Matched Population Comparison of the Visian Implantable Collamer Lens and Standard LASIK for Myopia of −3.00 to −7.88 Diopters

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ABSTRACT

PURPOSE: To compare matched populations of LASIK and Visian Implantable Collamer Lens (ICL) cases in the correction of myopia between −3.00 and −7.88 diopters (D).

METHODS: One hundred sixty-four LASIK eyes with prospective data collected from a single center and 164 ICL eyes from the multicenter US ICL Clinical Trial were compared in this observational non-randomized study. The LASIK and ICL groups were well matched for age, gender, and mean level of preoperative spherical equivalent refraction.

RESULTS: At 6 months, best spectacle-corrected visual acuity (BSCVA) ⩾20/20 was 85% with LASIK and 95% with ICL (P=.003) compared to preoperative values of 93% and 88%, respectively (P=.292). Loss of ⩾2 lines of BSCVA was significantly lower with the ICL at 1 week (0.6% vs 10%, P<.001) and 1 month (7% vs 0%, P=.001) with comparable outcomes at 6 months (0% vs 1%). At 6 months postoperatively, uncorrected visual acuity (UCVA) ⩾20/15 (11% vs 25%, P=.001) and ⩾20/20 (49% vs 63%, P=.001) was better in the ICL cases. Predictability within 0.50 D at 6 months for ICL cases was 85% (67% LASIK, P<.001); 97% of ICL cases were within 1.00 D (88% LASIK, P=.002). Refractive stability (±0.50 D) between 1 and 6 months was 93% with ICL compared to only 82% with LASIK (P=.006).

CONCLUSIONS: The ICL performed better than LASIK in almost all measures of safety, efficacy, predictability, and stability in this matched population comparison, supporting the ICL as an effective alternative to existing refractive laser surgical treatments for the range of myopia studied. [*J Refract Surg*. 2007;23:537-553.]

A previous report of the multicenter United States Food and Drug Administration (US FDA) Visian Myopic Implantable Collamer Lens (Visian ICL; STAAR Surgical, Monrovia, Calif) clinical investigation has documented the safety and effectiveness of the Visian ICL in the correction of low, moderate, and high levels of myopia with follow-up out to 3 years.[1,2] Outcomes from this large multicenter clinical study have demonstrated the viability of the Visian ICL as an alternative to current refractive laser surgical treatment options. In December 2005, the FDA approved the Visian ICL for myopia −3.00 to −20.00 diopters (D).

This article presents a comparison of clinical outcomes with the current commercially approved version of the Visian ICL with LASIK for the correction of myopia at the lower range for which the ICL is being considered for approval (−3.00 to −7.88 D). The overall study populations have been matched for age, gender, and mean preoperative manifest refraction spherical equivalent (MRSE) to provide a comparison of these two refractive surgical techniques.

PATIENTS AND METHODS

A matched patient population evaluation was performed involving 164 LASIK eyes (136 patients) from the Davis Duehr

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Eye Center, Madison, Wisconsin and 164 ICL eyes (106 patients) from the multicenter US FDA Clinical Trial for ICL for Myopia. Implantable Collamer Lens implantations occurred between November 1998 and September 2000; LASIK surgeries were performed from May 2001 to June 2002. In both groups, preoperative MRSE ranged between −3.00 and −7.88 D, and study follow-up was 1 day, 1 week, 1 month, and 6 months postoperatively. All LASIK cases were conducted at a single center by 9 surgeons. Implantable Collamer Lens surgeries were performed at 12 centers by 16 surgeons. Implantable Collamer Lens cases were conducted under the supervision of an institutional review board at all participating centers and written surgical informed consent was obtained for all ICL and LASIK patients prior to surgery.

The 164 ICL case series included a consecutive series of all ICL cases in the US FDA trial for this range of myopia. The LASIK series was drawn from a consecutive series of 2577 cases for this range of myopia during the enrollment period described above. This enrollment period was chosen because extensive follow-up data were available as part of a prospective data collection of all cases at the center. The computerized database of all LASIK cases was discontinued shortly after this period. An attempt was made to match each case in the ICL population with a case in the LASIK population of similar age, gender, and spherical equivalent refraction without knowledge of postoperative outcomes. If more than one LASIK case adequately matched an ICL case, preference was given to the case with ⩾6-month follow-up. If more than one case matched that had ⩾6-month follow-up, the first such case encountered was used. If an exact match could not be made for all three variables (age, gender, and spherical equivalent refraction), a correction was attempted in a later case to maintain a matched population set. All refraction data in both series were obtained by manifest refraction without cycloplegia.

The LASIK and ICL study populations were well matched for age (LASIK: 37.3±7 years; ICL: 37.3±6 years; *P*=.85), gender (65.2% female, LASIK; 59.1% female, ICL; *P*=.3), and the mean level of preoperative MRSE (LASIK: −6.01±1.40 D; ICL: −6.01±1.40 D; *P*=.79). The range of inclusive ages was slightly higher in the LASIK group (21 to 50 years vs 21 to 45 years in the ICL group). The mean preoperative refractive cylinder for the LASIK group was 0.74 D (range: 0.00 to 2.75 D), which was significantly greater than the ICL group, of 0.58 D (range: 0.00 to 2.50 D) (*P*=.037).

VISIAN ICL DEVICE

The current Visian ICL was implanted in all eyes in the phakic intraocular lens (IOL) arm of the series. The ICL configuration was designed to vault anteriorly to the crystalline lens and is intended to have minimal contact with the natural lens. As discussed previously by the authors, the lens is made from a new generation of biocompatible IOL materials, termed "Collamer."[1-4] It is composed of a proprietary hydrophilic porcine collagen (<0.1%) hydroxyethyl methacrylate (HEMA) copolymer into which an ultraviolet-absorbing chromophore has been incorporated in the polymer chains. The ICL features an optic with an overall diameter that varies with its dioptric power, with the smallest optic/overall diameter being 4.9 mm/12.1 mm and the largest being 5.8 mm/13.7 mm. Its plate–haptic design resembles lenses already in use with cataract surgery; it also incorporates four separate, distinct extensions of the haptics referred to as footplates.

