



# Managing residual refractive error after cataract surgery

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We present a review of keratorefractive and intraocular approaches to managing residual astigmatic and spherical refractive error after cataract surgery, including laser in situ keratomileusis (LASIK), photorefractive keratectomy (PRK), arcuate keratotomy, intraocular lens (IOL) exchange, piggyback IOLs, and light-adjustable IOLs. Currently available literature suggests that laser vision correction, whether LASIK or PRK, yields more effective and predictable outcomes than intraocular surgery. Piggyback IOLs with a rounded-edge profile implanted in the sulcus may be superior to IOL exchange, but both options present potential risks that likely outweigh the refractive benefits except in cases with large residual spherical errors. The light-adjustable IOL may provide an ideal treatment to pseudophakic ametropia by obviating the need for secondary invasive procedures after cataract surgery, but it is not widely available nor has it been sufficiently studied.

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Cataract surgery is one of the most common procedures performed in the United States, with nearly 3 million carried out every year.<sup>1,2</sup> Refractive outcomes after cataract surgery play a central role in shaping patient satisfaction as well as community recognition for the provider,<sup>3–7</sup> and adverse results can have medicolegal implications.<sup>8</sup>

Cumulative research efforts have significantly optimized refractive outcomes after cataract surgery. For example, third- and fourth-generation intraocular lens (IOL) power formulas have proven to be more accurate than earlier iterations<sup>9</sup> and specialized formulas are available for nearly every permutation of

keratorefractive patient.<sup>10–25</sup> Yet even in the hands of the most experienced and meticulous surgeon, refractive surprises can occur due to myriad factors.<sup>26–29</sup>

Reviewing currently available modalities for the management of pseudophakic refractive error may be of timely interest to today's cataract surgeon. This review comprises 3 sections. The first briefly summarizes longstanding keratorefractive procedures for correcting pseudophakic ametropia; the second focuses on intraocular surgical procedures, with particular emphasis on emerging technologies; and the third reviews the limited data available for comparing keratorefractive and intraocular approaches.

## SEARCH METHODS

Review of the literature was conducted by searching PubMed and Ovid Medline. No date or language restrictions were used in the electronic searches. Reference lists of published articles and the Web of Science citation index were also reviewed. The date of the last electronic search was February 1, 2014.

## KERATOREFRACTIVE APPROACHES FOR CORRECTING PSEUDOPHAKIC AMETROPIA

Keratorefractive approaches comprise (1) laser vision correction with laser in situ keratomileusis (LASIK)

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or photorefractive keratectomy (PRK), (2) laser vision correction after implantation of a multifocal IOL, and (3) arcuate keratotomy after cataract surgery.

### Consecutive Keratorefractive Surgery in Pseudophakic Eyes Versus Primary Surgery in Virgin Eyes

The proven safety, efficacy, predictability, and stability of excimer laser surgery for the correction of a wide range of refractive errors<sup>30-33</sup> make LASIK and PRK good options for treating pseudophakic ametropia. Combining keratorefractive surgery with intraocular surgery emerged first as a refractive paradigm coined “bioptics” in the late 1990s by Güell and Vázquez.<sup>34</sup> Bioptics combines an IOL—a phakic IOL or a pseudophakic IOL—with keratorefractive surgery, typically in patients with high myopia.<sup>35</sup> The IOL treats most of the spherical error, leaving a small amount of residual sphere and cylinder that can be readily treated with LASIK or PRK without sacrificing the cornea’s prolate asphericity and quality of vision, which would otherwise occur if a keratorefractive approach were the only modality used. Using LASIK and PRK to correct residual refractive error after cataract surgery is fundamentally the same as bioptics except that the postoperative ametropia is not planned.

