Comparison of the IntraLase femtosecond laser and mechanical keratomes for laser in situ keratomileusis

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Purpose: To compare laser in situ keratomileusis (LASIK) results obtained with the femtosecond laser (IntraLase Corp.) to those obtained using 2 popular mechanical microkeratomes.

Setting: Private practice, Greensboro, North Carolina, USA.

Methods: This retrospective analysis compared LASIK outcomes with the femtosecond laser to those with the Carriazo-Barraquer (CB) microkeratome (Moria, Inc.) and the Hansatome® microkeratome (Bausch & Lomb, Inc.). The 3 groups were matched for enrollment criteria and were operated on under similar conditions by the same surgeon.

Results: There were 106 eyes in the IntraLase group, 126 eyes in the CB group, and 143 eyes in the Hansatome group. One day postoperatively, the uncorrected visual acuity (UCVA) results in the 3 groups were similar; at 3 months, the UCVA and the best spectacle-corrected visual acuity results were not significantly different. A manifest spheroequivalent of ±0.50 diopter (D) was achieved in 91% of eyes in the IntraLase group, 73% of eyes in the CB group, and 74% of eyes in the Hansatome group ($P<.01$). IntraLase flaps were significantly thinner ($P<.01$) and varied less in thickness ($P<.01$) than flaps created with the other devices. The mean flap thickness was 114 μm ± 14 (SD) with the IntraLase programmed for a 130 μm depth, 153 ± 26 μm with the CB using a 130 μm plate, and 156 ± 29 μm with the Hansatome using a 180 μm plate. Loose epithelium was encountered in 9.6% of eyes in the CB group and 7.7% of eyes in the Hansatome group but in no eye in the IntraLase group ($P = .001$). Surgically induced astigmatism in sphere corrections was significantly less with the IntraLase than with the other devices ($P<.01$).

Conclusions: The IntraLase demonstrated more predictable flap thickness, better astigmatic neutrality, and decreased epithelial injury than 2 popular mechanical microkeratomes.

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The femtosecond laser (IntraLase Corp.) is a solid-state laser used to create flaps in laser in situ keratomileusis (LASIK). The laser uses an infrared wavelength (1053 nm) to deliver closely spaced, 3 μm spots that can be focused to a preset depth to photodisrupt tissue within the corneal stroma. The laser bursts are short (1 quadrillionth of a second). The resultant plasma produces a cavitation bubble, consisting of water and carbon dioxide primarily.

The IntraLase femtosecond laser software creates a circular cleavage plane starting at 1 side of the cornea and progressing across the cornea using a raster (back and forth) pattern. It then creates a flap edge of a programmable angle (side-cut angle) using a circumferential pattern of progressively shallower pulses. A predefined arc along the edge is left uncut to create the

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hinge. The entire process takes place through a glass applanation plate that is fixed to the eye with a low-pressure suction ring.

Others have reported safety advantages of this technology over mechanical keratomes, including improved uniformity of the flap and better predictability of the flap thickness.[2,3] These features may improve the safety of the procedure by avoiding iatrogenic ectasia.[4–6]

This report provides new information about the effects of IntraLase femtosecond flaps on refractive outcomes in LASIK, specifically on refractive predictability and improved astigmatic neutrality in flaps created with laser versus mechanical keratomes. These findings may have significant implications for wavefront-guided treatments and visual function after LASIK. The data show decreased epithelial trauma during creation of the flap with the IntraLase, which has significant implications for visual recovery and avoidance of complications after surgery.[7–10]

Patients and Methods

Study Design

This retrospective consecutive enrollment crossover study was designed to compare the effects of using laser and mechanical keratomes to create the LASIK flap on LASIK outcomes.

Study Cohort and Patient Enrollment

The following enrollment criteria were used to define the study cohort: surgery performed between January 2002 and March 2003; bilateral LASIK treatments for spherical and spherocylindrical myopia; preoperative manifest spheroequivalent (SE) between −1.0 diopter (D) and −7.0 D; preoperative manifest astigmatism between 0 D and 4.0 D at the spectacle plane; targeted myopia between −0.5 D and plano; preoperative best spectacle-corrected visual acuity (BSCVA) 20/20 or better; flap created using the IntraLase laser, the Moria Carriazo-Barraquer (CB) microkeratome, or the Bausch & Lomb Hansatome® keratome; ablation performed using the Visx S3 laser at 10 Hz with a 6.5 mm optical zone; and postoperative care provided by the operating surgeon (no comanagement).