LASIK EQUIPMENT

All 164 eyes underwent LASIK using a current LASIK technique performed with the same microkeratome design. Three manual microkeratomes (Carriazo-Baraquer; Moria, Antony, France), all with a 160-µm head, were used to perform the flap creation in all eyes by the LASIK surgeon group for these cases. The STAR 193 nanometer excimer laser system (VISX Inc, Santa Clara, Calif) incorporating the S3 software version was the laser used to perform all ablations.

LENS SIZING AND POWER CALCULATION

Sizing of myopic lenses (12.2 to 13.7 mm) was determined by the horizontal white-to-white and the anterior chamber depth measurements. For eyes with anterior chamber depth measurements of 2.8 to 3.5 mm, the lens size was calculated by adding 0.5 mm to the horizontal white-to-white measurement. Eyes exhibiting an anterior chamber depth >3.5 mm required the addition of up to 1.0 mm to the white-to-white measurement, up to a maximum length of 13.7 mm. Patients with an anterior chamber depth <2.8 mm were excluded from the study. Calculated lens sizes between the available lens diameters (in 0.5-mm increments) were generally rounded down if the anterior chamber depth was ⩽3.5 mm and rounded up if the anterior chamber depth was >3.5 mm. White-to-white measurements were obtained using calipers at a slit lamp checked against a steel ruler. All lens power calculations were performed by STAAR Surgical Company using a clinically optimized vergence formula that was based upon paraxial optics and vergence equations. The formula was recently enhanced to allow for toric as well as spherical calculations,[5] and this formula was utilized using an effective lens position (elp) value of 3.64. The refractive target was between 0 and −0.50 D in all cases.

ICL Surgical Procedure

Within 7 days of surgery, patients received two peripheral iridectomies performed 90° apart with an Nd:YAG or Argon-Krypton laser, generally at 10:30 and 1:30 clock hours. On the day of surgery, patients were administered dilating and cycloplegic agents, after which an anesthetic of the surgeon's choice was applied to the operative eye. All ICL implantations were performed under topical anesthesia. Following placement of viscoelastic into the anterior chamber, an ICL was inserted through a small 3-mm horizontal (0 to 180°) clear corneal incision. The lens was injected through the incision into the anterior chamber (STAAR MicroSTAAR injector) and allowed to slowly unfold. Distal and proximal footplates were tucked under the iris with a modified intraocular spatula. Correct positioning of the ICL in the center of the pupillary zone was verified before intraocular miotic was used to decrease pupil size. Any remaining viscoelastic was scrupulously irrigated out of the anterior chamber with balanced salt solution (BSS).

Patients were administered one drop of Ocuflox (ofloxacin solution 0.3%; Allergan Inc, Irvine, Calif) and prescribed Tobradex (tobramycin and dexamethasone suspension; Alcon Laboratories Inc, Ft Worth, Tex) four times daily for a total of 16 days, beginning with one drop four times daily for the first four postoperative days and steadily reducing the dose by one drop every four days thereafter. No postoperative medication was routinely used after this time frame.

No operative or postoperative procedures were permitted for the treatment of residual spherical or astigmatic refractive error.

LASIK Surgical Technique

Topical 0.5% proparacaine, three to six drops, was applied immediately prior to surgery. Orientation marks were placed on the cornea with gentian violet to facilitate repositioning of the flap. Average attempted corneal flap diameter was 8.5 mm with a superior hinge position. All LASIK procedures were done using the VISX STAR excimer laser with the S3 software with a repetition rate of 6 or 10 Hz and an ablation zone diameter of 6.0 or 6.5 mm. During ablation, patients autofixated on a target light and centration was achieved by the surgeon using an aiming reticule centered on the pupil. Following ablation, the corneal flap was repositioned using a 27-gauge blunt cannula with BSS (Alcon Laboratories Inc). The flap position was confirmed and the cornea air-dried for 3 minutes. At the completion of the procedure, one drop each of topical Ciloxan (Alcon Laboratories Inc) and prednisolone acetate (Alcon Laboratories Inc) were instilled and clear corneal shields were taped into position. In the event of epithelial abrasion, a bandage contact lens was applied at the surgeon's discretion.

Ciloxan and prednisolone acetate were prescribed four times daily and discontinued after 5 days. Patients were seen 1 day following surgery and typically at 1 day, 1 week, 1 month, and 6 months postoperatively.

Enhancement criteria were unique for each surgeon but in general the following criteria were adhered to by all participating surgeons. Enhancement was driven by patient desire, not by the level of visual acuity. Enhancements were performed when uncorrected visual acuity (UCVA) was $<20/30$ and there was sufficient corneal bed thickness/structural corneal stability to allow re-treatment.

The original refractive target was between 0 and -0.50 D in all cases. Astigmatism was routinely treated as part of the surgical procedure.

Statistical Methods

Implantable Collamer Lens outcomes were compiled from the prospective, standardized case report forms in Clindex 2.0 (Fortress Medical Systems Inc, Hopkins, Minn) provided in the US multicenter clinical study protocol. For LASIK, outcomes reported in the clinical records were compiled on an Excel spreadsheet (Microsoft Corp, Redmond, Wash). If enhancements were performed, data after enhancement were included in the visual and refractive results.

The following statistical analyses were used to compare the LASIK and ICL series. For dichotomous variables (gender, BSCVA or UCVA 20/15, 20/20, and 20/40 or better, predictability ± 0.50 or ± 1.00 D, and stability ± 0.50 or ± 1.00 D), Fisher's exact test was performed. For ordered categories and interval level data (patient age, vision distributions, line changes in BSCVA and spherical equivalent refraction, predictability, and stability refractive distributions) Mann-Whitney U tests were performed. SPSS 11.0 (SPSS Inc, Chicago, Ill) was used for all tabulations of data and statistics.

