acuity. Any secondary procedures are deferred until a full 3 months postoperatively and refractive stability documented before proceeding.

Bimanual micro incision refractive lens exchange

Bimanual micro incision phacoemulsification (BMMI phaco) offers unique advantages that enhance surgical control and safety in refractive lens exchange. Understanding the essential features of this lens extraction technique allows an appreciation of its benefits in refractive procedures.

In a recent letter to the editor of the *Journal of Cataract and Refractive Surgery*, Arshinoff [25] points out the incorrect application of several terms used to describe cataract extraction by means of two paracentesis type incisions. For example, he correctly notes that virtually all cataract surgeons use two hands during surgery, practicing a ‘‘bimanual’’ technique. He also eschews all relative terms describing incision size, because yesterday’s small incision size rapidly becomes today’s large incision size, and the term *micro* will always connote ‘‘smaller than anything else, except nano.’’

Language often evolves in spite of logic rather than because of it. The application of the term *bimanual* to phacoemulsification grew naturally out of its use in describing bimanual irrigation/aspiration, a technique that differs from monomanual irrigation/aspiration in that it really does require two hands instead of one. Use of the term *micro incision* probably carries with it a hint of the boast, ‘‘My incision’s smaller than yours!’’ Nevertheless, it has shown great tenacity. For better or worse, the terms *bimanual micro incision phaco* and *micro incision cataract surgery* are probably here to stay. Unfortunately, they do not truly reflect the essential feature of the technique they have come to represent.

Akahoshi [26] recently reported coaxial cataract extraction and IOL insertion through a 2-mm incision. Using a flared phaco tip and a small-diameter sleeve, he described prechopping and extracting the cataract, followed by introducing a single piece AcrySof IOL through the unenlarged incision by placing the insertion cartridge tip just at the edge of the incision and pushing the IOL through with the plunger. He calls this method the ‘‘Sayonara’’ technique, because he believes it will allow surgeons to say ‘‘Sayonara, bimanual.’’ The underlying assumption that BMMI phaco is only about incision size demonstrates a superficial understanding of the technique that relates directly to the unfortunate nomenclature that Arshinoff has criticized.

In fact, reduction of the incision size is only one of many advantages that make BMMI a superior technique. The crucial difference is not the size of the incision but the separation of inflow and outflow. The authors believe that the benefits of this fluidic paradigm shift include greater flexibility, improved control, and better outcomes. At the same time, one must recognize the significant role that the introduction of micropulsed ultrasound energy (WhiteStar technology, AMO, Santa Ana, California) has had in setting the stage for bare needle phacoemulsification. The use of extremely short pulses of ultrasound energy with a variable duty cycle initially allowed safe BMMI phaco through elimination of the risk of thermal injury to the cornea.

Separation of irrigation from the aspirating phaco needle allows for improved followability by avoiding competing currents at the tip of the needle. In some instances, the irrigation flow from the second handpiece can be used as an adjunctive surgical device by flushing nuclear pieces from the angle or loosening epinuclear or cortical material from the capsular bag. In refractive lens exchange, the lens material may be washed completely out of the bag and extracted with aspiration and vacuum only, so that no ultrasound is used and no instrument enters the endocapsular space, increasing the safety profile of this demanding procedure. The flow of fluid from the open end of an irrigator represents a gentle instrument that can mobilize material without trauma to delicate intraocular structures.

Another benefit of a separate infusion stream comes to bear in scrubbing troublesome plaques from the posterior capsule (Fig. 6). Focusing the flow of fluid on the posterior capsule and putting the tissue on stretch facilitates capsule polishing with a roughened or silicone-covered aspiration tip. The taut posterior capsule shows less inclination to become entrapped in the aspiration port, and the subcapsular plaque material is more easily stripped away.

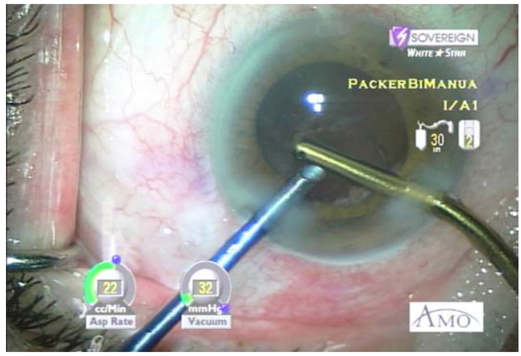


Fig. 7. Cortex that is subincisional to the left-handed incision can be reached easily from the right-handed incision.

Perhaps the greatest advantage of the bimanual technique lies in its ability to remove subincisional cortex without difficulty. As originally described by Brauweiler [27], by switching infusion and aspiration handpieces between two micro incisions, 360 degrees of the capsular fornices are easily reached, and cortical cleanup can be performed quickly and safely (Figs. 7 and 8). The ability to switch hands also represents a significant advantage for instructors of phacoemulsification, who may find they must take over a case from a resident with opposite manual dominance [28].