Keratome Assignment

The surgeon changed from mechanical keratomes (Hansatome and CB) to the IntraLase at the end of December 2002. The IntraLase laser kerataome was used in all patients operated on after that date. Assignment to either mechanical keratome (Hansatome or CB) before that time was random and based on operating-room logistics, alternating between cases.

Surgical Procedure and Laser

The LASIK procedure has been described.[11] All procedures were performed by the same surgeon (K.G.S.) using the Visx S3 laser at 10 Hz with a 6.5 mm optical zone with a blend zone. Beam calibration was performed at the start of each treatment day and after every third patient. The laser room temperature was maintained at 70°F ± 2°F and the relative humidity, 50% ± 5% in all cases.

The IntraLase flap thickness was programmed to 130 μm. The flap-edge angle was programmed to 60 degrees, and the hinge size was set at 30 degrees of arc. With the mechanical keratome, the selected plate thickness was 130 μm with the CB keratome and 180 μm with the standard Hansatome. In all eyes, surgery was planned to leave at least 50% of the total corneal thickness and not less than 250 μm of corneal thickness after ablation.

Pachymetry measurements were performed using a DGH Pachette 50/60 KHz pachymeter. Pachymetry measurements were taken just before the flap was created with the patient in an upright position. Pachymetry of the stromal bed was performed just after the flap was lifted, and the difference between the 2 measurements was considered the flap thickness.

Following creation of the keratectomy, the flap was reflected and laser ablation performed immediately. Visible moisture was removed as needed using a Merocel® sponge (Medtronic Solan).

Postoperative Management

Postoperative medications included prednisolone acetate (Pred Forte® 1%) and ofloxacin (Ocuflox® 0.3%) 4 times a day for 2 weeks, topical wetting solutions as needed, and oral analgesic agents per the investigator's discretion (optional). No topical nonsteroidal antiinflammatory agents were used.

Data Acquisition and Analysis

This report is limited to single-procedure outcomes. Data collection was performed in an ongoing manner using Refractive Surgery Consultant Elite software (Refractive Consulting Group, Inc.) as part of the routine practice of the surgeon. Data analysis was performed using the Refractive Surgery Consultant Elite and Microsoft® Excel 2002 Analysis Tool Pack using standard statistical methods.

Main Outcome Measures

Data were analyzed for the effect of the flap creation method on intraoperative and postoperative outcomes. The following parameters were compared:

Intraoperative Parameters. Flap thickness was calculated by subtracting the pachymetric stromal bed thickness ob-

Table 1. Preoperative characteristics of the 3 groups.

Device	N	Mean Age (Range), Y	P*	Preop SE (Range), D	P*	Preop Pachymetry (Range), μm	P*	Preop K (Range), mm	P*
IntraLase	106	38.3 ± 9.0 (21 to 56)	—	−4.06 ± 1.39 (−0.88 to −7.00)	—	540 ± 28 (490 to 632)	—	44.61 ± 1.40 (41.10 to 48.10)	—
CB	126	40.7 ± 9.8 (21 to 60)	NS	−3.82 ± 1.48 (−0.75 to −7.00)	NS	559 ± 27 (500 to 640)	<.01	43.93 ± 1.17 (40.68 to 46.87)	<.01
Hansatome	143	38.6 ± 8.8 (21 to 59)	NS	−4.62 ± 1.73 (−1.00 to −7.00)	<.01	553 ± 30 (500 to 635)	<.01	43.76 ± 1.34 (40.06 to 47.06)	<.01

Mean ± SD

K = keratometry; NS = not significant; SE = spheroequivalent

*Probability of significance of difference compared to the IntraLase data set using Student *t* test.

tained after the flap was lifted from the preoperative ultrasonic pachymetry. Epithelial integrity of the flap was graded using the following system: loose epithelium (LE) grades 1 (1 quadrant) to 4 (all 4 quadrants) and epithelial defect (ED) ≤1 mm and >1 mm. Device failure rate and other complications such as failure to create flap, buttonhole creation, and incomplete flap inadequate to perform ablation were noted.

