IOL Power Choice in Children

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When one of my children had cataract surgery and IOL implantation in 25 years ago at the age of 3, the optics of the growing eye and the pattern of growth were poorly understood. He received an IOL power of +25 D in the eye that had surgery, with an intended initial postoperative refraction of +2.5 D.

During fellowship, I studied the patterns of long-term refractive change in hundreds of aphakic pediatric eyes from the practice of Marshall M. Parks, M.D. The pattern of ocular growth was clear: on average, there was a myopic shift that was greatest early in life and declined with age [1]. Subsequently, others and I studied the long-term refractive change in a large number of pseudophakic pediatric eyes, and found the same pattern [2–4]. The aphakic or pseudophakic refractive error follows a semi-logarithmic decline with age through at least 20 years of age. Notably, there is a large variance in the rate of this refractive growth, and there is no way to precisely predict future refractions for a particular child [5].

Great emphasis has been placed on which IOL formula is most accurate in children's eyes. However, the fact is that these pseudophakic pediatric eyes grow, and with ocular growth comes a large and highly variable quantity of myopic shift. Seeking the most accurate formula for initial postop refraction with a goal of long-term refractive prediction is analogous to the parent who tries to predict her young child's future adult weight by using an accurate scale at age 3. Instead, the choice of IOL power for a child should take into consideration the myopic shift that results from ocular growth with age.

Although the goal of IOL power choice in adults is usually emmetropia, the goal of cataract surgery in children is twofold: optimal management of vision in childhood and emmetropia in adult life. The former requires spectacles to manage the changing refractive error in the growing eye, as well as often-intensive treatment for

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amblyopia. The latter requires a combination of careful choice of the initial postoperative refraction (based primarily on age), with a goal of achieving an adult refractive error that can be easily managed with spectacles or contact lenses. In some cases, due to the large variance in the rate of refractive growth, resulting high refractive errors in adults may require refractive surgery or IOL exchange.

IOL Formula Accuracy

Studies of the accuracy of IOL formulas find that the prediction error is worse in children than in adults, especially for children less than 3 years of age [6, 7]. This is primarily due to the current limits of biometry in a child, and to the limits of measuring post-operative pseudophakic refractions in children.

Errors with biometry in children are primarily driven by errors in axial length (AL) measurements. As very young children require general anesthesia for biometry, currently ultrasound is used to measure AL. The surgeon or ultrasonographer must be careful to center the probe on the cornea, and align the beam to the axis of the eye. Ideally the A-scan is done using immersion, but contact A-scan is commonly used by pediatric ophthalmologists [8]. When the tip of the contact A-scan probe touches the soft cornea, it tends to depress the corneal apex, resulting in a shorter measurement of AL by 0.27 [9] to 1 mm [10], increasing the calculated IOL power for emmetropia by 1 to 3 D. There can be a greater variance in measurements of AL when using a contact probe: a prospective study of 50 eyes (mean age: 3.87 years) found the absolute prediction error of <0.5 D in 50% of eyes when AL was measured using immersion, vs 23% when using a contact probe [9], although a retrospective study found no difference in absolute prediction error (APE) between a recent group of 65 eyes measured using immersion, vs. 138 historical controls measured using contact A-scan [11]. The surgeon should also account for the speed of ultrasound in an infant eye: the speed of sound in a 20-mm eye is 1561 m/s, vs. 1555 m/s for a 23.5 mm phakic eye [8]. Because the child's eye is small, the same quantity of power prediction error is greater in proportion to that in an adult eye: a 1 mm AL error in an adult eye could result in a 2.5 D IOL power change, but in a child's eye, this same error could change the IOL power by 4 D.

Hand-held keratometers measure corneal power (K) with an accuracy equivalent to mounted keratometers. However, under supine general anesthesia, the supple nature of an infant eye can lead to flatter Ks [10].

With optimal biometry, these errors can be reduced, depending on age. Younger children have a shorter axial length, require a higher power IOL, and their refraction is measured with less precision: because of these factors, the measured and expected postop refractive error goes up substantially in infants. In a study of children with a median age of 3.56 years, Trivedi et al. found a median absolute error of 0.53–0.67 D using common theoretical IOL formulas (Holladay 1 & 2, Hoffer Q and SRK-T) [12]. By my calculations, this is close to the theoretic minimum postop error for this age (unpublished data). In the Infant Aphakia Treatment Study (IATS), where cataract surgery with IOL implantation was performed on much younger children (<7 months of age), the median APE was 1.2 D using the Holladay 1 formula, and was worse for eyes with AL < 18 mm [13].

