Three Multizone Photorefractive Keratectomy Algorithms for Myopia

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ABSTRACT

OBJECTIVE: To compare the efficacy and complications of three different excimer laser algorithms for multizone photorefractive and photoastigmatic keratectomy.

METHODS: Three different software algorithms were applied to treat myopia and myopic astigmatism with the VISX 20/20 excimer laser. Each algorithm had a maximum ablation zone of 6 mm but differed in the number of zones employed, the proportion of the total treatment allocated to each ablation zone, and the treatment of astigmatism. The Melbourne multizone technique equally divided myopia correction into a maximum of three ablation zones. The Pop multizone technique biased myopia treatment into the smaller diameter zones to a maximum of six ablation zones, with one central island pretreatment. The Alpins multizone technique equally divided myopia treatment through all zones up to a maximum of six, with one central island pretreatment.

RESULTS: A total of 585 patients (780 eyes) were treated and 625 eyes (80%) were followed for more than 6 months. The mean baseline spherical equivalent refractive error was -5.63 D (-1.00 to -19.50 D). Between 71 and 79% of eyes were treated for astigmatism. There was no statistically significant difference in baseline refractive error or other characteristics among the three groups. At 6 months, the Alpins multizone algorithm had more eyes with a refractive error within ±1.00 D of emmetropia (p=0.01) and more within ±2.00 D of emmetropia (p<0.01). This new algorithm produced more eyes with an uncorrected visual acuity of 20/20 or better at 6 months (p<0.01). When multiple logistic regression was used to correct for any differences in baseline myopia among the three groups, this algorithm also had a higher odds ratio for achieving 20/20 or better uncorrected visual acuity (OR=1.58).

CONCLUSION: At 6 months, all three algorithms were effective in the reduction of myopia. Significantly better visual acuity and refractive results were achieved with the Alpins multizone algorithm that spread the total treatment over a larger number of ablation zones, with an equal number of diopters of treatment in each zone. [*J Refract Surg* 1997;13:535-544]

Numerous reports in the last few years have shown that photorefractive keratectomy (PRK) can give good results in the correction of low myopia and myopic astigmatism.[1-9] However, less satisfactory results are seen when attempting the deeper photoablations required to correct moderate and high myopia.[10-12] To improve the results of PRK, especially for higher corrections, a number of investigators have studied the use of multizone PRK techniques.[13-20] These multizone techniques enable an increase in the effective ablation zone while minimizing the central ablation depth. Theoretically, a multizone technique should also result in a more gradual peripheral transition zone and potentially reduce the incidence of adverse corneal wound healing complications.

Multizone techniques have been used to try and improve the results and reduce the incidence of wound healing-related complications of PRK in high myopia.[14,18,20] However, these studies did not show any benefit for a multizone approach for treating high myopia. Other studies have shown that multi-

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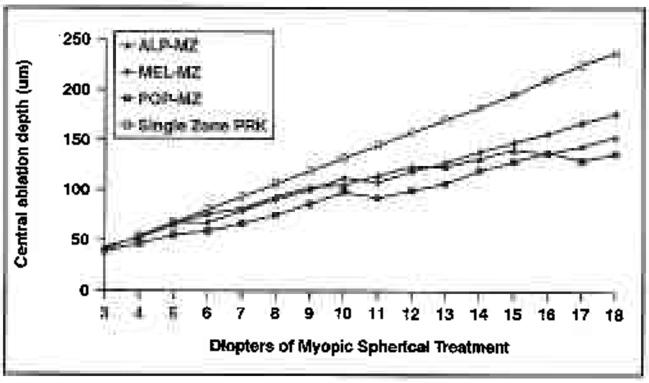

Figure 1: Total central ablation depth for spherical treatments between -3.00 and -18.00 D for three multizone PRK and one single zone PRK treatment (ALP = Alpins; MEL = Melbourne; POP = Pop).

zone techniques produce good results in the treatment of low and moderate myopia.[13,15-17,19] A number of multizone PRK algorithms are currently in use. These differ in the diameter of ablation zones used and the proportion of the total treatment at each ablation zone. We compare three different multizone PRK algorithms for the treatment of low to extreme myopia and myopic astigmatism.