Postoperative Parameters. The effectiveness measures were as follows: 1 day, UCVA at 20/20 and 20/40 levels; 3 months, UCVA at 20/20 and 20/40 levels, manifest refraction SE ±0.50 D and ±1.00 D, and accuracy of cylinder correction. The safety measure was the change in BSCVA at 3 months.

Visual acuity measurements were done using a Marco CP-670 Automatic Chart Projector. All calculations of visual acuity outcomes were performed using logMAR equivalents. Refraction calculations were performed at the corneal plane, using vector analysis as appropriate. Cylinder outcomes were analyzed using doubled-angle plots and were performed in minus-cylinder notation. Refractive outcomes were reported relative to the targeted amount.

Results

Study Cohort

The IntraLase was used in 106 eyes, the Moria CB microkeratome in 126 eyes, and the Hansatome microkeratome in 146 eyes. Table 1 presents the demographic and preoperative clinical characteristics of the 3 groups. Despite some statistical differences, the clinical ranges for preoperative SE, pachymetry, and keratometry were similar and the cohorts were adequate for statistical analysis.

Intraoperative Parameters

Flap Thickness. Results of the calculated flap thickness are shown in Table 2. The mean flap thickness with the IntraLase was 16 μm less than programmed; with the CB, the mean flap thickness was 23 μm thicker than the plate thickness and with the Hansatome, 24 μm thinner than the plate thickness.

The range of flap thicknesses varied less with the IntraLase than with the CB and Hansatome. With the IntraLase, the mean flap thickness was significantly thinner ($P<.001$) and the reproducibility (variance) of flap thickness was significantly better ($P<.001$) than with the mechanical keratomes. The maximum flap thickness was seen with the Hansatome (225 μm) and then with the CB (210 μm). The thickest flap with the IntraLase was 155 μm.

Epithelial Integrity. No eye in the IntraLase group experienced loose epithelium. In the CB group, loose epithelium in 1 quadrant (LE1) was seen in 5.5% of eyes and LE2, in 4.1% of eyes. The total 9.6% with loose epithelium was significantly higher than the rate in the IntraLase group ($P = .001$, chi square analysis). In the Hansatome group, LE1 was seen in 5.1% and LE2 in 2.6% of eyes for a total 7.7% with some loose epithelium ($P = .001$ compared with the IntraLase group, chi square analysis).

No eye experienced LE grade 3 or 4 or epithelial defects.

Device Failure Rate and Other Complications. There were no complete failures with any device, nor were there buttonholes, transected flaps, or other sight-threatening complications.

Postoperative Parameters

Effectiveness Measures. Day 1 distance UCVA outcomes are shown in Figure 1. The 20/20 rate in the IntraLase group was lower than in the other groups, but the differences were not statistically significant (chi-square analysis). The 20/40 rate was similar in the 3

Table 2. Calculated flap thickness in the 3 groups.

	IntraLase	CB	Hansatome
Plate thickness/programmed depth, μm	130	130	180
Calculated flap thickness			
Mean ± SD, μm	114 ± 14	153 ± 26	156 ± 29
Range, μm	(78 to 155)	(59 to 210)	(25 to 250)
Difference, μm	77	151	225
Comparison to IntraLase			
P (*t* test for mean)	—	<.001	<.001
P (F test for variance)	—	<.001	<.001

groups, ranging from 98% to 99%. Mean acuities at day 1 were also similar. All eyes in this series were targeted for distance vision.

Three month visual and refractive outcomes in the 3 groups are shown in Figure 2. The UCVA rate was similar in the groups. The 20/20 rate ranged from 66% to 71% and the 20/40 rate, from 98% to 99%. The differences were not statistically significant.

A manifest refractive SE (MRSE) of ±0.50 D was achieved in 91% of IntraLase eyes (95% confidence interval [CI], 88.2%-93.6%), 73% of CB eyes (95% CI, 69.4%-77.4%; $P<.01$), and 74% of Hansatome eyes (95% CI, 69.9%-77.3%; $P<0.01$). The rate of MRSE ± 1.00 D was statistically similar with all 3 devices and ranged from 95% to 99%.