Primary keratorefractive surgery and consecutive keratorefractive surgery in pseudophakic patients are conceptually similar, with a few exceptions. Pseudophakic patients tend to be older than refractive patients by at least 2 decades, which can make treatments less predictable and less effective.<sup>36-40</sup> Older age may also make these patients more susceptible to tear-film abnormalities after excimer laser surgery.<sup>41</sup> Unlike most refractive patients, pseudophakic patients have at least 2 corneal incisions from their cataract surgery and may have additional incisions that were made to correct astigmatism. In addition to their potential effects on refractive outcomes, these incisions can complicate the suction required to fashion a flap if LASIK is performed too soon after surgery as well as affect the flap itself if a femtosecond laser is used. Finally, counseling pseudophakic patients differs from counseling refractive patients. The expectations can be higher than those of primary refractive patients, who may be more inclined to view additional refractive procedures as “enhancements” rather than “fixes” for “mistakes” made in cataract surgery. In addition, the visual outcome of corneal refractive surgery after cataract surgery may not be in the range of 20/20 as often as it is after primary refractive surgery; it may be closer to 20/30 or 20/40.<sup>42</sup>

### Photorefractive Keratectomy and Laser In Situ Keratomileusis

In 1995, Maloney et al.<sup>43</sup> reported on the efficacy of PRK in correcting residual refractive error after previous ocular surgery. Although this was the first study to investigate PRK in pseudophakic eyes, only 2 of the 107 eyes evaluated had had PRK; the majority had had radial keratotomy. In 1999, Artola et al.<sup>44</sup> published a retrospective study of 30 eyes with residual myopic ametropia from 30 patients whose mean age was 66 years. Twelve months after PRK, 93% of the cohort was within  $\pm 0.50$  diopter (D) of emmetropia and 53% had an uncorrected distance visual acuity (UDVA) of 20/40 compared with no patients before PRK; 1 eye lost 1 line of corrected distance visual acuity (CDVA). The authors concluded that PRK was a safe, effective, and predictable technique for correcting residual myopia after cataract surgery.

Laser in situ keratomileusis has been shown to be safe and effective in the treatment of residual hyperopia, myopia, and astigmatism in pseudophakic patients.<sup>45-48</sup> Early data on correcting pseudophakic myopia were reported by Ayala et al.,<sup>45</sup> who conducted a retrospective study of 22 eyes of 22 patients with spherical equivalents (SEs) ranging from  $-0.80$  to  $-8.50$  D after cataract surgery. Twelve months after LASIK was performed with a microkeratome and the Nidek EC-5000 laser, 82% of the cohort (18 eyes) achieved an SE refraction within  $\pm 1.0$  D of emmetropia. In 2003, Norouzi and Rahmati-Kamel<sup>48</sup> showed that LASIK could also correct induced astigmatism from cataract surgery performed with a superior limbal incision. In 20 eyes of 20 patients with astigmatism ranging from 3.50 to 6.00 D, LASIK was performed with a microkeratome and the Nidek EC-5000. At 6 months, the mean percentage reduction in astigmatism was 90%, with the mean SE refraction decreasing from  $-2.19$  to  $-0.32$  D.

In 2005, Kim et al.<sup>46</sup> validated earlier observations with a retrospective review of 23 eyes of 19 patients with SEs ranging from  $-4.75$  to  $+3.00$  D. Laser in situ keratomileusis was performed with a microkeratome and the Summit Apex Plus or the Ladarvision excimer laser. The mean age of the cohort was 64 years, and the mean follow-up was 12 months. Based on the parameters of a UDVA of 20/40 or better, a refraction within  $\pm 0.5$  D or  $\pm 1.0$  D of the intended target, and loss of 1 or fewer lines of CDVA, the authors concluded that the refractive outcomes after LASIK in pseudophakic eyes rivaled the efficacy previously reported with refractive correction of naïve eyes.

Kuo et al.<sup>47</sup> reported similar conclusions the same year in a retrospective review of 11 eyes of 10 patients, 5 of whom had had PRK and 6 of whom had had

LASIK with a microkeratome and the Visx Star laser. The cohort's mean age was 75 years, and SEs ranged from  $-6.50$  to  $+0.75$  D, with cylinder as high as  $+5.50$  D. The mean attempted SE was  $-2.92$  D in the LASIK group and  $-3.73$  in the PRK group. There was no significant difference between the targeted and achieved SE refraction at 12 months, but older patients became more hyperopic than intended ( $P=.05$ ). Sixty-four percent (7 eyes) achieved a UDVA of 20/30, and 18% (2 eyes) achieved a UDVA of 20/50 or 20/60. The authors concluded that both LASIK and PRK were effective in correcting pseudophakic ametropia but postulated that neither may be as effective as primary refractive surgery due to the older age of the pseudophakic population.

