

# 22

## LASER BLENDED VISION FOR PRESBYOPIA CORRECTION

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A tremendous increased interest in surgical presbyopic correction has recently been seen. The effective treatment of presbyopia, combined with any refractive error, has proven to be a significant challenge for refractive surgeons. Traditionally, the same principles as originally used for monovision contact lenses (see Chapters 14 and 16) have been applied to corneal refractive surgery.<sup>1</sup> However, many of the limitations found with monovision contact lenses also apply to monovision induced by refractive surgery, including loss of fusion and stereoacuity.<sup>2</sup> Multifocal corneal ablation profiles have been suggested as an alternative approach (see Chapter 21). However, although an overall improvement in visual acuity has been reported for both near and distance vision, the efficacy has remained relatively low,<sup>3</sup> and safety and quality of vision have been compromised.<sup>4</sup> A better solution, offering improved visual results and greater tolerance, is still required. In this chapter, we describe the use of corneal aspheric ablation profiles to increase depth of focus (DOF) in both eyes individually, combined with monovision, to treat presbyopia in emmetropic, myopic, and hyperopic patients.

### LASER BLENDED VISION

To better understand the way laser blended vision works, instead of viewing presbyopia as the inability to accommodate, it is helpful to consider it as a decrease in DOF. This decrease can be overcome, at least in part, by using an optimized ablation profile that increases the DOF of each eye without significantly compromising visual quality, contrast sensitivity, or night vision. The optimization is based on the patient's age, refraction, preoperative spherical aberration, and tolerance for anisometropia. Treatment is centered on the corneal vertex.

It is known that one way of increasing the DOF is to increase the amount of corneal spherical aberration independent of the zonal power shift that would be created by calculating the sphere for a particular zone in a cornea with spherical aberration.<sup>5</sup> Based on that knowledge, during early work, the initial aim was to increase DOF in the hope that it would be enough to provide clear vision from distance through intermediate to near, creating an eye that could see 20/20 at distance, could also see a computer screen, and could read at J1. However, it was soon realized that, although

spherical aberration could be increased, visual quality and contrast sensitivity were compromised by large amounts of spherical aberration.<sup>6,7</sup> This implied there was a tolerable maximum level of spherical aberration within which a beneficial increase in DOF could be obtained.<sup>7</sup> It was discovered that, with photopic pupil diameters, the DOF could be safely increased to 1.50 D for any starting refractive error. Given only this limited 1.50-D DOF, it would not be possible to achieve full distance and full near vision monocularly. Therefore, based on the time-tested concept of monovision, the nondominant eye was set to be slightly myopic so that the DOF of the predominantly distance (dominant) eye allowed it to see at distance down to intermediate, whereas the predominantly near (nondominant) eye would see in the near range and up to intermediate. In the intermediate region, both eyes had similar acuity, which is an optimal situation for stereopsis (see Chapter 14, Figure 14-1). Monovision depends on the inherent cortical processes of neuronal gating and blur-suppression (the ability for conscious attention to be directed to the specific area within the entire visual field of both eyes with the best image quality). This is in contrast to other attempts that try to induce a multifocal cornea with 2 distinct focal points to treat presbyopia.

A further component of laser blended vision is the increase in DOF produced by pupil constriction during accommodation, a component that persists even in eyes that have lost the ability to change crystalline lens power during the accommodative effort. The combination of controlled induced corneal aberrations and pupil constriction produces a significant increase in DOF for the retinal image, although the image is never perfect. Intraretinal and cortical processing and edge detection provide the final component contributing to laser blended vision; the retinal image, as modified by spherical aberration, is enhanced by central processing to yield the perception of clear and well-defined edges.

In principle, enhanced DOF can be achieved through the introduction of either positive corneal spherical aberration, in which corneal power increases with zonal diameter, or negative aberration, in which power decreases with distance from the corneal vertex.<sup>8</sup> Most patients have some positive spherical aberration before treatment. A standard myopic ablation induces positive spherical aberration, which will add to the pre-existing positive spherical aberration. The important thing is to control the induced spherical aberration to avoid increasing the spherical aberration

above the tolerance threshold, which can cause loss of contrast sensitivity and night-vision disturbances and can result in a topographic central island. To account for this, the nonlinear aspheric ablation profile includes a precompensation factor for the induction of spherical aberration. A standard hyperopic ablation induces negative spherical aberration, but it is unlikely that the spherical aberration will be increased above the tolerance threshold because most patients start with some positive spherical aberration, and the range of hyperopic treatments is smaller than the range of myopic treatments. In emmetropic patients, you cannot rely on the induction of spherical aberration by the ablation, and the spherical aberration component is increased, but this has an effect on the refractive accuracy. As emmetropic patients have high expectations and low tolerance to refractive inaccuracy, the best option is to somewhat increase the DOF and make sure that the monovision component is as accurate as possible. The ablation profiles, which also take age and preoperative spherical aberration into account, are referred to as nonlinear aspheric ablation profiles, as the spherical aberration component is governed by a nonlinear function.