Linear regression of the attempted versus achieved MRSE showed significantly better correlation in the IntraLase group than in the CB group ($P<.05$, Fisher *R* to *z*-transformation) but not in the Hansatome group ($P = .14$) (Figure 3). Although the same nomogram was used in all cases, the slope of the regressions varied. It was 0.99 in the IntraLase group, 0.98 in the CB group, and 0.94 in the Hansatome group.

Figure 4 shows doubled-angle plots of the postoperative cylinder amounts for each device for all eyes, spheres, and spherocylinders. Table 3 provides companion data summarizing the cylinder refractive outcomes. In all groups, the mean postoperative cylinder amount was less than 0.25 D and the differences between the devices were not significant (*z*-test).

The accuracy of astigmatism corrections was better with the IntraLase than with the other devices (Figure 4, Table 3). The postoperative mean astigmatism means was similar, but the predictability (variance) was significantly better with the IntraLase (F test for variance) than with the other devices.

The standard deviation of postoperative cylinder in eyes that had spherical corrections (no cylinder treated) was 0.22 D in the IntraLase group, 0.32 D in the CB group, and 0.40 D in the Hansatome group ($P<.01$ for both comparisons, F test for variance). The amount of induced astigmatism with the IntraLase was approximately one third less than with the CB and one half less than with the Hansatome.

Safety Measures. Changes in Snellen BSCVA were similar in the 3 groups (Figure 2).

Discussion

This retrospective series compared LASIK outcomes with the IntraLase femtosecond laser to the outcomes

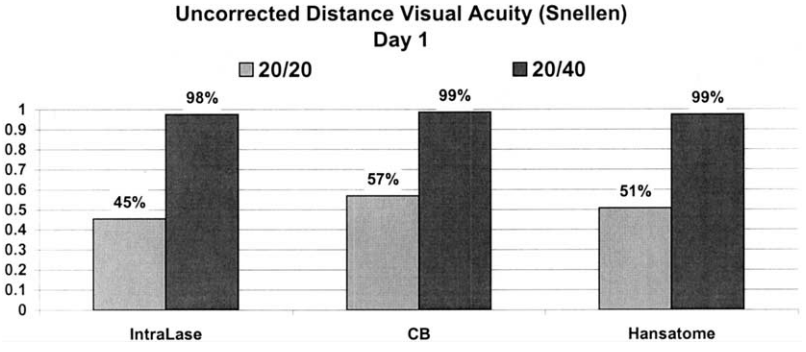

Figure 1. (Kezirian) Uncorrected distance visual acuity on the first postoperative day. Differences were not statistically significant. Results in all groups improved by the 3-month visit, as shown in Figure 2.