PATIENTS AND METHODS

Patient Selection

Patients eligible for inclusion in this study were required to be at least 18 years of age, have stable myopia or myopic astigmatism with less than 0.50 diopters (D) change in the previous 12 months and have a spectacle-corrected visual acuity of 20/40 or better (20/60 if greater than -6.00 D). Stability was determined on the basis of subjective manifest and cycloplegic spherical equivalent refraction. Wearers of soft contact lenses were assessed 1 week after lens removal and hard lens wearers were required to discontinue their lens wear for 1 month and demonstrate stability of refraction and topography for a further month before treatment. Patients were excluded from this study if they had a history of ocular trauma or surgery, keratoconus, ocular or significant systemic disease, or if they were receiving therapy likely to interfere with corneal wound healing. A commitment was also required from the patient to be available for follow-up for at least 1 year after the treatment.

Patients' treated eyes were allocated into one of the three groups, each following a common protocol. Between October 1994 and April 1995, all patients were also allocated to the Melbourne Excimer Laser Multizone PRK group. Subsequent to this date patients were also allocated to one of two other multizone treatment groups in a non-randomized, sequential manner, according to surgeon's preference. Thirty surgeons treated 316 eyes in the Melbourne multizone PRK group, six surgeons treated 94 eyes in the Pop multizone PRK[19] group, and 18 surgeons treated 370 eyes in the Alpins multizone PRK group. There were 21 surgeons who treated eyes in two groups and 33 surgeons who treated eyes in one or more of the three groups. There was substantial uniformity of prevailing operating room atmospheric conditions and staff. Minor variations in technique, such as means of epithelial removal, type of fixation, use of bandage contact lens or pressure pads did not significantly affect outcomes.[9]

The study protocol was approved by the Human Research Ethics Committee of the Royal Victorian Eye and Ear Hospital, East Melbourne, Victoria, Australia and written consent was provided by each patient.

The total central ablation depth for each of the three algorithms at spherical corrections from -3.00 to -18.00 D is shown by Figure 1. Note that the pretreatment at the 2.5 mm ablation zone increased the central ablation depth in the Pop and Alpins multizone PRK algorithms. This was evident for corrections of -5.00 D or less, where the central ablation depths were greater than a 6 mm single zone PRK ablation.

Although three different treatment algorithms were used (Tables 1-3), other surgical parameters were standardized by protocols that all surgeons followed and that have previously been shown not to influence patient outcome.[9]

Epithelial removal was performed mechanically in all eyes, using either a blunt spatula or a dulled blade.[9] During most procedures, the patient maintained self fixation of the eye on the target light. In some instances, forceps were used to immobilize the eye. A vacuum aspirator was used to remove ablated debris.

Immediately following the procedure, the cornea was rehydrated with one drop of indomethacin 1% and one drop of 2% homatropine hydrobromide and the speculum was removed. Chloramphenicol sodium succinate 1% or a combination of 1% chloramphenicol and 0.5% hydrocortisone acetate ointment was applied prior to the application of an eye pad. Treatment with topical antibiotics (chloramphenicol) was continued until re-epithelialization was complete. Postoperatively, 0.1% fluorometholone was used four times daily for the first week, three times daily for the second, twice daily for the third, once daily for the fourth, and then ceased.

Table 1
Melbourne Excimer Laser Group Multizone PRK Treatment Algorithm

Ablation Zone (mm)	Diopters at Corneal Plane															
	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14	-15	-16	-17	-18
4.5	-	-	-	-	-	-	-	-	-3.67	-4.00	-4.33	-4.67	-5.00	-5.33	-5.67	-6.00
5.0	-	-	-	-3.00	-3.50	-4.00	-4.50	-5.00	-3.67	-4.00	-4.33	-4.67	-5.00	-5.33	-5.67	-6.00
6.0	-3.00	-4.00	-5.00	-3.00	-3.50	-4.00	-4.50	-5.00	-3.67	-4.00	-4.33	-4.67	-5.00	-5.33	-5.67	-6.00