We compiled the results of several recent studies of formula accuracy in children, with the results for absolute prediction error (APE) shown in Tables 70.1 and 70.2. APE is the most indicative of the accuracy of the formula; medians are preferred to means because APE does not follow a Gaussian curve.

Eibschitz-Tsimhoni et al. studied the sensitivity of errors in axial length and corneal power for a variety of IOL formulas (HofferQ, Holladay, SRK-T, Haigis and SRK II) on the IOL power

Table 70.1 Study population characteristics for recent studies of IOL formula accuracy in pediatric patients, in order of mean age at surgery

Study reference	*N*	Mean age (std dev), years	Axial length measurement technique
[13]	43	0.2 (0.1)	Immersion A-scan for most
[6]	68	2.8 (2.1)	A-scan for very young (no mention of immersion vs. applanation); Lenstar if cooperative
[12]	45	3.9 (2.9)	Immersion A-scan
[7]	377	4.6 (2.3)	Applanation A-scan
[14]	64	5.9 (3.6)	Immersion A-scan
[15]	135	6.4	Applanation A-scan

Table 70.3 Calculated initial pseudophakic refractions for IOL implantation in children of 0–20 years of age, for three commonly used IOL formulas

Age (years)	AL (mm)	K (D)	IOL (D)	SRK-T	HofferQ	Holladay
0.0	16.8	51.3	29.0	8.01	10.50	7.96
0.3	18.5	47.9	29.0	4.36	5.68	4.68
0.8	19.2	45.3	28.0	4.55	5.61	5.00
1.5	20.2	45.0	26.0	3.20	3.87	3.53
2.5	21.4	44.2	23.0	2.63	3.01	2.85
4.0	22.4	43.8	22.0	1.21	1.42	1.35
20.0	23.6	43.2	21.0	−0.30	−0.27	−0.25

Table 70.2 Median absolute prediction error (APE, in diopters) for recent studies of IOL formula accuracy in pediatric patients, in order of mean age at surgery

Ref	SRK II	SRK-T	Hoffer Q	Holladay 1	Holladay 2	Haigis	Barrett U II	Olsen	T2	Super	Notes
[13]	2.2	1.3	2.1	1.2	1.4						
[6]	0.83	0.75	0.83	0.88	1.00	0.74	0.89	0.89			*1
[12]		0.67	0.56	0.58	0.53						
[7]	0.95	0.81	0.68	0.70					0.76	0.73	*1
[14]		0.86	0.88		0.81		0.79				
[15]	0.90	0.71	0.61	0.64							*2

Ref = study reference number
*1: much greater scatter in APE for eyes before the age of 3 years
*2 biometry done in office resulted in better APE than when done under anesthesia; e.g., 0.83 vs. 0.60 D using the Holladay 1 formula

calculated to give emmetropia [16]. They found the calculated IOL power to be relatively insensitive to a +1 D error in K (0.5 to 1.4 D). However, a +1 mm error in AL resulted in large differences in calculated IOL powers, especially in infancy (ranging from −6.7 D for the SRK-T formula to −14.2 D for HofferQ).

However, we think that this analysis can be improved in two significant ways. Axial length errors in children are most commonly underestimates, especially if AL is measured by contact A-scan or the A-scan is off axis. In addition, the important outcome for the child and surgeon is the refractive outcome rather than the IOL power. Therefore, we calculated the resulting error in a different way from Eibschitz-Tsimhoni et al.: we calculated the resulting refractive error due to a −1 mm error in axial length measurement for a similar group of patients, given a combination of age, AL, K, and IOL power likely to be chosen by the surgeon who wishes to leave the child with initial hyperopia that is greater at younger ages. The results are shown in Tables 70.3 and 70.4. Although the error in IOL power for emmetropia is especially large for the HofferQ formula, the resulting error in refraction is less sensitive to errors in axial length for IOL powers typically implanted in children.