RESULTS

Postoperative Follow-up

Implantable Collamer Lens and LASIK patients were examined at 1 day, 1 week, 1 month, and 6 months postoperatively. As part of the US ICL FDA multicenter clinical study, follow-up was excellent with 96% of eyes seen 6 months postoperatively. In the LASIK group, 99% of eyes were examined at 6-month follow-up.

TABLE 1

Matched Population Comparison of ICL Versus LASIK Clinical Outcomes

Variable	No. Eyes (%) LASIK	ICL	*P* Value	*P* Value (Entire Distribution)
BSCVA (20/20 or better)				
Preop	152/164 (93)	144/164 (88)	.192	.048
1 week	90/134 (67)	137/156 (88)	<.001	<.001
1 month	111/136 (82)	158/163 (97)	<.001	<.001
6 months	137/162 (85)	149/157 (95)	.003	<.001
Loss of BSCVA				
⩾2 lines				
1 week	13/134 (10)	1/156 (0.6)	<.001	<.001
1 month	9/136 (7)	0/163 (0)	.001	<.001
6 months	2/162 (1)	0/157 (0)	.499	<.001
⩾1 line				
1 week	41/134 (31)	24/156 (15)	.003	<.001
1 month	26/136 (19)	11/163 (7)	.001	<.001
6 months	22/162 (14)	7/157 (5)	.006	<.001
Improvement of BSCVA				
⩾2 lines				
1 week	2/134 (2)	4/156 (3)	.690	<.001
1 month	5/136 (4)	7/163 (4)	1.000	<.001
6 months	4/162 (3)	5/157 (3)	.747	<.001
⩾1 line				
1 week	14/134 (10)	45/156 (29)	<.001	<.001
1 month	24/136 (18)	57/163 (35)	.001	<.001
6 months	24/162 (15)	69/157 (44)	<.001	<.001
Change in BSCVA (mean line change)				
1 week	−0.34±1.00	+0.17±0.83	<.001	NA
1 month	−0.07±0.95	+0.34±0.73	<.001	NA
6 months	+0.03±0.65	+0.45±0.72	<.001	NA
Mean MRSE				
Preop	−6.01±1.33	−6.01±1.40	.794	NA
1 week	−0.18±0.67	−0.25±0.43	.093	NA
1 month	−0.25±0.69	−0.14±0.38	.579	NA
6 months	−0.33±0.65	−0.09±0.31	.001	NA

ICL = Implantable Collamer Lens, BSCVA = best spectacle-corrected visual acuity, MRSE = manifest refraction spherical equivalent, UCVA = uncorrected visual acuity, NA = not applicable

Clinical Outcomes

Table 1 provides an overall comparison of the major safety and efficacy outcomes between the LASIK and ICL groups. The column labeled "*P* Value" for values that were dichotomous variables represents results of Fisher's exact tests. For these dichotomous variables the entire distribution of outcomes for that variable was also analyzed and significance was determined by a Mann-Whitney U test. The results of this test are given in the last column labeled "*P* Value, Entire Distribution."

TABLE 1 CONTINUED

Matched Population Comparison of ICL Versus LASIK Clinical Outcomes

Variable	No. Eyes (%) LASIK	ICL	*P* Value	*P* Value (Entire Distribution)
Mean cylinder				
Preop	+0.74±0.66	+0.58±0.56	.037	NA
1 week	+0.23±0.31	+0.56±0.56	<.001	NA
1 month	+0.24±0.36	+0.52±0.55	<.001	NA
6 months	+0.25±0.31	+0.50±0.53	<.001	NA
UCVA (20/15 or better)				
1 day	6/160 (4)	14/164 (9)	.105	.273
1 week	11/134 (8)	15/159 (9)	.837	.293
1 month	17/136 (13)	28/164 (17)	.330	.010
6 months	17/162 (11)	40/161 (25)	.001	<.001
UCVA (20/20 or better)				
1 day	41/160 (26)	50/164 (31)	.387	.273
1 week	60/134 (45)	78/159 (49)	.483	.293
1 month	59/136 (43)	96/164 (59)	.011	.010
6 months	79/162 (49)	102/161 (63)	.010	<.001
UCVA (20/40 or better)				
1 day	134/160 (84)	115/164 (70)	.004	.273
1 week	123/134 (92)	149/159 (94)	.650	.293
1 month	123/136 (90)	158/164 (96)	.055	.010
6 months	154/162 (95)	159/161 (99)	.104	<.001
Predictability — Attempted vs Achieved				
±0.50 D				
1 week	101/134 (75)	123/156 (79)	.487	.894
1 month	99/136 (73)	131/163 (80)	.131	.173
6 months	108/162 (67)	134/158 (85)	<.001	.144
±1.00 D				
1 week	124/134 (93)	152/156 (97)	.059	.894
1 month	123/136 (90)	154/163 (94)	.191	.173
6 months	143/162 (88)	154/158 (97)	.002	.144
Stability of Manifest Refraction				
±0.50 D				
1 week to 1 month	85/111 (77)	140/155 (90)	.003	.023
1 month to 6 months	110/134 (82)	146/157 (93)	.006	.019
±1.00 D				
1 week to 1 month	102/111 (92)	153/155 (99)	.009	.023
1 month to 6 months	130/134 (97)	156/157 (99)	.184	.019

ICL = Implantable Collamer Lens, BSCVA = best spectacle-corrected visual acuity, MRSE = manifest refraction spherical equivalent, UCVA = uncorrected visual acuity, NA = not applicable

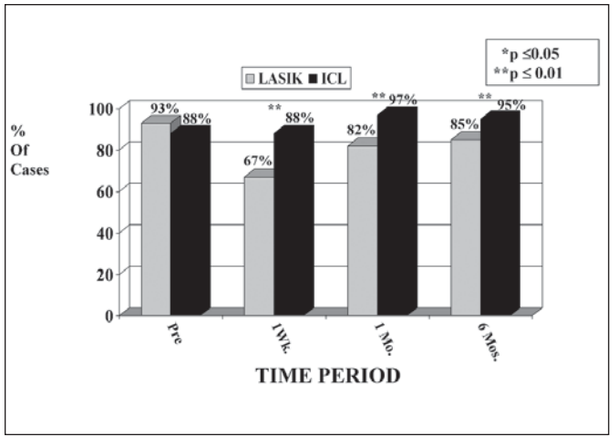

Figure 1. Proportion of cases with BSCVA ⩾20/20 preoperatively and at each postoperative follow-up examination in the LASIK and Implantable Collamer Lens (ICL) series. Asterisks reflect the statistical significance of the difference between LASIK and ICL series.