Table 2
Pop Multizone PRK Treatment Algorithm

Ablation Zone (mm)	Diopters at Corneal Plane															
	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14	-15	-16	-17	-18
2.5 (pre treatment)	-1.50	-1.50	-1.50	-1.50	-1.50	-1.50	-1.50	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-4.00	-4.00
4.0	-	-	-	-	-	-	-	-	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00	-4.00
4.5	-	-	-	-3.00	-4.00	-4.00	-4.00	-4.00	-2.00	-3.00	-4.00	-4.00	-4.00	-4.00	-3.00	-4.00
5.0	-	-2.00	-3.00	-1.00	-1.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-3.00	-4.00	-2.00	-2.00
5.5	-2.00	-1.00	-1.00	-1.00	-1.00	-1.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00	-2.00
6.0	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-2.00	-1.00	-1.00	-1.00	-2.00	-2.00	-2.00	-2.00	-2.00

Table 3
Alpins Multizone (ALP-MZ) PRK Treatment Algorithum

Ablation Zone (mm)	Diopters at Corneal Plane															
	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14	-15	-16	-17	-18
2.5 (pre treatment)	-1.50	-1.50	-1.50	-1.50	-1.50	-1.50	-1.50	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
3.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-2.67	-2.83	-3.00
4.0	-	-	-	-	-	-	-	-	-	-	-2.60	-2.80	-3.00	-2.67	-2.83	-3.00
4.5	-	-	-	-	-	-	-	-2.50	-2.75	-3.00	-2.60	-2.80	-3.00	-2.67	-2.83	-3.00
5.0	-	-	-	-	-2.33	-2.67	-3.00	-2.50	-2.75	-3.00	-2.60	-2.80	-3.00	-2.67	-2.83	-3.00
5.5	-	-2.00	-2.50	-3.00	-2.33	-2.67	-3.00	-2.50	-2.75	-3.00	-2.60	-2.80	-3.00	-2.67	-2.83	-3.00
6.0	-3.00	-2.00	-2.50	-3.00	-2.33	-2.67	-3.00	-2.50	-2.75	-3.00	-2.60	-2.80	-3.00	-2.67	-2.83	-3.00

Excimer Laser Treatment

All patients were treated with the same centrally located excimer laser (VISX 20/20, VISX Inc., Sunnyvale, Calif) according to a common protocol by one of 33 surgeons. The laser was operated at a frequency of 5 Hz and a fluence of 160 mJ/cm^2 without nitrogen blowing. Three different treatment algorithms, as described, were used to determine the treatment of spherical and cylindrical refractive error.

All three treatment algorithms were multizone indicating two or more treatments were applied at more than one ablation zone diameter. The inclusion of the term multipass with multizone means that after completion of each ablation zone treatment, at least one complete pass was commenced and completed for each successive zone. For the purposes of brevity we refer to the technique simply as multizone.

The Melbourne multizone PRK algorithm used the least number of ablation zones and split the treatment equally between the zones used with only one pass per zone (Table 1). No pre-treatment for central islands was performed. The treatment of

Table 4
Baseline Characteristics of 780 Eyes (%) According to Multizone PRK Algorithm

	Melbourne	Pop	Alpins
Number of eyes (%) in each group	316 (41)	94 (12)	370 (47)
Baseline myopia (D)			
Low (-5.00 or less)	173 (55)	45 (48)	226 (61)
High (-5.01 to -10.00)	125 (39)	41 (44)	132 (36)
Extreme (over -10.00)	18 (6)	8 (8)	12 (3)
Astigmatism correction	220 (70)	74 (79)	261 (71)
Bandage contact lens used	33 (10)	62 (66)	57 (15)
Mean age (yrs)	38	37	38
Male	173 (55)	34 (36)	158 (43)
Number of surgeons	30	6 18	

astigmatism was performed at the 6.0 mm ablation zone, up to a maximum of 80% of the spherical correction. Higher astigmatic corrections were divided equally between the 5.0 and 6.0 mm ablation zones. A coefficient of 1.20 was also used to adjust for system undercorrection of astigmatism.[21] If the astigmatism zones were maximally utilized at 80%, then the cylinder could be treated up to 100% of the sphere. If the cylinder exceeded the magnitude of the sphere, then the excess was treated sequentially by the plano-cylindrical mode. This remaining cylinder was treated in a 6.0 x 6.0 mm or 4.5 x 6.00 mm zone without any associated spherical correction.