Table 70.4 The resulting error when there is an underestimate of axial length by 1 mm, for three common formulas. The errors are shown for the IOL power for emmetropia, or the resulting pseudophakic refraction for the specific IOL choice stated in Table 70.3

	Error in IOL power (D) for emmetropia			Error in refraction (D) for chosen IOL power		
Age (years)	SRK-T	HofferQ	Holladay	SRK-T	HofferQ	Holladay
0.0	6.34	12.44	6.81	3.61	4.21	3.87
0.3	5.11	7.23	5.48	3.27	3.95	3.43
0.8	4.67	6.04	5.01	3.05	3.54	3.17
1.5	4.21	5.05	4.50	2.83	3.15	2.94
2.5	3.75	4.27	3.99	2.53	2.75	2.64
4.0	3.43	3.84	3.65	2.37	2.57	2.47
20.0	3.10	3.47	3.29	2.18	2.38	2.28

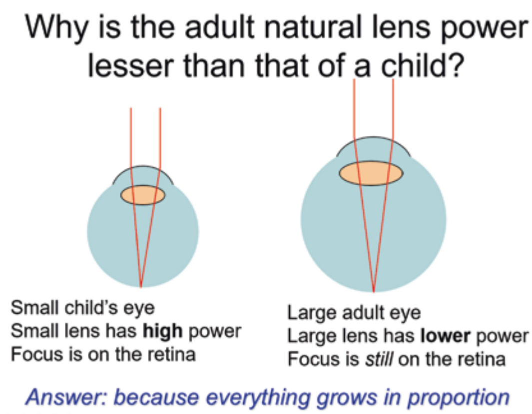

Fig. 70.1 In a normal child's eye, the optical components of the eye grow in approximate proportion

The Growth of the Eye

For young children, the large and variable growth of the eye is far more important than the initial biometric errors.

The growth of the eye follows a logarithmic curve with age. The eye grows as the child grows, rapidly at first, then slowing down over time. The components of the eye that determine its refractive error consist of the cornea, lens, and axial length. In a normal child, the nearly proportional growth of all optical elements of the eye results in the maintenance of near-constant refraction from birth through adult life (Fig. 70.1), although there is a trend in modern societies towards disproportionate growth of AL, resulting in myopia in many, and there are individual variations.

If an eye is rendered aphakic in infancy, the crystalline lens is removed and the aphakic eye has a high hyperopic refractive error, typically about +21 D. If the aphakic eye grows normally, the increased axial length results in greatly reduced hyperopia, while the flattening of the cornea increases hyperopia but to a lesser degree. The overall result is a myopic shift with age (Fig. 70.2). Just like the growth of the eye itself, this myopic shift is rapid at first and then slows with age.

Gordon and Donzis first described this changing growth of the eye [17]. They measured the axial length and keratometry of otherwise normal children. Other authors based their cataract surgery IOL power choice on the growth of the eye. For example, Enyedi et al. recommended initial postoperative refraction goal by age: +6 at 1 year, +5 at 2 years, +4 at 3 years, +3 at 4 years, +2 at 5 years, +1 at 6 years, 0 for 7 years, and −1 to −2 for ≥8 years of age [18].

Some authors have described limited or segmented ocular growth with age. Nyström et al. described 49 eyes with surgery at an average of 2.8 months: the refraction in aphakic eyes fol-

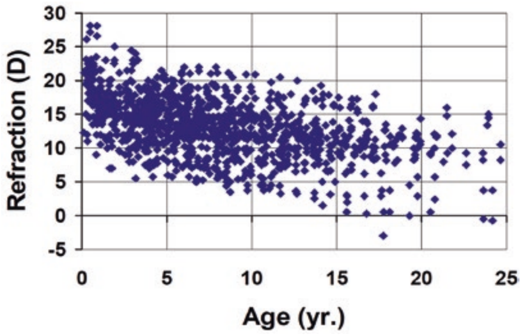

Fig. 70.2 Longitudinal refraction data from 281 aphakic pediatric eyes [1]