Longer follow-up of pseudophakic LASIK patients has shown good stability. Zaldivar et al.<sup>49</sup> reported a retrospective review of bioptics in 345 eyes, 64 of which were pseudophakic and 281 of which had phakic IOLs. The SE refraction remained stable in both groups after 4 years.

#### Laser Vision Correction After Implantation of a Multifocal Intraocular Lens

In 2008, Alfonso et al.<sup>50</sup> published a prospective study of 53 eyes showing that LASIK could also be efficacious in treating pseudophakic ametropia after implantation of a diffractive multifocal IOL. After refractive IOL exchange with the AcrySof Restor IOL had been performed in patients with a mean age of 52 years and SE refractions ranging from  $-2.00$  to  $+1.00$  D, LASIK was performed with the Intralase FS-60 and the Visx Star. Six months after LASIK, 100% of the eyes were within  $\pm 1.0$  D of the target and 96.2% were within  $\pm 0.5$  D. All eyes achieved a UDVA of 20/30 or better, and no patient lost more than 1 line of CDVA.<sup>50</sup>

In 2009, Muftuoglu et al.<sup>51</sup> validated the findings of Alfonso et al. in a retrospective study of 85 eyes of 59 patients with pseudophakic myopic, mixed astigmatic, and hyperopic refractive error after implantation of a diffractive multifocal IOL. Laser in situ keratomileusis was performed with the Intralase FS-60 and Visx Star in patients with a mean age of 61 years, SE refractions ranging from  $-2.58$  to  $+1.63$  D, and astigmatism as high as 3.00 D. At 6 months, 99% of the eyes were within  $\pm 1.0$  D of emmetropia and 96% were within  $\pm 0.5$  D of emmetropia; 98% of eyes had 1.0 D or less of astigmatism. Refractions remained stable over 6 months, and 86% had a UDVA of 20/25 or better and an uncorrected near visual acuity (UNVA) of Jaeger 1 or better concurrently; no patient lost more than 1 line of CDVA.<sup>51</sup>

Fifteen percent of the cohort (13 of 85 eyes) studied by Muftuoglu et al.<sup>51</sup> had wavefront-guided treatment

with iris registration. The authors observed no significant differences between wavefront-guided and conventional LASIK for the parameters of refraction, UDVA, and UNVA. Because of the small sample size, the authors called for a sufficiently powered direct comparison of wavefront-guided and conventional LASIK in pseudophakic patients with multifocal IOLs, highlighting concern expressed by others about the accuracy of Hartmann-Shack aberrometers in this patient population.<sup>52,53</sup>

In 2004, Leccisotti<sup>54</sup> published a prospective study that was the first to describe the efficacy of PRK in treating pseudophakic ametropia after implantation of a refractive multifocal IOL. He studied 52 patients who had presbyopic IOL exchange with the Abbott Medical Optics Array IOL. The patients were offered PRK if they reported reduced distance vision or halos that improved with optical correction. Photorefractive keratectomy was performed in 18 eyes (19% of the cohort); 83% of them attained an SE refraction within  $\pm 0.5$  D of emmetropia and 100% were within  $\pm 1.0$  D.<sup>54</sup>

#### Arcuate Keratotomy

Although there are many studies of performing arcuate keratotomy and limbal relaxing incisions (LRIs) during cataract surgery to treat corneal astigmatism, there are very few of performing these procedures after cataract surgery. In 1998, Oshika et al.<sup>55</sup> conducted the only study of arcuate keratotomy after cataract surgery. The study comprised 104 eyes of 86 patients sampled from 9 medical centers in Japan. The mean age of the patients was 75 years, and the residual corneal astigmatism ranged from 1.5 to 6.0 D. Arcuate incision parameters were determined by the ARC-T Study Group,<sup>56</sup> Lindstrom,<sup>57</sup> and Thornton<sup>58</sup> nomograms. After 6 months of follow-up, the cohort's mean cylinder decreased from  $3.23$  D  $\pm 1.14$  (SD) to  $1.41$   $\pm 0.97$  D, with a mean correction of  $2.47$   $\pm 1.27$  D calculated by the vector method. The mean UDVA improved from about 20/100 to about 20/70; UDVA improved by 2 lines or more in 27% of the eyes, but 7% lost 2 lines or more. Overall, the amount of astigmatism corrected was less than that predicted by the nomograms, which Oshika et al.<sup>55</sup> attributed to Japanese ethnicity.