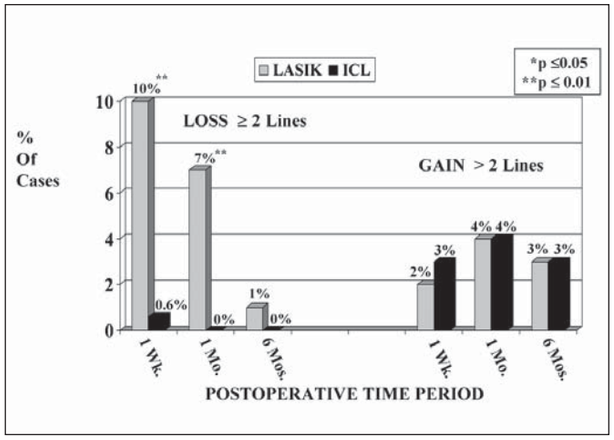

Figure 2. Proportion of cases with losses and gains of ⩾2 lines of BSCVA at each postoperative follow-up examination in the LASIK and Implantable Collamer Lens (ICL) series. Asterisks reflect the statistical significance of the difference between LASIK and ICL series.

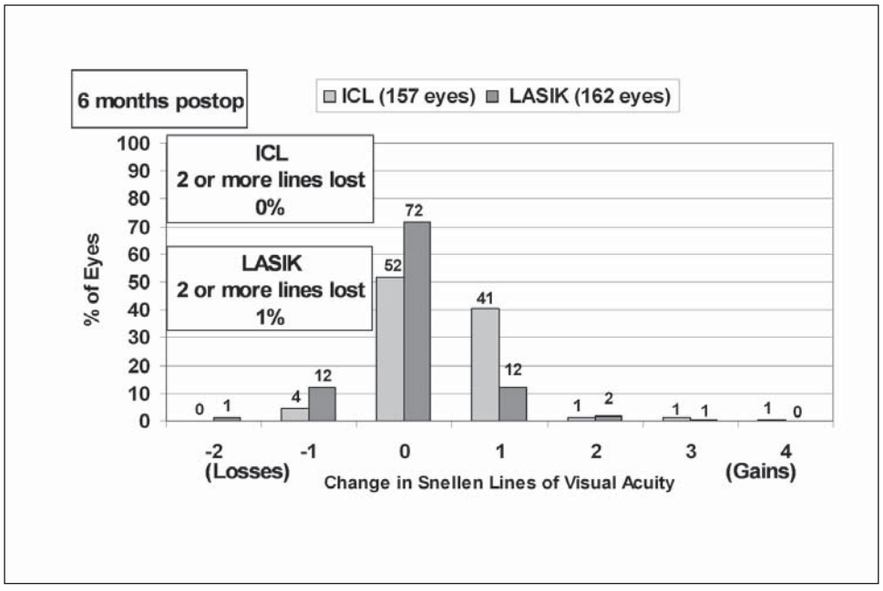

Figure 3. Change in best spectacle-corrected visual acuity at 6 months postoperatively compared to preoperative values for the LASIK and Implantable Collamer Lens (ICL) series.

Safety Outcomes

Although the proportion of eyes with BSCVA ⩾20/20 was not significantly different between the LASIK and ICL groups preoperatively (93% vs 88%, P=.192), postoperatively at all time periods between 1 week and 6 months the ICL patients demonstrated a larger percentage of eyes with BSCVA ⩾20/20 than their LASIK counterparts (Table 1, Fig 1). The differences were statistically significant at all three postoperative follow-up examinations where BSCVA was measured: 1 week (88% vs 67%, P<.001), 1 month (97% vs 82%, P<.001), and 6 months (95% vs 85%, P=.003). Using the entire distribution of BSCVA values and not just a breakdown at 20/20, the ICL patients had better BSCVA at all postoperative visits between 1 week and 6 months (P<.001).

Preservation of BSCVA was better with the ICL during the immediate healing period and through 6-month follow-up. Loss of ⩾2 lines of BSCVA was significantly higher in the LASIK series in the early healing period (1 week 10% vs 0.6%, P<.001) and at 1-month follow-up (7% vs 0%, P<.001) (Table 1, Fig 2). Improvement in BSCVA (⩾2 lines) was not statistically different between the two groups although the entire distribution of change in BSCVA was statistically better with the ICL at all follow-up examinations through 6 months (P<.001).

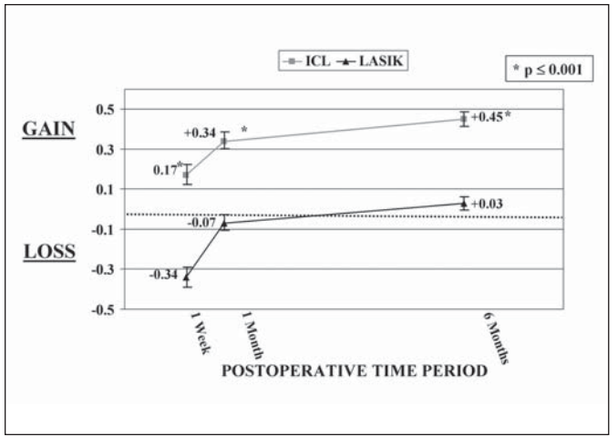

Figure 4. Mean change in lines of BSCVA at each postoperative follow-up examination in the LASIK and Implantable Collamer Lens (ICL) series. Asterisks reflect the statistical significance of the difference between LASIK and ICL series. Brackets enclose 95% confidence intervals for the mean values.