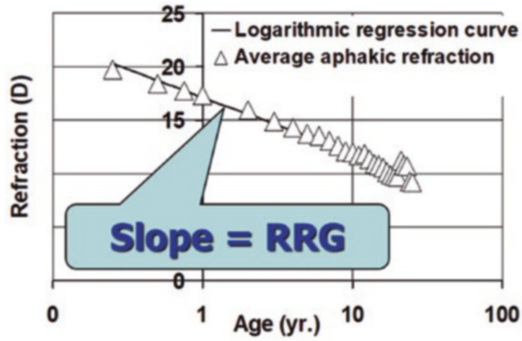

Fig. 70.3 Refraction vs. log of age for aphakic eyes [1]

lowed a logarithmic change in refraction in the first 3 years of life [19]. Wilson and Trivedi noted three phases of ocular growth, from birth to 6-months, 6–18 months, and >18 months [8]. Ohara noted that the cornea steepness stabilizes in the first 18 months of life; axial length increases dramatically in first 2 years of life, then grows at a slower rate into the second decade of life [20]. Even at the age of 10 years, the globe has not stopped growing. Wilson et al. studied 98 eyes with two AL measurements in the second decade of life [21]. A theoretical eye with an AL at the age of 10 years of 23.11 mm would grow to 24.41 mm by the age of 20 (with a wide variance), resulting in a 4-diopter difference between IOL powers needed for emmetropia at the two ages. This implies that a surgeon who implants multifocal IOLs in this age range should consider the continuing ocular growth.

Instead of thinking of the child's eye growing in phases, or until a certain age, we have found that a simpler approach is to recognize the semi-logarithmic growth of the eye from infancy through at least 20 years of age. In a group of 156 aphakic pediatric eyes followed for a mean of 8.8 years, a plot of average refraction vs. log of age was a straight line (Fig. 70.3).

The same plot (equivalent aphakic refraction vs. log of age) can be obtained for pseudophakic and normal eyes, by mathematically removing the effect of the IOL power (in the former case), or by calculation of aphakic refraction from AL and K taken from Gordon and Donzis study [17]. The slope of the straight line, called "Rate of Refractive Growth" (RRG, or the preferred RRG2 or RRG3), is a measure of how fast the eye is growing. In data from aphakic, pseudophakic and normal eyes, the mean RRG2 is nearly the same in the three groups. A study by Tadros et al. backs this up: in 24 children with surgery at 2.6 months average and 8.4 years mean FU time, the growth of the AL and fellow eyes (4.1 vs 4.4 mm) was not statistically different [22]. In short, it appears that cataract surgery does not affect the growth of the eye. Applying Occam's razor, because it is simpler to work with a single description (rate of refractive growth) than one with several segments of varied growth rates, the semi-logarithmic model is preferred.

RRG2 is a characteristic parameter of each eye, correlating to how fast it grows. Data on mean RRG2 and its variance exists for aphakic and pseudophakic eyes [23]. The mean RRG2 and variance have been used to make calculators [24, 25] that predict the future refraction of any eye, whether aphakic or pseudophakic (Fig. 70.4).

There is a very large variance in RRG3 in both aphakic and pseudophakic eyes. This variance prevents precise prediction of future refractions, but has been included in pediatric IOL calculators to allow the surgeon to predict the approximate likely range of future refractions for any given child (Fig. 70.5). The variance in RRG3 is so large that it tends to overwhelm any initial errors in IOL power calculation.

Normal eyes also have a variance in the rate of refractive growth. However, a study of 103 subjects from the Infantile Aphakia Treatment Study (IATS) found that the variance in RRG3 in nor-

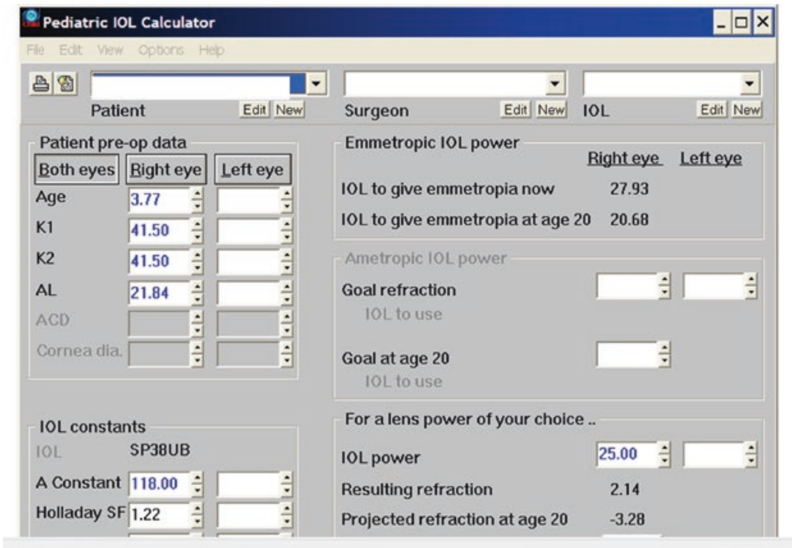

Fig. 70.4 The Pediatric IOL Calculator computer program.