The Pop multizone PRK algorithm[19] used up to six ablation zones, had a pre-treatment for central islands, and was biased toward more treatment in the lower diameter ablation zones with the facility for multiple passes per zone (Table 2). The treatment of astigmatism was performed at the 5 mm ablation zone. To compensate for system undercorrection, a correction factor of 1.25 + 0.50 D was used (approximately net 1.33 D). There was a maximum of 2.25 D for single zone cylindrical correction after which the cylindrical correction was split into two passes at the 5.0 mm clear zone.

The Alpins multizone PRK algorithm was devised by the first author. It was similar to the Pop multizone PRK algorithm in using a maximum of six ablation zones and pre-treatment for central island prevention, but split the dioptric treatment equally among each of the ablation zones with only one pass per zone (Table 3). The treatment of astigmatism was preferentially placed in the 6.0 mm ablation zone. If the cylinder exceeded 80% of the sphere, then the astigmatism treatment was split equally between one to three additional zones (6.0, 5.5 and 5.0 mm).

The total central ablation depth for each of the three algorithms at spherical corrections from -3.00 to -18.00 D is shown by Figure 1. Note that the pre-treatment at the 2.5 mm ablation zone increased the central ablation depth in the Pop and Alpins multizone PRK algorithms. This was evident for corrections of -5.00 D or less, where the central ablation depths were greater than a 6 mm single zone PRK ablation.

Although three different treatment algorithms were used, other surgical parameters were standardized by protocols that all surgeons followed and that have previously been shown not to influence patient outcome.[9]

Epithelial removal was performed mechanically in all eyes, using either a blunt spatula or a dulled blade.[9] During most procedures, the patient maintained self fixation of the eye on the target light. In some instances, forceps were used to immobilize the eye. A vacuum aspirator was used to remove ablated debris.

Immediately following the procedure, the cornea was rehydrated with one drop of indomethacin 1% and one drop of 2% homatropine hydrobromide and the speculum was removed. Chloramphenicol sodium succinate 1% or a combination of 1% chloramphenicol and 0.5% hydrocortisone acetate ointment was applied before application of an eye pad. Treatment with topical antibiotics (chloramphenicol) was continued until re-epithelialization was complete. Postoperatively, 0.1% fluorometholone was used four times daily for the first week, three times daily for the second week, twice daily for the third week, once daily during the fourth week, and after that time therapy was ceased.

Examination Protocol

All patients were followed-up according to a standardized examination protocol.[22] Baseline data regarding ocular history, medications, and contact lens wear were collected and videokeratography

Table 5
Attendance at Follow-up (No. Eyes) for Each Algorithm

		Time after Surgery (Mos)		
	Before PRK	1 mo (% eyes)	3 mos (% eyes)	6 mos (% eyes)
Melbourne multizone	316	305 (97)	285 (90)	253 (80)
Pop multizone	94	87 (94)	81 (86)	75 (80)
Alpins multizone	370	352 (95)	323 (87)	297 (80)
Total eyes	780	744	689	625

Table 6
Number of Adverse Reactions Reported for Each Algorithm

	Melbourne	Pop	Alpins
Raised intraocular pressure	3	0	1
Monocular diplopia	2	0	0
Glare/halos	1	1	0
Filamentary keratitis	0	1	0
Infectious keratitis	0	0	0
Ulcerative keratitis	0	0	0
Iritis	0	0	0
Accommodation defect	0	0	0
Reaction to drugs	0	0	0
Number of eyes with adverse reactions	6	2	1
Total number of eyes	316	94	370

X^2 not significant

(Topographic Modeling System, TMS-1, Computed Anatomy Inc., New York, NY) was performed routinely. The following factors were measured before PRK and at 1, 3, and 6 months after surgery: uncorrected and spectacle-corrected visual acuity (LogMAR), subjective manifest refraction, cycloplegic refraction (preoperatively), keratometry and slit-lamp examination with assessment of corneal clarity. Corneal haze was graded clinically with the assistance of standard photographs according to a subjective scale.[23,24]

The presence of glare or halos was recorded if the patient reported the symptoms. It was not considered an adverse reaction unless it persisted beyond 3 months.