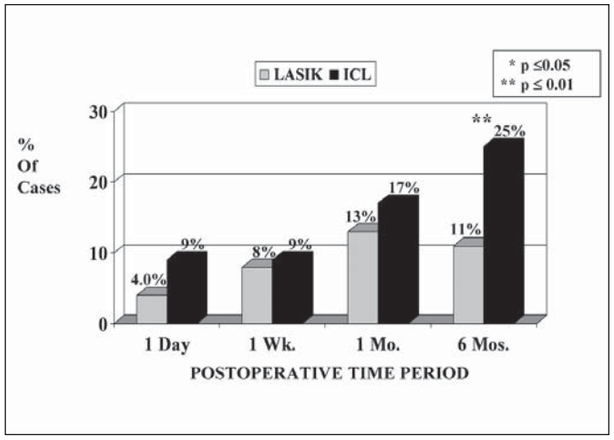

Figure 5. Proportion of cases with UCVA ⩾20/15 at each postoperative follow-up examination in the LASIK and Implantable Collamer Lens (ICL) series. Asterisks reflect the statistical significance of the difference between LASIK and ICL series.

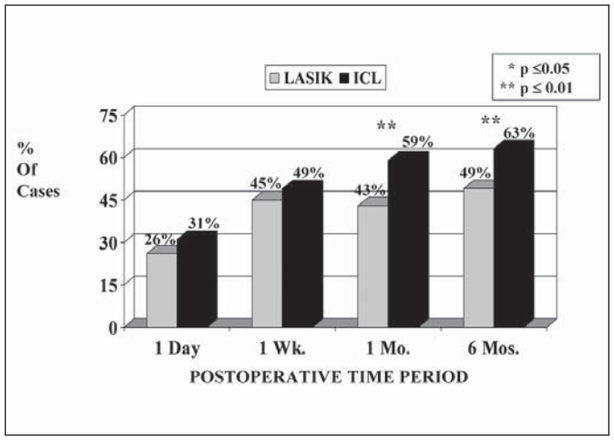

Figure 6. Proportion of cases with UCVA ⩾20/20 at each postoperative follow-up examination in the LASIK and Implantable Collamer Lens (ICL) series. Asterisks reflect the statistical significance of the difference between LASIK and ICL series.

These differences between the two surgical procedure groups were also noted when comparing gains and losses of ⩾1 line of BSCVA (Table 1). Losses of ⩾1 line of BSCVA were significantly higher in the LASIK series at 1-week (31% vs 15%, *P*=.003), 1-month (19% vs 7%, *P*=.001), and 6-month follow-up (14% vs 5%, *P*=.006). Improvement of ⩾1 line BSCVA was better with the ICL series at all time periods studied (*P*⩽.001 at 1 week and 6 months; *P*=.001 at 1 month). At 6-month follow-up, 44% of patients had an improvement of ⩾1 line of BSCVA in the ICL series at 6-month follow-up compared to 15% in the LASIK series. Figure 3 presents the entire distribution of BSCVA gains and losses at 6 months postoperatively demonstrating a shift of the cases to the right (toward more improvement in BSCVA) in the ICL series relative to the LASIK series.

The mean change in BSCVA was significantly better with the Visian ICL than with LASIK at all time periods from 1 week through 6-month follow-up (Table 1, Fig 4). Improvements were noted at 1 week postoperatively in the ICL series and reached approximately a ½ line gain at 6-month follow-up. The LASIK series showed an average loss of BSCVA at 1 week postoperatively, a minimal loss/no change at 1 month with essentially no change in BSCVA at 6 months postoperatively. At all time periods, the ICL group demonstrated significantly more improvement in BSCVA than the LASIK group (*P*<.001).

Secondary Surgeries/Adverse Events

During the 6-month course of this study, one (0.6%) ICL was replaced within the first postoperative week because the ICL was too long, and one (0.6%) ICL was repositioned twice due to two improper rotational placements of the ICL. Six (3.7%) eyes underwent an additional YAG iridotomy during the postoperative period usually due to acute pressure rises, which resolved after the YAG procedure, and one (0.6%) eye had a YAG procedure postoperatively that did not undergo one prior to ICL implantation. No (0.0%) ICL removals occurred during the course of the study. None of these events were associated with a significant loss of BSCVA.

No anterior subcapsular crystalline lens opacities were noted. Furthermore, no cataract extractions were performed on any patient during the course of the study. No ICL cases were treated with LASIK or had an ICL replacement for improper refractive correction.