BMMI phaco also provides significant advantages in complication management. If the posterior capsule is compromised during surgery, the first goal of the surgeon is to maintain stability of the anterior chamber

Fig. 6. The stream of irrigation fluid from the open-ended irrigator on the left is directed toward the posterior capsule while the silicone-sleeved aspirator is used to mobilize gently the plaque.

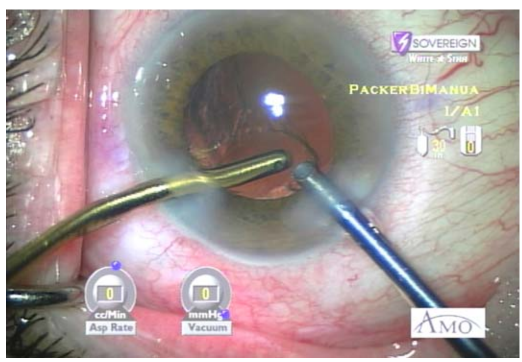


Fig. 8. Difficult to reach subincisional cortex below the right-handed incision is more safely aspirated from the left. The surgeon avoids potentially dangerous intraocular gymnastics that place the posterior capsule at risk.

to prevent posterior migration of lens material and anterior prolapse of the vitreous. By maintaining infusion high up in the anterior chamber, it becomes safer to reach posteriorly with the phaco needle, aspiration tip, or vitrector to remove residual lens tissue. Irrigation need never be brought down into the capsule where it may dislodge lens tissue, enlarge the capsular tear, or engage the vitreous. Hypotony is avoided at all times by keeping the flow of irrigation constant, much in the same way that an anterior chamber maintainer works [29]. Once all lens material has been evacuated from the eye, viscoelastic material may be injected before removal of the irrigator so that the vitreous face remains under tamponade.

Use of BMMI phaco as described herein for refractive lens exchange and routine cataract surgery offers an enormous advantage of maintaining a more stable intraocular environment during lens removal. This advantage may be especially important in high myopes who are at a greater risk for retinal detachment following lens extraction [30]. By maintaining a formed and pressurized anterior chamber throughout the procedure, there should be fewer tendencies for anterior movement of the vitreous body with a theoretical lower incidence of posterior vitreous detachment from intraoperative manipulations. Future studies will be needed to document a significant reduction in posterior segment morbidity using this method of lens removal.

Some of the major advantages of BMMI phaco do relate to incision size, for example, there has been an improvement in control of most of the steps involved in endocapsular surgery owing to increased chamber stability. Because viscoelastics do not leave the eye easily through these small incisions, the anterior chamber is more stable during capsulorrhexis construction, and there is much less likelihood for an errant rhexis to develop. The added chamber stability can also make a difference in control of the capsulorrhexis in refractive lens exchange in high myopia with a deep anterior chamber and floppy capsule. Adoption of the micro incision techniques has also served as a catalyst for instrument manufacturers, who have developed delicate exquisite forceps for construction of the capsulorrhexis. The result has been unparalleled surgical control. Hydrodelineation and hydrodissection can be performed more efficiently by virtue of a higher level of pressure building in the anterior chamber before eventual prolapse of viscoelastic through the micro incisions.

The authors have found this technique to be simple, efficacious, and safe, because most of the lens extraction occurs in the plane of the iris away from the posterior capsule and the corneal endothelium. Regardless of whether surgeons employ 18- or 21-gauge incisions, the principle advantages of BMMI phaco arise from the separation of infusion and aspiration. No matter how small the incision, these advantages cannot be achieved with coaxial techniques.

Refractive lens exchange in high myopia: weighing the risks

The desire for a life free of spectacle and contact lens correction is not limited to low and moderate myopes under the age of 40 years. The high myope with accommodative reserve may be a good candidate for phakic refractive lens implantation, and the presbyopic hyperope has become well recognized as a candidate for refractive lens exchange with an accommodating or multifocal IOL [31]. The myope aged greater than 45 years may be greeted with skepticism. Surgeons worry that presbyopic low myopes will not be satisfied with a simple trade of distance correction for near after bilateral LASIK surgery or with a compromise of depth perception with monovision, whereas a multifocal or accommodating IOL may not offer the same quality of near vision they already have without correction. Refractive lens exchange for moderate to high myopes may raise concerns about significant complications, especially retinal detachment. In particular, eyes with a long axial length and vitreoretinal changes consistent with axial myopia may be at higher risk for retinal detachment following lens extraction and IOL implantation. A review of the published literature is helpful in the evaluation of this risk.