Statistical Methods

Data were entered into a personal computer database and statistical analyses were performed using commercially available software (SPSS). Differences among treatment groups were analyzed with Chi-square for categorical data. Multiple logistic regression was employed to control for the effect of preoperative myopia on refractive and visual outcomes.

RESULTS

A total of 780 multizone PRK procedures were enrolled in the study (Table 4). Between 70 and 79% of eyes had an excimer laser treatment for astigmatism. Six hundred and twenty-five eyes (80.1%) were available for 6 month examination (Table 5). Within the first 6 months of follow-up there were a few mild complications (Table 6). No infectious keratitis, ulcerative keratitis, iritis, accommodation defect, or reaction to drugs were observed. There were no significant differences among the three treatment algorithms in the rate of adverse reactions.

The Alpins multizone PRK algorithm produced the most accurate refractive outcome (Fig 2). There was a significant difference among the percentages of eyes achieving a refraction of within ±1.00 D of emmetropia ($X^2 = 9.17, p = 0.01$) and for ± 2.00 D ($X^2 > 5000, p < 0.01$). There were no statistically significant differences for the other refractive criteria. The Alpins multizone PRK algorithm also showed a

Table 7
Astigmatism at 6 Months after PRK for Each Algorithm

	Geometric Mean (% Astigmatism Corrected)	95% Confidence Interval (% Astigmatism Corrected)	Mean Angle of Error ± SEM*
Melbourne Multizone			
Sphere treated in PRK mode sequentially with cylinder treated in plano-cylindrical mode, N=17	79.2	72.9 to 86.1	5.60 ± 6.1
Sphere and cylinder treated concurrently in elliptical mode, N=159	92.4	84.0 to 101.7	2.60 ± 2.3
Pop Multizone			
Sphere treated in PRK mode sequentially with cylinder treated in plano-cylindrical mode, N=2	98.1	54.3 to 176.8	-8.00 ± 12.0
Sphere and cylinder treated concurrently in elliptical mode, N=58	96.7	77.0 to 121.5	-1.30 ± 3.7
Alpins Multizone			
Sphere treated in PRK mode sequentially with cylinder treated in plano-cylindrical mode, N=28	86.6	75.4 to 99.6	4.70 ± 3.6
Sphere and cylinder treated concurrently in elliptical mode, N=181	94.6	85.7 to 104.5	0.01 ± 1.7

* *Standard error of the mean*

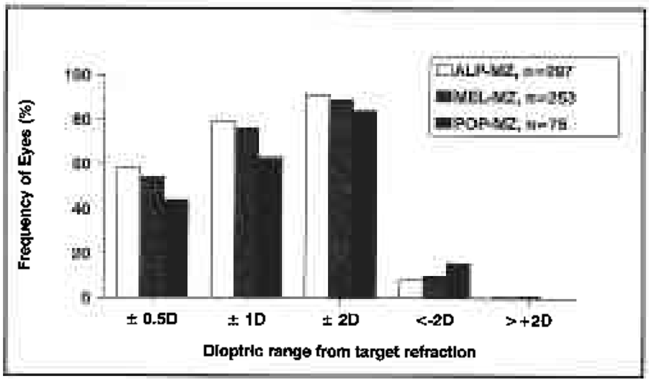

Figure 2: Accuracy of refractive outcome at 6 months after multizone PRK using three algorithms (ALP = Alpins; MEL = Melbourne; POP = Pop).

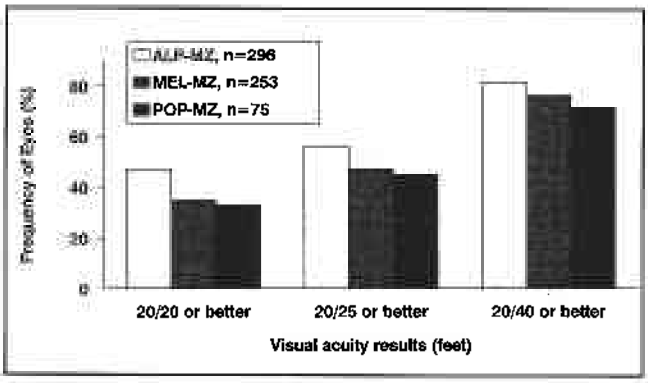

Figure 3: Uncorrected visual acuity at 6 months after multizone PRK using three algorithms (ALP = Alpins; MEL = Melbourne; POP = Pop).

trend toward less undercorrection, although this was not statistically significant. There were no differences among the three treatment groups in the rate of overcorrection.