Since Oshika et al.'s publication,<sup>55</sup> manual and mechanical techniques for performing arcuate keratomies and LRIs have been surpassed by femtosecond laser-assisted approaches, which offer improved accuracy, safety, and reproducibility.<sup>59-64</sup> No studies have assessed whether arcuate keratotomy performed with a femtosecond laser after cataract surgery results in better outcomes than those achieved by Oshika et al.<sup>55</sup> with manual techniques. However,

Rückl et al.<sup>65</sup> performed intrastromal arcuate keratotomy with a femtosecond laser to compare this approach with the conventional method that penetrates Bowman layer. One of the 16 participants in the study had had cataract surgery, and 13 of the remaining 15 expected to have it within 6 months. Although the quantity of cylinder was not reported, the post-cataract-surgery participant achieved emmetropia and gained 4 lines of UDVA.<sup>65</sup>

## INTRAOCULAR APPROACHES FOR CORRECTING PSEUDOPHAKIC AMETROPIA

Intraocular approaches comprise (1) piggyback IOLs, (2) IOL exchange, and (3) the light-adjustable IOL.

### Piggyback Intraocular Lenses Versus Intraocular Lens Exchange

Before the advent of light-adjustable IOL technology, IOL exchange and secondary piggyback IOLs were the primary intraocular options available to correct residual refractive error after cataract surgery. In 1993, Gayton and Sanders<sup>66</sup> reported the first piggyback IOL implantation, which was done to provide sufficient plus power in a microphthalmic eye. Others<sup>67-71,A</sup> subsequently used this approach more broadly for the correction of high hyperopia. In 1999, Gayton et al.<sup>67</sup> reported a case series demonstrating that piggyback IOLs could also be used to correct a wide range of pseudophakic ametropias. Comprising 15 eyes, 7 of which were post penetrating keratoplasty, the study included preoperative SE refractions ranging from  $-5.12$  to  $7.50$  D, which improved to  $-2.75$  to  $0.50$  D postoperatively; the UDVA also improved, with 50% of the cohort achieving 20/40 or better compared with 7% preoperatively. Gayton et al.<sup>67</sup> achieved these refractive outcomes by selecting piggyback IOL powers based on SE refractions after cataract surgery without considering keratometry or axial length. Eyes with myopic refractions received a minus IOL equal to the refractive error; eyes with hyperopic refractions received a plus IOL equal to 1.5-times the refractive error. Gills<sup>A</sup> described an alternative method for hyperopic eyes that adds 1.0 D to 1.4-times the refractive error, and Holladay et al.<sup>70</sup> created a formula to calculate the appropriate power of a piggyback IOL in myopic eyes. These approaches have proven to be more predictable than Gayton's initial methods.<sup>71-73</sup>

Gayton et al.<sup>74</sup> outlined several advantages of piggyback IOLs over IOL exchange, which have been reaffirmed by expert opinion as well as confirmed by clinical data.<sup>72,73</sup> Implanting a second IOL anterior to the one already in place is generally easier and less traumatic than IOL exchange because it requires less

manipulation. This is particularly true when the primary IOL is not freely mobile in the capsule due to fibrosis. In such cases, additional manipulation increases the risk for posterior capsule rupture, vitreous loss, cystoid macular edema (CME), retinal tears, and corneal endothelial damage. Another advantage of piggyback IOLs is the relative simplicity of IOL power selection, which according to Gayton et al.<sup>67</sup> is theoretically more predictable than IOL exchange because fewer parameters are subject to change. In addition to the manifest refraction, power selection for IOL exchange requires that the primary IOL power be known and that the secondary IOL's final position be in the same anterior-posterior plane as the explanted IOL. However, neither of these parameters is always known at the time of surgery.

The major drawbacks of piggyback IOLs are the risk for interlenticular opacities, the increased risk for IOL-related complications due to chafing against the pigment epithelium of the iris, the possibility of piggyback IOL dislocation due to the approximation of 2 convex surfaces, and the theoretical possibility of IOL curvature change from compression. Any of these complications can necessitate removal of both IOLs.