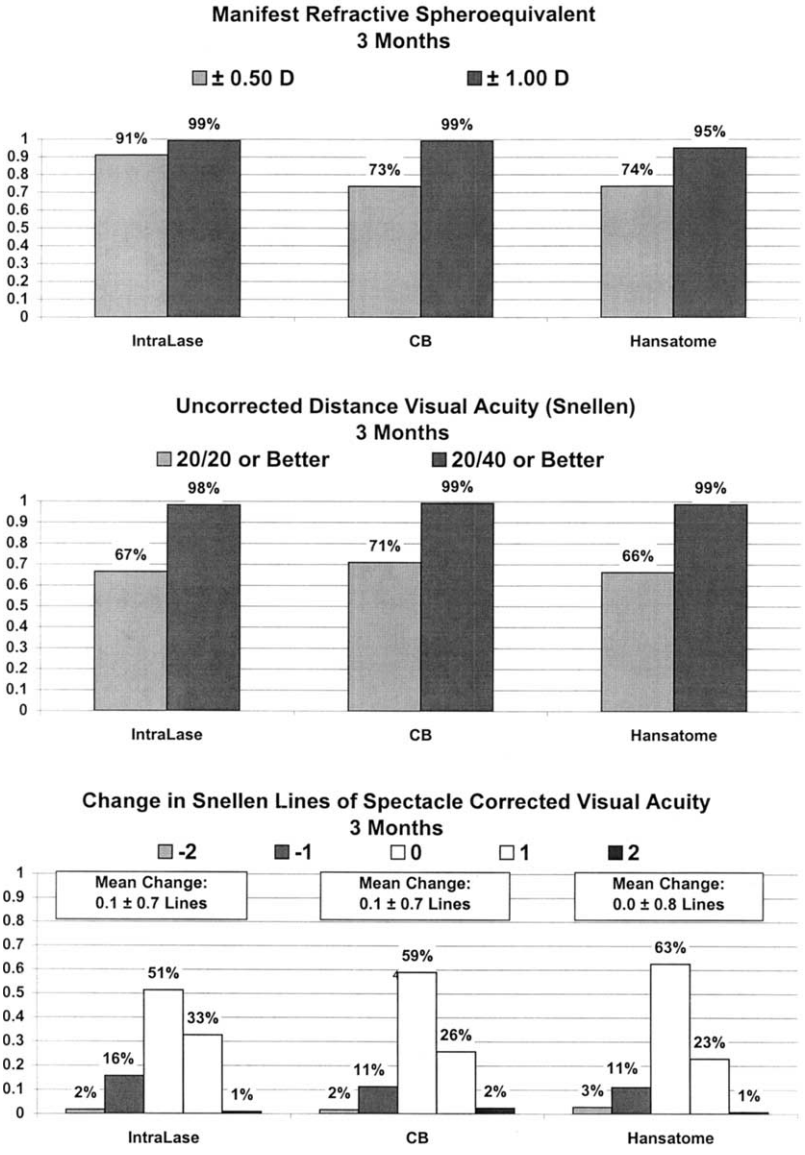

Figure 2. (Kezirian) Comparison of the refractive, visual, and best corrected acuity outcomes with the 3 devices showed few differences. Predictability of the MRSE at the ±0.50 D level was significantly better with the IntraLase at 91% ($P<.01$). Other measures were similar between the groups.

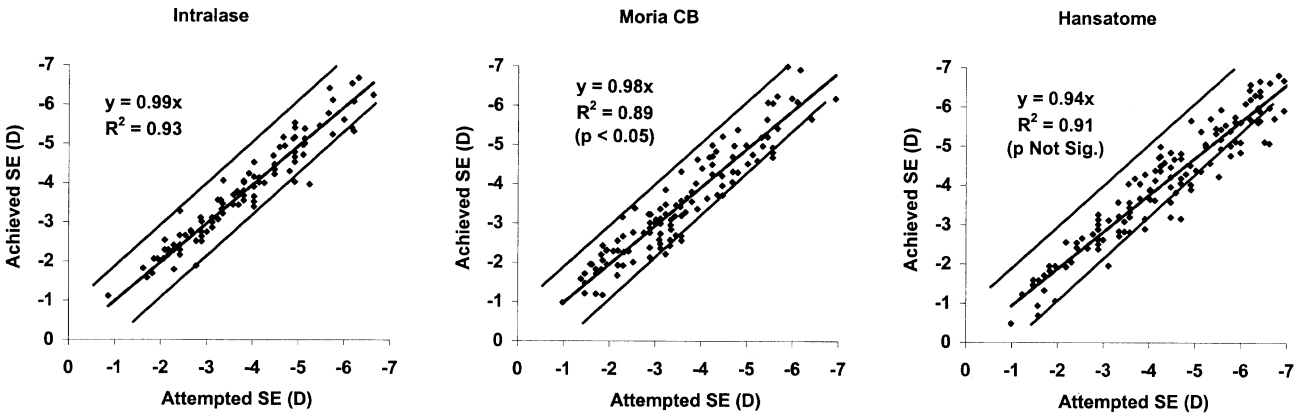

Figure 3. (Kezirian) Scatterplots and linear regression analysis of the attempted versus achieved SE results with the 3 devices. Correlation with the IntraLase was significantly better than with the CB but not better than with the Hansatome. Despite use of the same nomogram, the regression slopes varied from 0.99 to 0.94.