The Alpins multizone PRK algorithm produced the best uncorrected visual acuity results with 47% (139 of 296 eyes) achieving a visual acuity of 20/20 or better and 81% (240 of 296 eyes) 20/40 or better (Fig 3). In the Melbourne multizone PRK treatment group, 35% (89 of 253 eyes) achieved a visual acuity of 20/20 or better and 76% (192 of 253 eyes) achieved 20/40 or better. In the Pop multizone PRK treatment group the corresponding figures were 33% (25 of 75 eyes) and 71% (53 of 75 eyes). There was a statistically significant difference in the percentage of eyes that achieved a visual acuity of

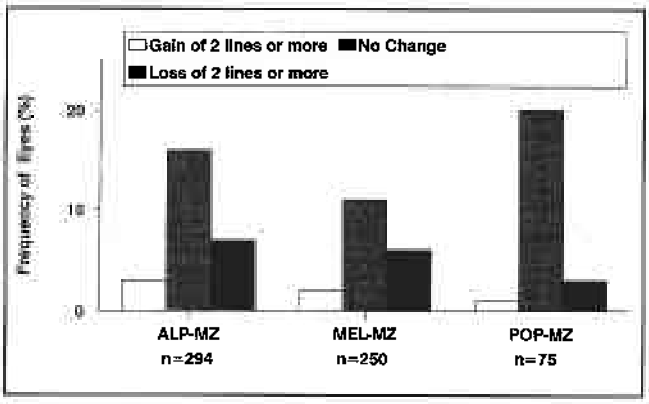

Figure 4: Change in spectacle-corrected visual acuity at 6 months after multizone PRK using three algorithms (ALP = Alpins; MEL = Melbourne; POP = Pop).

Table 8
Multiple Logistic Regression Analysis of Uncorrected Visual Acuity at 6 Months after PRK for Each Algorithm

20/20 or Better	No. Eyes	p Values		Odds Ratio
Melbourne multizone	253			1.00
		0.50		
Pop multizone	75		0.02	1.24
		0.76		
Alpins multizone	297			1.58
20/25 or Better				
Melbourne multizone	253			1.00
		0.71		
Pop multizone	75		0.32	1.12
		0.98		
Alpins multizone	297			1.22
20/40 or Better				
Melbourne multizone	253			1.00
		0.53		
Pop multizone	75		0.56	0.82
		0.30		
Alpins multizone	297			1.14

Table 9
Multiple Logistic Regression Analysis of Accuracy of Refractive Outcome at 6 Months after PRK for Each Algorithm

Within ±0.50 D	No. Eyes	p Values		Odds Ratio
Melbourne multizone	253			1.00
		0.29		
Pop multizone	75		0.85	0.75
		0.21		
Alpins multizone	297			1.03
Within ±1.00 D				
Melbourne multizone	253			1.00
		0.04		
Pop multizone	75		0.92	0.55
		0.04		
Alpins multizone	297			1.02

20/20 or better among the treatment groups ($X^2 = 10.2$, $p < 0.01$). There were no statistically significant differences among the three multizone algorithms for uncorrected visual acuity better than or equal to 20/25 or 20/40.

The percentage of eyes that lost or gained two lines of spectacle-corrected visual acuity did not differ significantly among the three treatment algorithms; the Pop multizone group showed the lowest incidence of either gain or loss of spectacle-corrected visual acuity (Fig 4).

There was no difference among the grades of corneal haze at any time (1, 3, or 6 months) after treatment (Fig 5).