In 2000, Gayton et al.<sup>74</sup> published the first clinicopathologic correlation of central interlenticular opacification; Shugar et al.<sup>75</sup> and Spencer et al.<sup>76</sup> later published case reports of this phenomenon. Although some have had long-term success implanting both IOLs in the bag,<sup>77</sup> the collective work of Gayton et al., Shugar et al., and Spencer et al. suggests that placing piggyback IOLs in the sulcus can prevent interlenticular opacification and an associated hyperopic shift. When sulcus positioning is not possible, a generous capsulorhexis that is larger than the optics should be performed to allow the posterior and anterior capsules to fuse and thereby sequester proliferating lens epithelial cells. However, even sulcus piggyback IOLs are not without potential complications. Case reports by Chang et al.<sup>78</sup> and Chang and Lim<sup>79</sup> show the potential for piggyback IOLs with a square profile to cause pigmentary dispersion glaucoma.

In 2013, El Awady and Ghanem<sup>72</sup> published a prospective case series comparing refractive and safety outcomes of piggyback IOLs with those of IOL exchange. The series comprised 23 pseudophakic eyes of 23 patients who were unhappy with residual spherical refractive errors due to anisometropia or more than 3.0 D of residual myopia or hyperopia. The mean interval between initial cataract surgery and the second surgery ranged from 3 to 25 days; the mean age in both groups was about 50 years. All primary, secondary, and piggyback IOLs were the Acrysof MA60MA, which measures 13.0 mm in total length and has a 6.0 mm optic with square edges coupled to

poly(methyl methacrylate) haptics. Piggyback IOLs were implanted in the ciliary sulcus through the original main wound; primary IOLs were explanted in 2 pieces after being cut with a Vannas scissors and were exchanged for secondary IOLs implanted in the bag, when possible. Piggyback IOL selections were based on Gills' and Holladay's methods, and all eyes were targeted to emmetropia.<sup>72</sup>

At baseline, there was no eye in El Awady and Ghanem's series<sup>72</sup> with a UDVA of 20/40 or better. After a mean follow-up interval of about 20 months, the piggyback group had a higher frequency of 20/20 or better UDVA than the exchange group (33% versus 18%; *P* value not published) and about the same frequency of 20/40 or better UDVA (92% versus 91%; *P* value not published). The piggyback group also exhibited more predictable refractive outcomes, with 92% achieving an SE within  $\pm 0.5$  D of emmetropia compared with 82% in the exchange group (*P* value not published). Consistent with prior comparisons, El Awady and Ghanem<sup>72</sup> observed fewer complications in the piggyback group than in the exchange group, which had 1 anterior vitrectomy due to posterior capsule rupture and 1 instance of a single line of CDVA loss due to CME; there was no clinically significant endothelial cell loss in either group. Four eyes in the piggyback group compared with 5 eyes in the IOL exchange group required neodymium:YAG capsulotomy for posterior capsule opacification.

### Light-Adjustable Intraocular Lens

Light-adjustable IOL technology has ushered in the possibility of correcting residual ametropia after cataract surgery without further invasive procedures. The refractive benefits of an adjustable IOL were recognized as early as the 1990s, with investigators proposing both invasive<sup>80-82</sup> and noninvasive<sup>83,84</sup> methods of adjusting the IOL power. However, it was not until the 2003 article by Schwartz<sup>85</sup> that the current iteration of this concept was realized as a viable technology. Schwartz outlined essential criteria for the development of the light-adjustable IOL, including that it must be adjustable by noninvasive means, able to correct as much as 2.0 D or more of refractive error within 0.25 D of the targeted adjustment, and foldable for use in small-incision cataract surgery. Precursors of the Calhoun light-adjustable IOL fulfilled these criteria in *in vitro* and *in vivo* rabbit testing; they also demonstrated the technology's potential to correct not only spherocylinder errors but also higher-order aberrations (HOAs) such as spherical aberration.<sup>85</sup> In 2006, Sandstedt et al.<sup>86</sup> demonstrated that even multifocal optics could be "imprinted" onto the light-adjustable IOL.