Re-treatments with the laser (enhancements) oc-

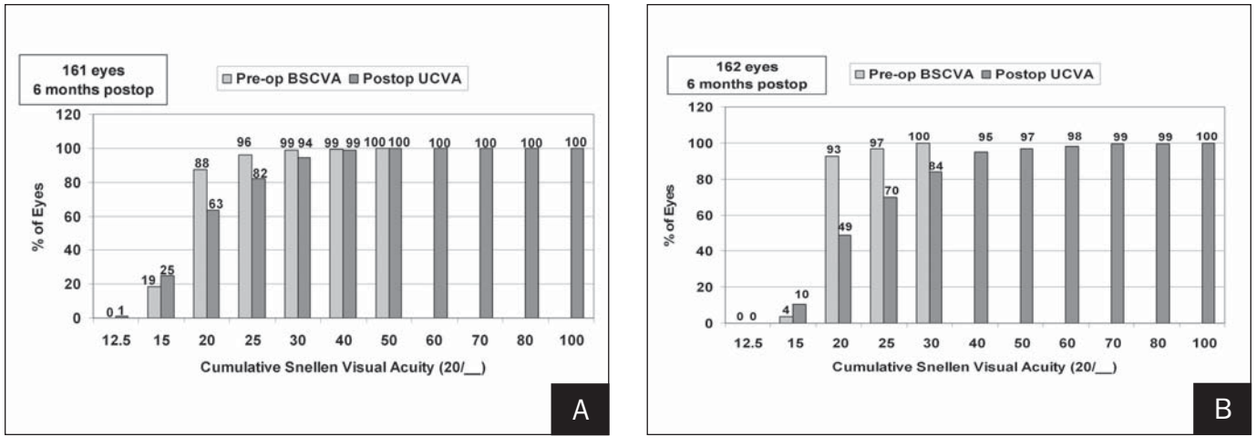

Figure 7. The proportion of eyes with preoperative best spectacle-corrected visual acuity (BSCVA) compared to 6-month postoperative uncorrected visual acuity (UCVA) for the **A)** Implantable Collamer Lens series and **B)** LASIK series.

curred in 15 (9.1%) LASIK eyes in the first 6 postoperative months. Diffuse lamellar keratitis (DLK) was diagnosed and treated in 11 (6.7%) eyes; 2 (1.2%) eyes required the flap to be lifted as part of the treatment. Striae were noted in the corneal flap in 3 (1.8%) eyes, and in 2 (1.2%) of these eyes, the flap was lifted to smooth out the striae. Two (1.2%) additional cases were observed with extremely thin flaps and 1 (0.6%) case demonstrated corneal ectasia. Only 1 case with a complication, a patient treated for DLK, demonstrated a loss of 2 lines of BSCVA (20/20 to 20/30) at 6-month follow-up. Of the 17 cases noted with one of the above complications, 1 (6%) case had 20/30, 2 (12%) had 20/25, and 14 (82%) had ⩾20/20 BSCVA at 6 months postoperatively.

Effectiveness Outcomes

Uncorrected visual acuity improved dramatically in both groups (Table 1). The proportion of cases seeing ⩾20/15 was numerically higher in the ICL series at all postoperative time periods and was significantly better at 6 months postoperatively (25% vs 11%, P=.001) (Fig 5). The proportion of cases with UCVA ⩾20/20 was significantly higher in the ICL group at 1 month (59% vs 43%, P=.011) and 6 months postoperatively (63% vs 49%, P=.010) (Fig 6). Although the proportion of cases with UCVA ⩾20/40 was significantly better in the LASIK series on the first postoperative day (84% vs 70%, P=.004), the proportion of eyes with UCVA ⩾20/40 was numerically higher in the ICL series at 1 week, 1 month, and 6 months but the differences were not statistically significant. Using the entire distribution of UCVA values and not just the 20/15, 20/20, or 20/40 cutoffs, the ICL was significantly better than LASIK at 1-month (P=.01) and 6-month (P<.001) follow-up.

Figures 7A and 7B provide comparisons of preoperative BSCVA to 6-month UCVA outcomes for the ICL and LASIK series, respectively. Uncorrected visual acuity appeared to approach BSCVA at better levels of visual acuity in the ICL series. Preoperatively, 88% of ICL patients saw 20/20 BSCVA and 63% saw 20/20 UCVA at 6 months postoperatively, a differential of 25%, whereas in the LASIK patients, 93% saw 20/20 BSCVA preoperatively and only 49% saw 20/20 UCVA at 6 months postoperatively, a differential of 44%. This differential also favored the ICL series at ⩾20/25 (14% ICL vs 27% LASIK) and ⩾20/30 (6% ICL vs 16% LASIK).

Predictability (attempted vs achieved correction) favored the ICL at all postoperative visits and was statistically better at 6 months postoperatively with regard to ±0.50 D (LASIK 67%, ICL 85%; P<.001) and ±1.00 D (LASIK 88%, ICL 97%; P=.002) (Table 1). Examination of the scattergrams demonstrates more variability in the LASIK group and a tendency to undercorrect especially for attempted corrections >6.00 D (Fig 8).

Postoperative defocus equivalent refraction ±0.50 D and ±1.00 D tended to slightly favor the LASIK group; however, the differences were not statistically significant (Fig 9).

Although significantly more refractive cylinder was noted in the LASIK series preoperatively than in the ICL series (0.74 vs 0.58 D, P=.037), there was significantly less in the LASIK series at all postoperative visits (P<.001) (Table 1). There was approximately half the amount of astigmatism present in the LASIK series (0.23 to 0.25 D) compared to the ICL series (0.50 to 0.56 D) postoperatively.

The stability of refraction (proportion of cases with ⩽0.50-D change) was significantly better in the ICL se-