In a frequently cited study, Colin and colleagues [32] reported an incidence of retinal detachment of 8.1% after 7 years in high myopes (> 12 D) undergoing refractive lens exchange. Colin's case series includes 49 eyes with four retinal detachments. The first occurred in a man with an axial length of 30 mm and preoperative myopia of −20 D who required preoperative argon laser prophylaxis for peripheral retinal pathology and underwent refractive lens exchange at 30 years of age. The retinal detachment occurred 18 months after the lens surgery. The other three retinal detachments occurred following yttrium-aluminum-garnet (YAG) laser capsulotomy. These two patients were 8 to 9 years older than the first patient was, and their eyes were not as extremely myopic, did not have preoperative retinal pathology, and sustained retinal detachment from 5.5 to 6 years after lens surgery and 1 to 2 years after YAG capsulotomy.

A striking feature of Colin's report is the relationship of YAG capsulotomy to retinal detachment. Ranta and colleagues [33] recently demonstrated that each millimeter increase in axial length increases the risk of retinal detachment after YAG capsulotomy by a factor of 1.5. Their findings also support the conclusion that about half of retinal detachments that occur after YAG surgery result from new lesions (horseshoe tears), whereas the other half result from "potentially antecedent small atrophic holes." Unfortunately, preoperative prophylaxis cannot address the former. The statistical methodology of this study represents a good model for further research in that it quantifies risk in terms of axial length rather than diopters of myopia. To the authors' knowledge, no one has suggested additional risk for retinal detachment with extremely steep keratometry.

A review of the literature to help determine the actual risk of retinal detachment after lens surgery should be limited as much as possible to current techniques, such as small incision lens extraction, capsulorrhexis, and in-the-bag IOL placement. Sanders [34] has recently pointed out that some of the publications cited in the literature employed techniques no longer representative of the standard of care. For example, Javitt [35] assumed an ultimate rate of retinal detachment of 7.5% based on the earlier work of Barraquer; however, Barraquer's series included 3% intracapsular lens extractions, whereas 9 of 165 eyes in his series received an IOL [36]. Sanders suggests that the 1372 subjects in 14 peer-reviewed articles who underwent refractive lens exchange by phacoemulsification with posterior chamber IOL implantation comprise a more pertinent comparison group. Retinal detachments in this group numbered 14, for a cumulative rate of 1%.

A more recent publication by Fernandez-Vega and coworkers [37] reports the results in a retrospective case series of 190 eyes in 107 patients with a minimum axial length of 26.00 mm that underwent refractive lens exchange with posterior chamber IOL implantation. The mean follow-up was 4.78 years (range, 3.1 to 8.03 years). The surgical technique involved capsulorrhexis, hydrodissection, phacoemulsification, and insertion of a one-piece polymethyl methacrylate IOL through an enlarged 6.5-mm incision with suture closure as needed. The reported YAG capsulotomy rate was 77.89% (148 eyes). Retinal detachment developed in four eyes with a mean axial length of 30.44 mm (range, 29.60–32.30 mm), all of which had undergone YAG capsulotomy. The overall incidence of retinal detachment was 2.1%.

The question arises as to the natural incidence of retinal detachment in high myopia without surgical intervention. A frequently quoted rate is 0.68% per year for myopia greater than −10 D [38]. That rate amounts to 3.25% over the 4.78-year mean follow-up period of the series studied by Fernandez-Vega. Their reported rate of 2.1% for eyes undergoing refractive lens exchange actually compares favorably with the rate for unoperated eyes, as does the cumulative 1% rate quoted by Sanders.

Minimizing risk is critical to the success of refractive lens exchange and refractive surgery because these are elective procedures. Several conclusions emerge from the literature on retinal detachment following refractive lens exchange. First, careful preoperative examination and counseling should precede any decision to operate. Complete funduscopic examination with scleral depression and determination of the state of the vitreous body are essential steps in the examination. Referral to a vitreoretinal specialist should be considered if any doubt emerges about the nature of a lesion or the indication for prophylaxis.

Second, surgical principles should emphasize minimal disturbance of the intraocular environment. Micro incision techniques facilitate maintenance of a stable chamber, construction of a round and centered capsulorrhexis, effective cortical cleaving hydrodissection, efficient aspiration of lens material without application of ultrasound energy, and safe bimanual cortical cleanup through two paracentesis type incisions. A fresh temporal clear corneal incision may be constructed for introduction of the IOL. All incisions should be Seidel negative at the conclusion of the case.

Third, eventual YAG capsulotomy should be avoided if possible. The construction of a capsulorrhexis that completely overlies the edge of the IOL optic, the use of cortical cleaving hydrodissection, meticulous cortical cleanup, and implantation of an IOL with a sharp posterior edge all facilitate maintenance of a clear posterior capsule.

By following these guidelines, one can improve on the outcomes recently reported by Fernandez-Vega. It is equally encouraging that none of the eyes with retinal detachment in that series lost a line of best-corrected visual acuity. Careful patient selection and follow-up will always contribute to improved results. For now, the published literature supports an acceptable safety profile for refractive lens exchange in high myopia. This procedure, with the implantation of an accommodative or multifocal IOL and the use of concomitant limbal relaxing incisions, can also successfully address astigmatism and presbyopia among the highly myopic population.

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