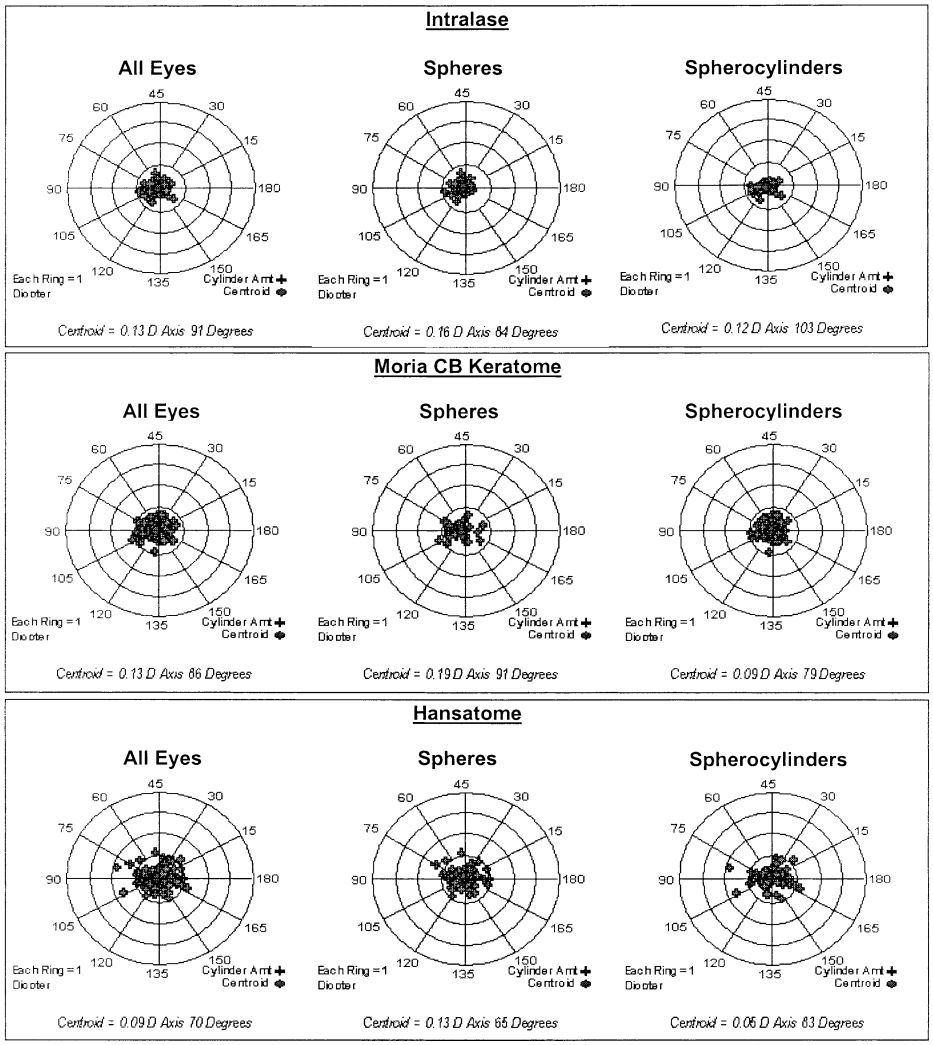

Figure 4. (Kezirian) Doubled-angle plots of the postoperative astigmatic results with each device. While the mean (centroid) outcomes did not significantly differ, the scatter of results did. The IntraLase also induced significantly less astigmatism in spherical procedures than the other devices.

with 2 mechanical microkeratomes (the Moria CB and the Bausch & Lomb Hansatome). Safety and effectiveness were compared using 3 sets of LASIK outcomes matched for surgeon, laser, treatment parameters, and treatment range. The retrospective study design precluded evaluation of other factors such as the comparative incidence of diffuse lamellar keratitis (DLK) and healing rates, which may have been possible with a prospective series.

Safety Considerations

The accuracy of the LASIK flap thickness is a key safety consideration for the avoidance of ectasia following LASIK.[5,6] In this study, flap thickness was calculated by subtracting the pachymetric stromal bed thickness obtained just after the flap was lifted from the preoperative ultrasonic pachymetry, as reported.[4,6] Recent reports provide an alternate methodology using optical pachymetry. Both methods are limited by possible errors from edema that may develop before the second measurement is taken. Since the same methodology was used to calculate flap thickness, this concern is somewhat mitigated.

In this series, the standard deviation and range of flap thickness were significantly less with the IntraLase than with the CB or the Hansatome. The 14 μm SD agrees with the SD in a recent study by Binder,[15] which reports a 12 μm SD with the IntraLase.