Four hundred and forty-five (71.2%) of the 625 eyes followed for 6 months had excimer laser treatment for astigmatism. The remaining 180 eyes had straight spherical myopic corrections. Of the 445

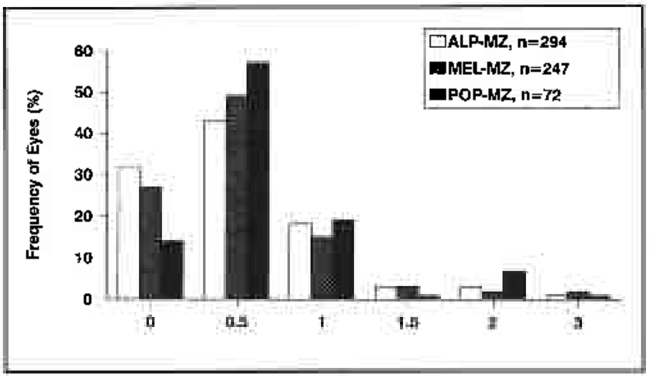

Figure 5: Corneal haze at 6 months after multizone PRK using three algorithms (ALP = Alpins; MEL = Melbourne; POP = Pop).

eyes, 89.4% (398 eyes) underwent photoastigmatic refractive keratectomy using the elliptical program, and 10.6% (47 eyes) underwent sequential spherical and plano-cylindrical correction (Table 7). There was no statistically significant difference in the amount of astigmatism corrected between the two methods. In eyes undergoing photoastigmatic refractive keratectomy, the Melbourne and Alpins algorithms corrected about 90% of the mean astigmatism and the Pop just over 80%. There was no difference in the mean angle of error among the three treatment groups.

In order to take into account any differences in the level of baseline myopia, we performed a multiple logistic regression analysis. The Melbourne multizone group was defined as the reference group and the other two groups were compared to it. The Alpins multizone PRK algorithm was 1.6 times as likely to achieve 20/20 visual acuity as the reference group (Table 8), but no more likely to be within ±0.50 D or ±1.00 D of emmetropia (Table 9). There was no statistically significant difference between the Pop multizone group and the reference group in terms of uncorrected visual acuity at 6 months (Table 8), but the Pop group was nearly half as likely to be within ±1.00 D of emmetropia (Table 9).

DISCUSSION

The introduction of multizone photorefractive and photoastigmatic refractive keratectomy techniques has provided the refractive surgeon, using a broad beam excimer laser, with several potential advantages over a conventional single zone ablation technique.

First, there is a reduction in central ablation depth with multizone PRK compared to single zone PRK. This is particularly seen with higher myopic corrections and may be an advantage as it reduces the total amount of tissue ablated in higher myopic corrections. However, this needs to be weighed against any potential reduction in the effective ablation zone. In the Pop multizone PRK treatment algorithm, the treatment is preferentially concentrated in the smaller ablation zones. While this reduces central ablation depth, it may also produce a smaller effective optical zone.

It is commonly suggested that multiple passes with the excimer laser beam may also result in a smoother ablation surface in the corneal stroma and facilitate a less aggressive corneal wound healing response. One would intuitively consider this smoothing to be a logical consequence of fractionating the dioptric treatment delivery, however, there is to date no firm scientific evidence to support this conclusion. Pop[19] has shown a tendency for there to be less corneal haze with multizone PRK compared to single zone treatment[19] and this may be a direct consequence of a less aggressive corneal wound healing response following multizone PRK.

Other potential advantages of multiple passes include better centration by stopping treatment between each zone and re-centering. However, it could be argued that consistent centration would be compromised because of difficulty experienced by the patient, with fixation becoming more difficult once the ablation has commenced and the duration of treatment is extended. A further advantage may result from the pause between each treatment zone, reducing the build-up of surface temperature[25] and hence decrease the likelihood of thermal damage to the corneal stroma.

Previous multizone studies have shown good results when treating low to moderate myopia[16,19] but poor results in high and extreme myopia.[14,18,20] Poorer results in the treatment of high myopia with multizone PRK are consistent with earlier studies using conventional single zone PRK treatments[2,24,26] with high rates of regression, corneal haze, and loss of spectacle-corrected visual acuity. In one study by Rajendran[20], 25% of eyes treated for high myopia developed dense corneal scars and required retreatment.