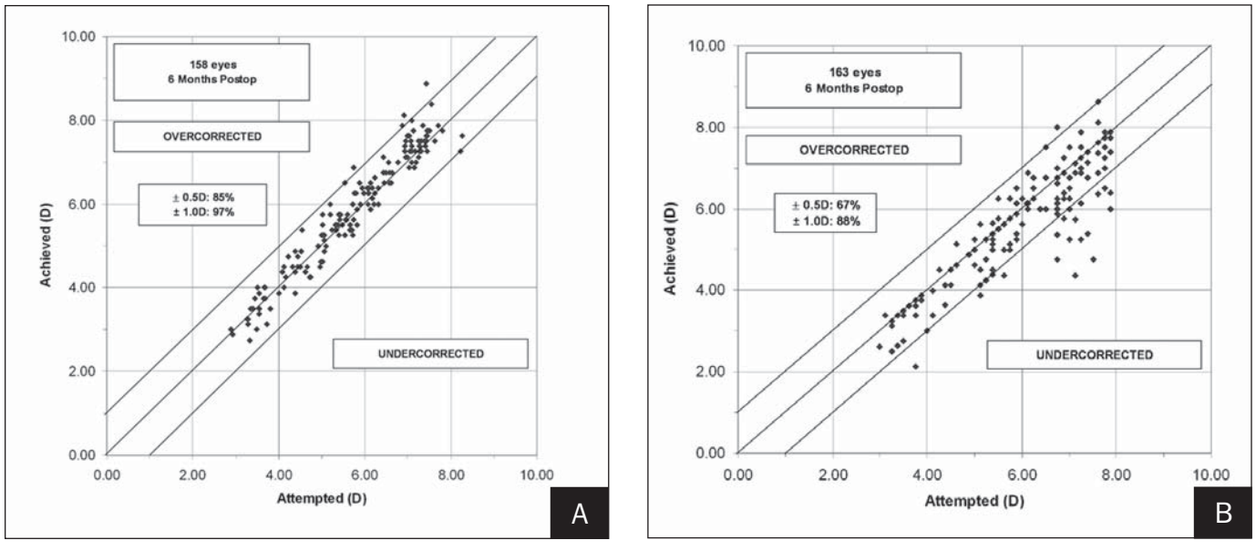

Figure 8. Scattergrams illustrating the spherical equivalent manifest refraction attempted versus achieved outcomes for the **A)** ICL series and **B)** LASIK series.

ries compared to the LASIK series through 6 months (Table 1). The proportion of eyes with a ≤0.50-D change between 1 month and 6 months was 93% in the ICL series and 82% in the LASIK series ($P<.006$). The stability of refraction (proportion of cases with ≤1.00-D change) was excellent (≥95%) in both groups (97% LASIK and 99% ICL) between 1 month and 6 months and was not statistically different. There was a statistically significant advantage with the ICL with regard to ≤1.00-D change between 1 week and 1 month (92% LASIK, 99% ICL, $P=.009$).

The stability of refraction graphs over time demonstrated good refractive stability in both groups (Fig 10). The postoperative spherical equivalent refraction outcome bar graphs for the ICL and LASIK groups at 6 months postoperatively are given in Figure 11. The ICL group had significantly more cases within ±0.50 D (91% vs 67%, $P<.001$) and ±1.00 D (99% vs 88%, $P<.001$) of emmetropia than the LASIK group.

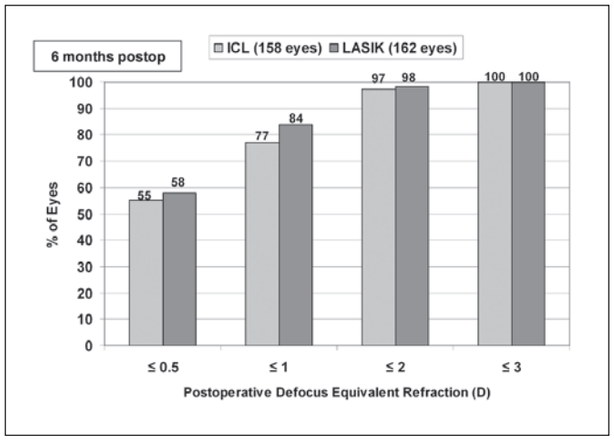

Figure 9. Comparison of 6-month postoperative defocus equivalent refraction outcomes in the LASIK and ICL series.

DISCUSSION

The most ideal method to compare these refractive techniques would involve conducting both the ICL and LASIK procedures under one randomized, prospective protocol. In this report, ICL cases from a US clinical trial were compared to prospectively collected LASIK cases from one medical center. Despite the prospective nature of the data collection in the LASIK series, the quality of data collected from the ICL US prospective clinical trial is probably more precise, complete, and reliable than that of the LASIK case-control series, with the ICL testing procedures and data collection being performed under a strict standardized protocol in contrast to the usual testing techniques in clinical practice. In addition, although this study was case-matched for certain variables, other factors as yet unknown can notably affect patient outcome, highlighting the importance of using the same comprehensive inclusion/exclusion criteria for both groups as well as randomization of the refractive treatment technique to minimize selection bias. A randomized prospective study design would provide a more precise comparison, yet a large case-control study of the ICL and LASIK series was well matched for key variables of preoperative MRSE, age, and gender, and a randomized trial may be impractical in a real world environment.

The ICL and LASIK outcomes presented in this article were compared to the FDA's target values for safety

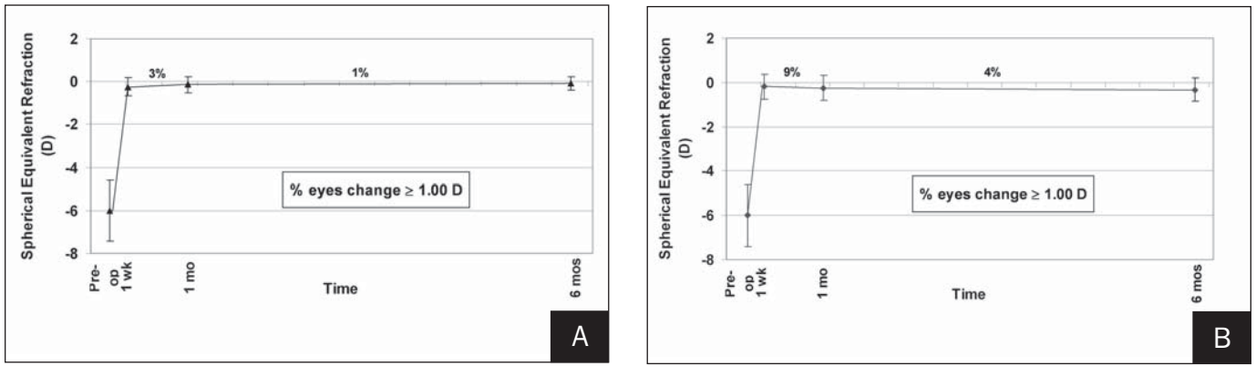

Figure 10. Stability of refraction graphs for the **A)** Implantable Collamer Lens series and **B)** LASIK series.