The light-adjustable IOL design stems from the principles of photochemistry and diffusion, whereby photoreactive macromers dispersed within a crosslinked silicone lens matrix are photopolymerized by ultraviolet light (365 nm) to form an interpenetrating polymer in the lens matrix. The newly formed polymer causes adjacent nonirradiated macromers to diffuse into irradiated areas, resulting in a change in shape or refractive index or both. Titration of the irradiation dosage, spatial intensity profile, and target area according to nomograms<sup>87</sup> changes the light-adjustable IOL's radius of curvature precisely, thus adding or subtracting spherical power, eliminating astigmatic error, or correcting HOAs. When the appropriate power adjustment is achieved, the entire IOL is irradiated in a second lock-in procedure to consume unreacted macromers in the lens.<sup>85</sup>

In a series of small pilot studies published in 2009 and 2010, Chayet et al.<sup>88-90</sup> demonstrated the efficacy and predictability of the Calhoun light-adjustable IOL across a range of refractive circumstances. In a prospective study of 14 eyes of 14 patients with a mean age of 63 years, light-adjustable IOLs were purposefully implanted to leave between  $-0.25$  D and  $-1.50$  D of residual myopia. Ten to 21 days after implantation, the light-adjustable IOL was irradiated with a digital light-delivery system to adjust its spherical power but not the coexisting cylinder; afterward, the adjustment was locked in. After lock-in, 93% of the eyes were within  $\pm 0.25$  D of the intended refraction and 100% were within  $\pm 0.5$  D. Refraction was stable for the 9-month follow-up, with a mean rate of change of 0.006 D per month, or about 6 times more stable than after corneal refractive procedures. Seventy-one percent of eyes showed significant improvement in UDVA and achieved a UDVA of 20/25 or better. The procedure was also found to be safe, with all patients maintaining the pre-procedure CDVA of 20/25 except 1 who developed a posterior capsule opacity.<sup>88</sup>

A similarly structured study<sup>89</sup> was conducted to investigate the light-adjustable IOL's performance in correcting residual hyperopia. In a sample the same size as in the myopia study, with a mean age of 68 years and between 0.25 D and 2.00 D of residual hyperopia, 89% of the cohort achieved a postoperative refraction within  $\pm 0.25$  D of the target and 100% were within  $\pm 0.50$  D 6 months after lock-in. The mean rate of change was the same as in the myopia trial. Seventy-one percent of the cohort achieved a UDVA of 20/25, and no patient lost CDVA.

Finally, in a small prospective study of 5 patients with a mean age of 68 years and cylinder ranging from 1.25 to 1.75 D, Chayet et al.<sup>90</sup> looked at the light-adjustable IOL's performance in correcting

astigmatism. All patients achieved an SE refraction within  $\pm 0.25$  D of emmetropia and a UDVA of 20/25 or better at the 9-month follow-up; no patient lost CDVA.

The light-adjustable IOL has continued to be studied, most notably and recently by Brierley.<sup>91</sup> In 2013, Brierley published a retrospective study of the light-adjustable IOL's performance in post-refractive ametropic pseudophakic patients, a population considered by many to be the most challenging to manage. Thirty-four post-refractive eyes of 21 patients with a mean age of 63 years were identified from 437 eyes implanted with the Calhoun light-adjustable IOL; follow-up was limited to 1 week after irradiation. Prior to light-adjustable IOL irradiation, SE refractions ranged from +2.88 to  $-1.00$  D; after 1 to 3 adjustments and 2 lock-in treatments, SEs improved to  $+0.50$  to  $-0.65$  D, with 74% and 97% of the cohort achieving SE refractions within  $\pm 0.25$  D and  $\pm 0.50$  D of the target, respectively, 1 week after lock-in. The mean absolute error was  $0.19 \pm 0.2$  D, or about 60% more predictable than the best refractive outcome achieved in previous studies of monofocal IOLs in post-refractive patients. Excluding 14 eyes that were targeted to monovision, the UDVA also improved. Prior to adjustment, only 10% of the cohort had a UDVA of 20/20 or better and 30% had 20/25 or better; this improved to 65% and 95%, respectively.<sup>91</sup>

## COMPARING KERATOREFRACTIVE AND INTRAOCULAR APPROACHES FOR CORRECTING PSEUDOPHAKIC AMETROPIA

### Laser In Situ Keratomileusis Versus Piggyback Intraocular Lenses Versus Intraocular Lens Exchange

Only 2 studies have compared LASIK and IOL-based intraocular approaches in patients with residual refractive error after cataract surgery.<sup>42,92</sup> The first was a retrospective case series by Jin et al.<sup>42</sup> The study comprised 57 eyes of 48 patients whose mean age was about 61 years; the mean follow-up was about 22 months. In 28 eyes, LASIK was performed to correct pseudophakic ametropia; in the remaining eyes, IOL exchange (8 eyes) or piggyback IOL implantation (21 eyes) was performed. Comparisons were made between the LASIK group and the IOL-based group, which was heterogeneous in regard to the IOL-based surgery performed, and each group was subdivided into myopic eyes and hyperopic eyes.