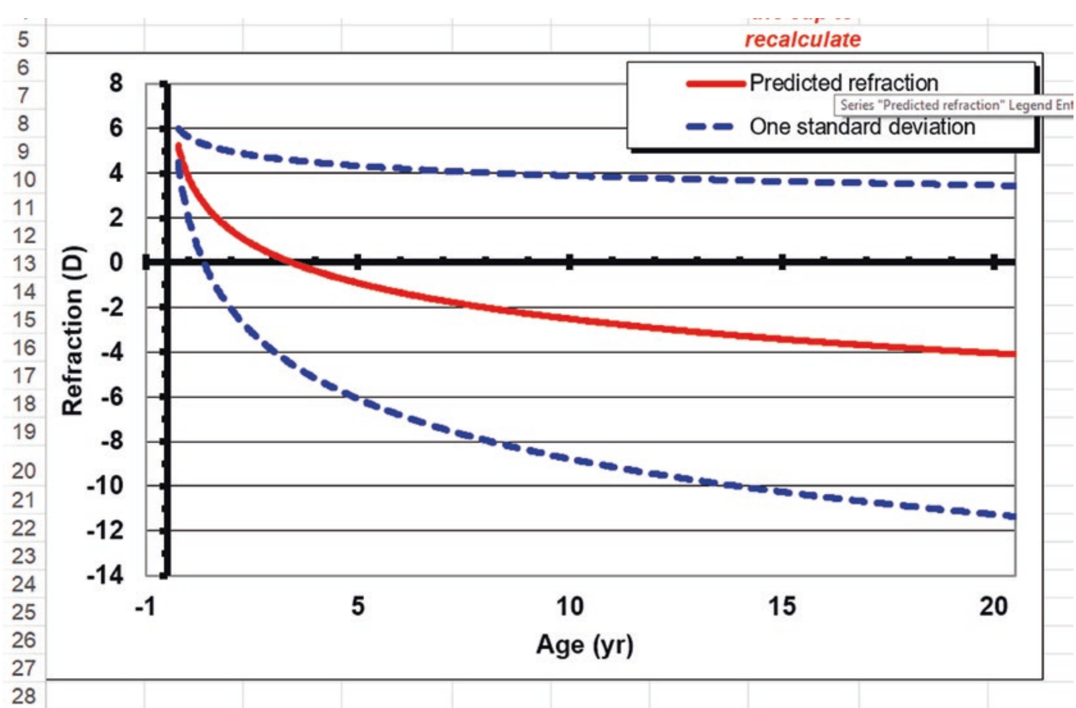

Fig. 70.5 A graph from the Pediatric Piggyback IOL Calculator spreadsheet, showing predicted refraction and standard deviation curves, of a child who has cataract removal with IOL implantation in infancy.

mal eyes was half that was seen in aphakic or pseudophakic eyes [26]. This study also found that RRG3 was greater in aphakic and pseudophakic eyes than the fellow, normal eyes. RRG3 for normal eyes was −15.0 (3.0) D (reported as mean (standard deviation)), for aphakic eyes −17.7 (6.2) D, and for pseudophakic eyes −16.7 (6.2) D.

The Choice of Initial Postoperative Refraction

There is no consensus on the choice of initial postoperative refraction in pseudophakic children. Most pediatric ophthalmologists prefer a moderate hyperopia that varies with age, and whether the IOLs are to be implanted uni- or bilaterally. Hiles in 1984 stated "…because of inaccuracies induced by the growth of the eye, a standard adult power lens is now routinely implanted" [27]. Eibschitz-Tsimhoni et al. noted in a Survey of Ophthalmology article that there are varied opinions: adult IOL power, myopia, emmetropia, and hyperopia. No study shows an advantage of one approach over another [28]. Nischal wrote, "Ideally, a child should be left as close as possible to emmetropia for visual rehabilitation" but it is recommended to under-correct to leave initial hypermetropia [29]. Indram et al. stated, "the goal is… to achieve emmetropia or a low level of myopia when the child is fully grown" [10]. A study by Lambert et al. of 24 children with unilateral cataract, age 2 to <6 years of age, divided into two groups: group 1 (full correction) and group 2 (undercorrection by ≥2 D). Neither the myopic shift nor the median final visual acuity differed significantly between the groups [30]. Lekskul et al. studied that 50 children were given initial undercorrection of IOL power (resulting in initial hyperopia) of between 10 and 30%, based on age at surgery for those between 0.5 and 5 years of age. In the children ≥7 years of age at last follow-up (quite varied length of follow-up), 45 of 74 eyes were myopic (up to −8.25 D, higher in those with surgery at younger ages); 21 eyes were hyperopic (up to +3.25 D). The authors propose to aim for a greater degree of undercorrection in future surgical cases [31].