A system based on these general principles has now been made commercially available as the Laser Blended Vision module of the CRS Master software (Carl Zeiss Meditec, Jena, Germany), the custom ablation profile software for the MEL 80 excimer laser.

## METHODS

To illustrate the quality of vision achievable with this approach, we present the outcomes for laser blended vision using the MEL 80 in 136 myopic (spherical equivalent [SEQ]  $\leq -8.50$  D),<sup>9</sup> 111 hyperopic (SEQ  $\leq +5.75$  D),<sup>10</sup> and 71 emmetropic patients (SEQ within  $\pm 0.88$  D).<sup>11</sup> All treatments were performed as bilateral simultaneous LASIK by a single surgeon (DZR). Inclusion criteria were medical suitability for LASIK, presbyopia with corrected distance visual acuity (CDVA) no worse than 20/25 in either eye, minimum 1-year follow-up, and tolerance of at least  $-0.75$  D of anisometropia.

The standard monovision protocol corrected the dominant eye to plano and the nondominant eye to  $-1.50$  D, irrespective of age. Patients were tested for tolerance with the intended refraction in place using a phoropter. The amount of cross-blurring reported by the patient during simulation was evaluated.

**TABLE 22-1. PREOPERATIVE DEMOGRAPHIC, POSTOPERATIVE SPHERICAL EQUIVALENT, AND SAFETY DATA FOR THREE POPULATIONS**

	MYOPIA	HYPEROPIA	EMMETROPIA
Patients (N)	136	111	71
Gender (M/F) (%)	43/57	34/66	45/55
Preop SEQ (D)	-3.58 ± 1.80 up to -8.50	+2.58 ± 1.17 up to +5.75	+0.18 ± 0.44 -0.88 to +0.88
Preop cylinder (D)	0.83 ± 0.64 up to 2.50	0.49 ± 0.50 up to 3.25	0.43 ± 0.32 up to 1.25
Median age (range) (y)	49 (43 to 63)	56 (44 to 66)	55 (44 to 65)
Preop CDVA 20/20 (logMAR 0) or better (%)	100	94	100
Preop CDVA 20/16 (logMAR -0.1) or better (%)	62	46	63
Postop SEQ within ±0.50 D (%)	92	79	89
Postop SEQ within ±1.00 D (%)	99	95	100
Lost 2 or more lines CDVA (%)	0.0	0.0	0.0
Lost 1 line CDVA (%)	8	17	11

CDVA, corrected distance visual acuity; SEQ, spherical equivalent refraction

Cross-blurring was used to describe a lack or reduction of interocular blur suppression. If the patient reported strong cross-blurring, the refraction of the nondominant eye was decreased in 0.25-D increments until a tolerable level was found. No contact lens monovision trials were performed. Patients were counseled to expect an adaptation period of up to 6 months. Ocular dominance was assessed using 4 methods: the “hole test,” pointing, a disposable camera, and shooting a rifle.

The surgical procedure was exactly the same as for standard LASIK treatments with the MEL80 and Hansatome microkeratome (Bausch & Lomb, Rochester, NY) or VisuMax femtosecond laser (Carl Zeiss Meditec). Both the flap and the ablation profile were centered on the corneal vertex for all patients, which closely approximates the visual axis.<sup>12</sup> The coaxially sighted corneal vertex was determined under the operating microscope of the laser by viewing through the surgeon’s contralateral eye. Centration on the corneal vertex was used so that the spherical