No statistically significant differences were found in SE refraction between the LASIK and IOL-based groups, but separate analysis of astigmatism showed better results in the LASIK group ( $P = .02$ ). The preoperative mean SE was  $-1.62 \pm 0.80$  D in the myopic

LASIK subgroup and  $0.51 \pm 1.25$  D in the hyperopic LASIK subgroup; these parameters improved postoperatively to  $0.05 \pm 0.38$  D and  $0.19 \pm 0.35$  D, respectively. In the IOL group, the preoperative mean SE was  $-3.55 \pm 2.69$  D in the myopic subgroup and  $2.07 \pm 2.38$  D in the hyperopic subgroup; these errors improved to  $-0.20 \pm 0.50$  D and  $0.07 \pm 0.85$  D, respectively. In the myopic and hyperopic LASIK subgroups, no eye had a preoperative UDVA of 20/20 or better; postoperatively, this improved to 44% and 25%, respectively. The same was true of the IOL-based group preoperatively; postoperatively, the proportions remained unchanged in the myopic subgroup (zero) and improved to 18% in the hyperopic subgroup. Overall, a postoperative UDVA of 20/20 or better was more frequent in the LASIK group than in the IOL-based group (38% versus 11%). There was no statistically significant difference in postoperative CDVA between the 2 groups.<sup>42</sup>

The authors concluded that LASIK offers greater flexibility and a more specific endpoint, especially in correcting astigmatism, but acknowledged that IOL-based surgeries (ie, IOL exchange and piggyback IOLs) may be more effective in correcting large spherical errors. The authors recommended that the expectations of UDVA in pseudophakic ametropic patients having LASIK should be set lower than those in primary refractive patients, with a UDVA of 20/30 or 20/40 being more realistic than 20/20 due to the combined effects of age, subclinical changes in the cornea and retina, inherent IOL aberration, and LASIK-related aberrations.<sup>42</sup>

Fernández-Buenaga et al.<sup>92</sup> published the most recent study comparing the available modalities for correcting pseudophakic ametropia. Their retrospective study comprised 65 eyes of 54 patients with a mean age of 53 years and about 6 months of follow-up after an enhancement procedure for residual myopia or hyperopia. The authors compared IOL exchange, piggyback IOL implantation, and LASIK, but unlike Jin et al.,<sup>42</sup> they analyzed IOL exchange and piggyback IOL implantation separately. In addition to refractive error and visual acuity, outcome measures included the efficacy index (postoperative UDVA/preoperative CDVA [1.0 = perfect]) and safety index (postoperative CDVA/preoperative CDVA [1.0 = perfect]).

Laser in situ keratomileusis was better than both IOL exchange and piggyback IOL implantation in correcting astigmatic error ( $P = .001$  and  $P = .002$ , respectively), but the latter 2 intraocular procedures exhibited no statistically significant differences when compared with each other. Moreover, astigmatism worsened in the IOL-exchange group postoperatively, possibly because of the wound enlargement that is

**Table 1.** Summary of the reviewers' recommendations.

Type of Ametropia	Recommended Approach	Evidence*
All pseudophakic ametropias	Counsel patients to expect that their UDVA may be 20/30 to 20/40 rather than 20/20 due to the age-related decrease in efficacy and predictability of all refractive approaches.	36–42,47
Large spherical errors with or without astigmatism	Piggyback IOLs are safer, more effective, and more predictable than IOL exchange.	35,42,72
Small spherical errors with or without astigmatism	Laser vision correction with LASIK or PRK is safer, more effective, and more predictable than intraocular approaches.	42,44–47,92
Astigmatism	Laser vision correction with LASIK or PRK is safer, more effective, and more predictable than intraocular approaches.	42,48,92
Ametropia after implantation of a multifocal IOL	Laser vision correction with LASIK or PRK is safe, effective, and predictable. Wavefront-guided treatments are not superior to conventional treatments.	50–54