Earlier investigators proposed that poorer results in higher myopia were related to the central ablation depth[26-28] as the more tissue removed in the center of the cornea, the greater the amount of adverse corneal wound healing. Multizone treatment does have the advantage of ablating less depth of the cornea (Fig 1). However, other subsequent studies have demonstrated that central ablation depth is not directly correlated with adverse corneal wound healing and poorer refractive and visual outcomes. For the same dioptric treatment, larger ablation zones have greater central ablation depths than smaller ablation zones. Despite this, PRK treatment with a 5 mm ablation zone has a better visual acuity and refractive result than a 4 mm ablation zone[29] and PRK with a 6 mm zone gives better results than a 5 mm zone.[30,31] Therefore, the central ablation depth is not the major factor that determines adverse corneal wound healing events after PRK. Other factors such as the rate of change in curvature of the ablated surface between the treated and untreated cornea are also likely to be important.

Our study shows that the Alpins multizone PRK algorithm produced the best refractive and visual acuity results and the Pop multizone PRK algorithm the poorer results. Even taking into account any differences in preoperative refraction with multiple logistic regression, there were more patients who achieved a visual acuity of 20/20 or better in the Alpins multizone PRK group. There are some reasons why this may be so. A greater number of passes with the excimer laser could be expected to result in the smoother ablation surface. Any abnormalities of beam homogeneity in a broad-beam excimer laser, such as the VISX 20/20, might be smoothed out over the multiple passes. If a smoother ablated surface was achieved, it should facilitate a less aggressive corneal wound healing response. It is thought that the less aggressive the corneal wound healing response incited by the treatment, the less likely the cornea is to develop epithelial hyperplasia and deposition of subepithelial extracellular matrix material. Subepithelial extracellular matrix material deposition is the clinical correlation of corneal haze.[32] However, these conclusions are conjectural and are without published evidence to support them.

The analysis of astigmatism results among the three multizone PRK algorithms shows some important features. The Melbourne and Alpins multizone PRK algorithms were similar, with astigmatism primarily treated in the 6.0 mm zone with some sharing in the 5.5 mm zone (Alpins multizone PRK) or the 5.0 mm zone (Melbourne multizone PRK) if required. An adjustment factor of 1.2 was used for both to achieve a full correction of astigmatism where undercorrection by the device was prevalent.[21] In contrast, the Pop multizone PRK algorithm treats the astigmatism in the 5 mm zone with a 1.33 adjustment factor. The Alpins and Melbourne multizone PRK algorithms corrected on average about 90% of the pre-existing refractive cylinder. The Pop multizone PRK algorithm corrected just over 80% of the refractive astigmatism, despite the higher adjustment factor. This strongly suggests that astigmatism should be treated in the larger 6.0 mm ablation zone rather than in the 5.0 mm ablation zone. Treatment in the larger ablation zone should result in a larger ablated area and a more gradual change in corneal curvature than astigmatism treatment with the smaller ablation zone. We would expect a more gradual peripheral change in corneal curvature to be less likely to stimulate an aggressive corneal wound healing response.

The best results following PRK and photoastigmatic refractive keratectomy are likely to be seen with the algorithm that results in both the smoothest ablation surface in the corneal stroma and the most gradual changes in corneal curvature. In this study, the Alpins and Pop multizone PRK algorithms used the greatest number of ablation zones and hence should theoretically result in a more graduated ablation of stromal surface than the Melbourne multizone PRK algorithm. However, by concentrating the treatment preferentially in the smaller ablation zones, the Pop multizone PRK algorithm probably caused the same adverse wound healing response as seen with the small ablation zone, single pass PRK.[29,30] A smaller ablation zone creates a steeper change in curvature in the blend zone between the treated and untreated cornea. A steeper change in the curvature of the cornea is likely to stimulate a more aggressive corneal wound healing response.

We recommend that multizone PRK algorithms using broad beam excimer lasers graduate and maximize the number of ablation zones in any algorithm for refractive treatment of the corneal stroma. We also recommend spreading the treatment equally among the ablation zones rather than allocating more treatment to the smaller ones. Third, we recommend treatment of astigmatism at the 6.0 mm ablation zone rather than the 5.0 mm zone, as this requires a lower coefficient of adjustment for the prevailing system undercorrection. Studies are being undertaken to further fractionate the treatment in one zone to two passes, where the dioptric correction exceeds 2.00 D sphere.

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