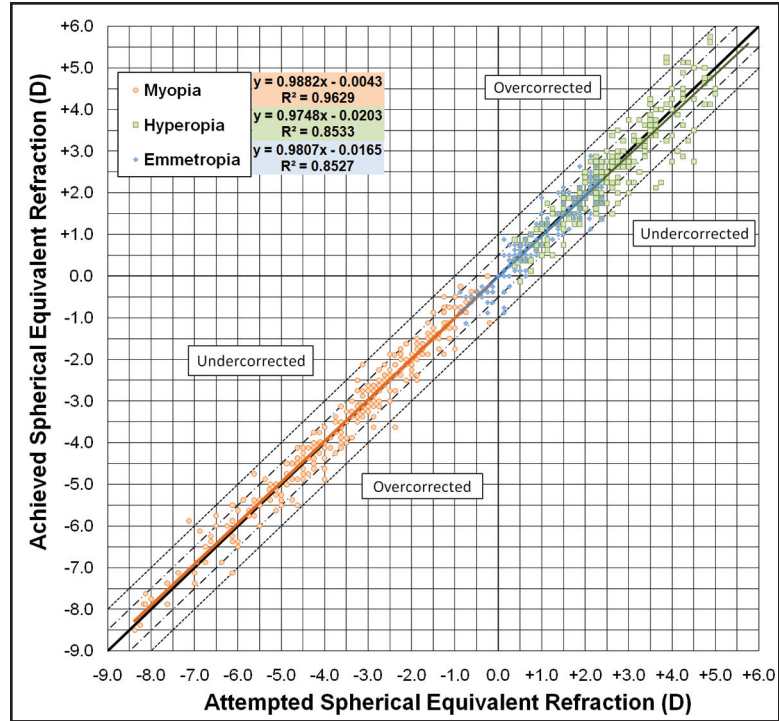
aberration induction was symmetrical around the visual axis rather than the line of sight.

Results are reported with 1-year follow-up and include all retreatments. The retreatment rate was 19% for the myopic population, 22% for the hyperopic population, and 13% for the emmetropic population. However, this included retreatments for patients that were already 20/20, or 20/25. If the threshold for performing a retreatment had been 20/32 or worse, the retreatment rate would have been 5% for the myopic population, 6% for the hyperopic population, and 4% for the emmetropic population.

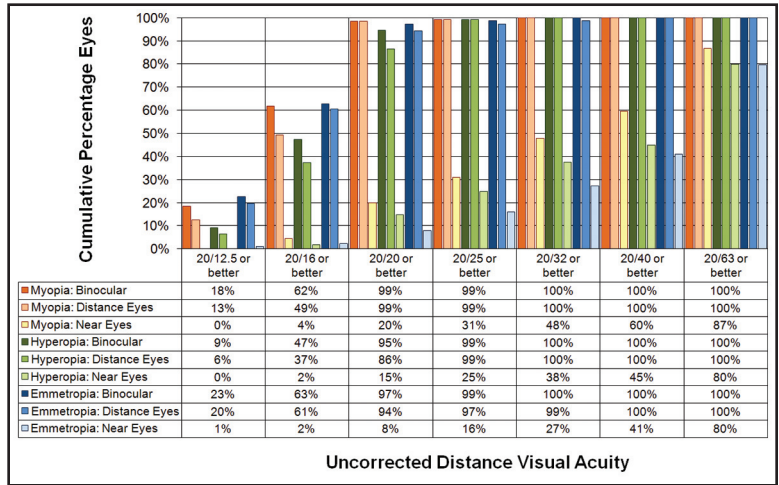
## RESULTS

Table 22-1 shows demographic and refractive statistics as well as a summary of postoperative accuracy and safety. Figure 22-1 shows the attempted versus achieved scatter plot for all 3 populations.

**Figure 22-1.** Scatter plot of attempted versus achieved spherical equivalent refraction for the myopic (orange, n=272), hyperopic (green, n=222), and emmetropic (blue, n=142) populations.



**Figure 22-2.** Uncorrected distance visual acuity grouped into binocular, distance, and near eyes for the 3 populations (136 myopic patients, 111 hyperopic patients, and 71 emmetropic patients).

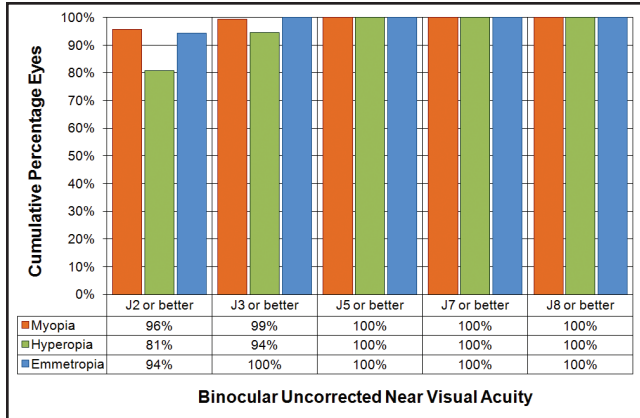


Figures 22-2 through 22-4 show the efficacy results reported as uncorrected distance visual acuity (UDVA) (Figure 22-2), uncorrected near visual acuity (UNVA) (Figure 22-3), and binocular uncorrected distance and near visual acuity for the myopic (Figure 22-4A), hyperopic (Figure 22-4B), and emmetropic (Figure 22-4C) populations.