Other authors[4–6] have provided mathematical analysis showing how the observed rates of ectasia can be

Table 3. Astigmatic outcomes with the 3 devices.

	All Eyes				Spheres				Spherocylinders			
Device	**Centroid**	***P***	**SD (D)**	***P****	**Centroid**	***P***	**SD (D)**	***P****	**Centroid**	***P***	**SD (D)**	***P****
IntraLase	0.13@91	—	0.23	—	0.16@84	—	0.22	—	0.12@103	—	0.24	NA
CB	0.13@86	NS	0.55	<.01	0.19@91	NS	0.32	<.01	0.09@79	NS	0.36	.05
Hansatome	0.09@70	NS	0.42	<.01	0.13@65	NS	0.40	<.01	0.05@83	NS	0.43	<.01

*Analysis of variance (F test)

traced to the mean and SD of flap thickness encountered with various devices. The range data provided here further their analysis and suggest that the range is also a risk factor for the development of ectasia.

The better predictability of flap thickness with the IntraLase can be expected to reduce the incidence of ectasia in eyes operated on using this device compared with eyes operated on with the mechanical keratomes. It may also ensure greater residual stroma in patients requiring second operations.

Epithelial Integrity

Epithelial defects after LASIK have been associated with patient discomfort, photophobia, delayed visual recovery, epithelial ingrowth, DLK, flap complications, and increased retreatment rates.[8–10]

The improved epithelial preservation with the IntraLase is a significant safety advantage. The IntraLase requires no moving instrumentation during the procedure. The mechanical keratomes pivot the keratome head across the corneal epithelium under high pressure. This difference likely explains the better epithelial preservation seen with the IntraLase. Newer designs of some mechanical keratomes may improve epithelial preservation with these devices.

Other Safety Measures

All 3 devices had similar rates of BSCVA loss. There were no major device failures, buttonholes, or transected flaps with any device.

Effectiveness Considerations

Clinical outcomes with the 3 devices were similar except in 2 areas: accuracy of the MRSE to the targeted amount and cylinder accuracy. Both findings have significant clinical implications.

The rate of ±0.50 D was significantly better with the IntraLase than with either mechanical keratome ($P<.01$, chi-square analysis). The reason for the improved predictability may lie in the decreased use of irrigation with the IntraLase. Laser ablation rates vary with tissue hydration.[16–18] By avoiding the need for irrigation, tissue hydration may be more standardized with the IntraLase than with mechanical devices, where irrigation is routinely used before the keratome is passed. The improved refractive predicability was not reflected in improved UCVA outcomes, a finding that is unexplained.

Surgically induced astigmatism in spherical corrections has been reported.[19] Eyes having spherical corrections had no preoperative astigmatism and no astigmatism was treated. Any postoperative astigmatism can be attributed to the procedure and can be considered to represent iatrogenic cylinder induced by the procedure. Conversely, treatments with no induced cylinder were astigmatism neutral. The IntraLase flaps induced significantly less astigmatism than the flaps created with the CB or Hansatome ($P<.01$, F test for variance of the postoperative astigmatism amounts).

This finding also may make the IntraLase more appropriate to wavefront-guided treatments in which small amounts of induced aberrations may undermine the benefits of the wavefront treatments.

The explanation for less astigmatism in the IntraLase group may lie in the morphology of the flap. IntraLase flaps are circular rather than truncated, extending beneath the hinge. By contrast, flaps created with mechanical keratomes are truncated at the hinge. Other potential factors such as programmed edge angle and constant flap thickness may also play a role and merit histologic study.

Understanding the exact mechanism that leads to improved astigmatic neutrality with the IntraLase merits further study of corneal biomechanics. In addition, further studies are needed to confirm this finding with other lasers and to compare this finding with eyes treated by photorefractive keratectomy.

In summary, this series showed significant safety benefits with the IntraLase compared with 2 popular

mechanical keratomes for flap thickness predictability and preservation of epithelial integrity. It also showed improvements in refractive outcomes and improved astigmatic neutrality of the flaps. These represent significant advantages over prior technologies, especially as an adjunct to wavefront treatments, for improved outcomes and the avoidance of flap-related complications.

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