My son's initial pseudophakic refraction was +1.5 D at the age of 3.77 years; it gradually shifted more towards myopia. As predicted, his myopic shift followed a semilogarithmic trajectory as he got older, though at a faster rate than average (Fig. 70.6). At the age of 20 years, he had

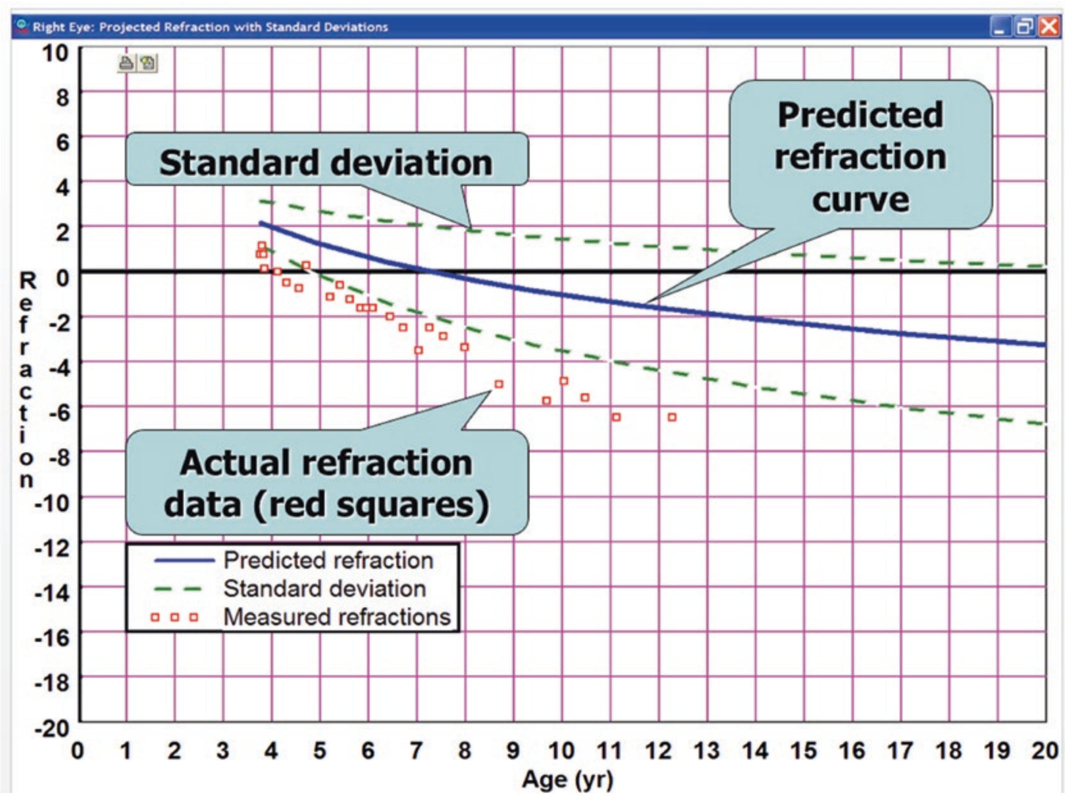

Fig. 70.6 Pseudophakic refraction, predicted vs. actual, for a child who had cataract surgery with a +25 D IOL implant at the age of 3.77 years

photorefractive keratectomy (PRK) for his refraction of −8 D. Now, several years later, he has a small amount of myopia, with 20/30 vision and good stereopsis. In retrospect, had we chosen an IOL power to result in initial myopia (say, −2.0 D), his refractive error at the age of 20 years would have required IOL exchange. Had we chosen an IOL power to result in greater initial hyperopia (say, +4 D), the PRK would could have removed less corneal stroma to achieve emmetropia.

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