IOL = intraocular lens; LASIK = laser in situ keratomileusis; PRK = photorefractive keratectomy; UDVA = uncorrected distance visual acuity  
 \*Reference number of study

sometimes necessary to explant an IOL. Predictability was better in the LASIK group than in both intraocular surgery groups, but the the latter groups had a wider range of preoperative refractive errors. Intraocular lens exchange corrected a median of 6.12 D, piggyback IOL implantation corrected 1.50 D, and LASIK corrected 1.00 D. Intraocular lens exchange and piggyback IOL implantation were not superior to each other in the efficacy index, but LASIK was more efficacious than both intraocular options (median efficacy: LASIK 0.91 versus piggyback IOL implantation 0.75,  $P=.004$ ; LASIK 0.91 versus IOL exchange 0.58,  $P=.003$ ). Laser in situ keratomileusis was the most predictable treatment, with 93% of its cohort achieving an SE refraction within  $\pm 0.50$  D of the target compared with 65% and 31% in the piggyback and IOL exchange groups, respectively ( $P=.000$ ). There were no statistically significant differences in the safety index between the groups ( $P=.094$ ), but there was a higher frequency of losing 1 or more lines of CDVA in the IOL exchange and piggyback groups than in the LASIK group (29% versus 35% versus 7%;  $P=.048$ ).

Based on these data, Fernández-Buenaga et al. concluded that LASIK is superior to both IOL exchange and piggyback IOL implantation for the correction of pseudophakic ametropia, but they acknowledged that intraocular approaches may be the methods of choice in cases of “extreme” ametropia or when an excimer laser platform is unavailable.<sup>92</sup>

## DISCUSSION

It is challenging, if not impossible, to make reasonable comparisons between all the keratorefractive and intraocular modalities discussed above—LASIK,

PRK, IOL exchange, piggyback IOL implantation, and the light adjustable IOL—because no comparative data that encompasses all of them are available (Table 1).<sup>35–42,44–48,50–54,72,92</sup>

Laser in situ keratomileusis and PRK have been shown to be safe, effective, and predictable in patients with residual refractive error after cataract surgery, but neither has been shown to be superior to the other in this particular application. The U.S. Food and Drug Administration approved topography-guided excimer treatments in late 2013. International reports support that topography-guided LASIK or PRK may address some corneal irregularities contributing to ametropia and/or quality of vision in pseudophakic patients. Moreover, some authors have compared conventional excimer laser refractive surgery and wavefront-guided approaches in this patient population,<sup>51</sup> but statistical power has been insufficient to reach valid conclusions about which is better.

By contrast, 2 prospective, albeit small, studies compared the 2 most pervasive intraocular options for correcting pseudophakic ametropia. El Awady and Ghanem<sup>72</sup> together with Habot-Wilner et al.<sup>73</sup> found piggyback IOLs to yield better safety, efficacy, and predictability than intraocular IOL exchange. Their work validated earlier postulates made by Gayton et al.<sup>67</sup>

Likewise, only 2 retrospective studies have compared LASIK with IOL exchange and piggyback IOL implantation. The studies by Jin et al.<sup>42</sup> and Fernández-Buenaga et al.<sup>92</sup> suggest that LASIK is a more effective and predictable option than both intraocular options, particularly for astigmatism. However, both groups of authors acknowledge the role of IOL-based methods for the correction of larger spherical errors.

The light-adjustable IOL has yet to be compared with any of the refractive technologies that are

currently available. Its performance in large clinical trials remains of particular interest because of the technology's potential application to preventing dreaded refractive surprises in post-refractive-surgery patients. Were it shown to be safe in large clinical trials and as effective as it has been in early pilot studies,<sup>88–90</sup> the light-adjustable IOL might obviate the need for further invasive keratorefractive or intraocular procedures. It could make the conundrum of how to manage pseudophakic refractive error faced by so many surgeons in effect moot.

Until the light-adjustable IOL becomes an approved mainstream treatment modality, a reasonable approach to managing pseudophakic refractive error is to use LASIK or PRK for the correction of astigmatic error and small spherical errors and piggyback IOLs implanted in the sulcus for larger spherical errors. In all cases, perhaps the most important component of the treatment plan is counseling patients about their decreased likelihood of attaining emmetropia and 20/20 UDVA compared with younger, phakic patients, even after multiple invasive procedures.

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