The distance vision of the “near” eye was better than expected, given the -1.50-D residual refraction, and approximately 80% of eyes were 20/63 or better (Figure 22-2). For a typical eye, 0.25 D of myopic defocus resulted in the loss of 1 logMAR line of UDVA. Therefore, an untreated eye with myopia of

-1.50 D would be expected to achieve a UDVA of only 20/80, which is more than 2 lines worse than the mean UDVA of 20/39 for the 3 populations. The improvement is attributable to the effect of the induced spherical aberration in increasing the monocular DOFs.

To demonstrate the effect of neural summation, when the relatively blurred nondominant eye was added for binocular distance vision, the percentage of all patients with distance vision of 20/20 or better increased from 93% monocularly to 97% binocularly. In other words, the addition of a blurred nondominant eye to the distance eye resulted in even better distance vision, unlike contact lens monovision (for



**Figure 22-3.** Binocular uncorrected near visual acuity for 3 populations (136 myopic patients, 111 hyperopic patients, and 71 emmetropic patients).

adds greater than 1.50 D) in which there is reduction of distance vision obtained monocularly when the nondominant blurred eye is added.

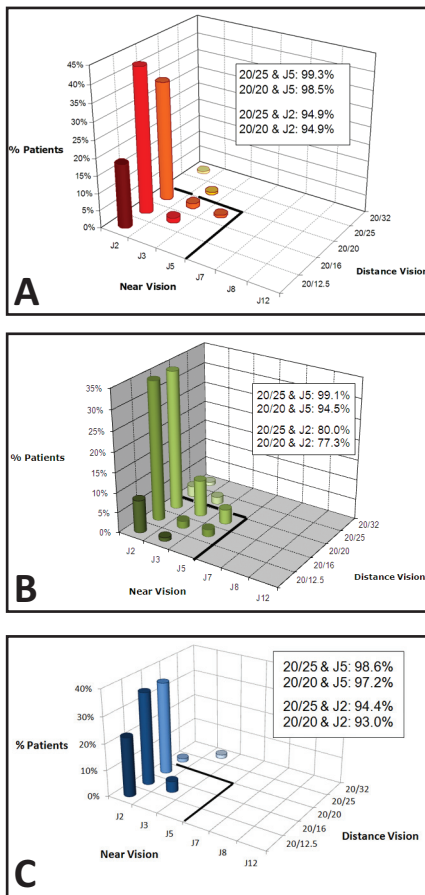
The near efficacy outcomes were also better than might be expected (see Figure 22-3). A person 55 years of age would be expected to need a near spectacle addition in the range of -1.50 to -2.25 D, whereas excellent near vision was achieved with -1.50 D anisometropia for these populations.

Figure 22-4 shows that visual acuity at distance and near lay within the zone defined by the heavy lines, ie, better than or equal to 20/20 at distance and J5 at near for most patients.

Safety, in terms of CDVA and contrast sensitivity, was the same as for standard LASIK with the MEL80. Mean postoperative mesopic contrast sensitivity was either the same or slightly better than preoperatively at 3, 6, 12, or 18 cpd for all 3 populations using the CSV-1000.

Monovision studies have demonstrated that, in a proportion of monovision patients, stereoacuity is lost, and after it is lost, it does not come back. We were somewhat concerned that we would induce this problem in our patients. However, the results of our stereoacuity studies (using a Rand-dot stereo test) confirmed that while postoperative uncorrected stereoacuity was lower than preoperative near-corrected stereoacuity, a functional level of stereoacuity was maintained postoperatively; 68% of patients had stereoacuity of 100 arc secs or better and 93% had stereoacuity of 200 arc secs or better. The study also found that near-correction restored preoperative near-corrected stereoacuity in the majority of patients; 5% of patients with 40 to 50 arc secs of stereoacuity preoperatively showed a 1-patch decrease in best-corrected stereoacuity, whereas 100% of patients initially 60 arc secs or less showed no loss at all.

As yet, no systematic testing of vision at mesopic and scotopic levels has been carried out.



**Figure 22-4.** Combined binocular uncorrected distance visual acuity and uncorrected near visual acuity for (A) the myopic population (136 patients), (B) the hyperopic population (111 patients), and (C) the emmetropic population (71 patients).

## SUMMARY

The combination of monovision with increased monocular DOF through appropriate nonlinear aspheric corneal ablation profiles improves visual outcomes substantially in comparison with the conventional monovision approach. Trials show that laser blended vision with the MEL80 and CRS-Master is effective with presbyopic patients having refractive errors between +5.75 and -9.00 D, including

emmetropic presbyopes. With the safety advantages of modern femtosecond LASIK, the rapid bilateral surgical procedure time, and the recovery period of a few hours, patient satisfaction is extremely high. Laser blended vision benefits from immediate advantages of LASIK, with the ability to offer easy retreatment of vision, if necessary in the future.

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