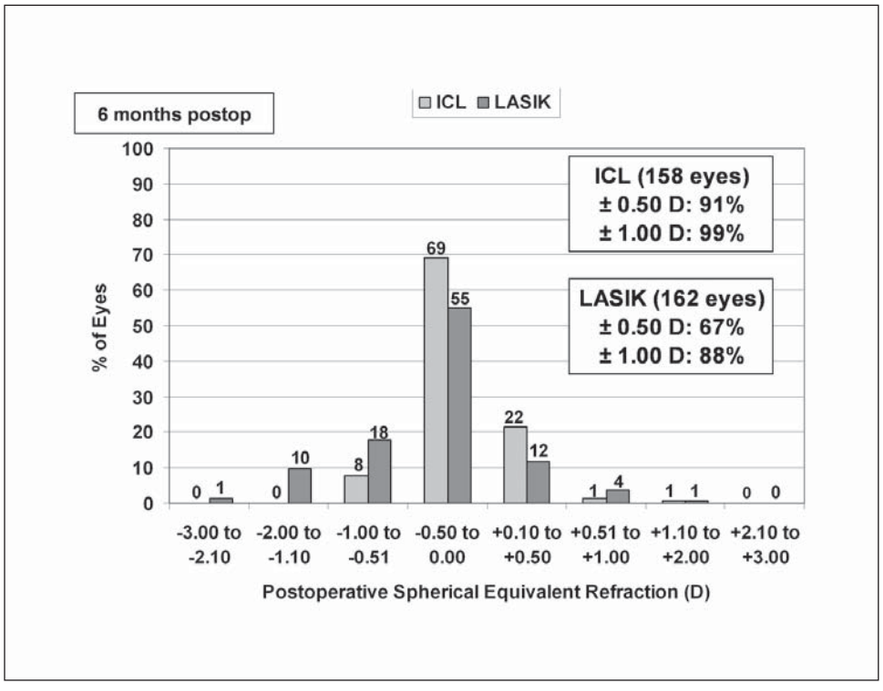

Figure 11. Six-month postoperative spherical equivalent manifest refraction graphs for the Implantable Collamer Lens (ICL) and LASIK series.

and efficacy (Table 2) as set forth in the "US Refractive Implants Guidance for Investigational Device Exemptions (2000)" and the "Checklist of Information Usually Submitted in an Investigational Device Exemptions (IDE) Application for Refractive Surgery Lasers (96)."

All of the reported ICL outcomes from the US Visian ICL study and LASIK outcomes from our series were better than the safety and efficacy FDA target values for preoperative myopia (MRSE) ⩽7.00 D and thus both procedures appear to be safe and efficacious for this level of myopia through 6-month postoperative follow-up.

In earlier publications, the authors presented two comparative analyses between the ICL and LASIK series, the first in the treatment of moderate to high myopia (−8.00 to −12.00 D)[3] followed by an analysis in a lower myopia patient series (−4.00 to −7.88 D).[4] In the moderate to high myopia population, every index of BSCVA/UCVA, predictability of refraction, and stability of refraction studied favored the ICL over the LASIK procedure in this range of correction.[3] In the low myopia evaluation, BSCVA of ⩾2 lines, the distribution of change in BSCVA, the proportion of eyes seeing 20/15 and 20/20 uncorrected, the proportion of eyes with predictability (within ±0.50 and ±1.00 D), and the stability of refraction (±0.50 and ±1.00 D change between 1 and 6 months) were all significantly better with the ICL compared to LASIK.[4]

In the two aforementioned comparative articles, no attempt was made to match the ICL and LASIK patient series beyond the range of preoperative myopia, and in

TABLE 2

Comparison to FDA Refractive Target Values at 6 Months Postoperative

	Percentage		
Variable	**LASIK**	**ICL**	**FDA Refractive Target Value**
BSCVA ⩾2 line loss	1	0	<5, refractive implants
UCVA ⩾20/40*	95	99	85, ⩽7.00 D preop MRSE
Predictability ±1.00 D	88	97	75, ⩽7.00 D preop MRSE
Predictability ±0.50 D	67	85	50, ⩽7.00 D preop MRSE
Stability endpoint criteria	92† (1 week to 1 month)	99 (1 week to 1 month)	95, ⩽1.00-D change between two consecutive visits

BSCVA = best spectacle-corrected visual acuity, UCVA = uncorrected visual acuity, MRSE = manifest refraction spherical equivalent
**Eyes with preoperative BSCVA ⩾20/20.*
†97% (1 month to 6 months).

both the moderate to high and low myopia analyses, the mean preoperative level of myopia was higher in the ICL study cohort. In the current series, the populations were well matched for preoperative spherical equivalent refraction, age, and gender. Myopia as low as 3.00 D was treated in both groups whereas in the previous low myopia comparison no patients were treated with <4.00 D of myopia.

The results in this current series were similar to the previously reported low myopia series[4] with the same parameters being statistically significantly better in the ICL group. In the previous series, all LASIK procedures were performed with the VISX S2 software and in this series all were performed with the VISX S3 software. The LASIK series reported here represented the current state of the art in LASIK surgical technique, laser/microkeratome equipment, and operative parameters during the dates of the study. During the time frames of these studies, wavefront-guided ablation (VISX STAR S4 CustomVue[6,7] and Alcon Laboratories Inc LADARVision4000 CustomCornea[8] excimer laser systems) and other subsequent improvements had not been approved and were not used as a comparison group but would provide a suitable comparator group for future studies. A randomized prospective trial of wavefront-guided ablation versus the use of the ICL is planned for early 2007.

The rate of complications in the LASIK series seems somewhat high; however, the visual results in these cases with complications were good, indicating that the complications were mild in nature. A significant visual loss (2 line loss of BSCVA) due to a complication occurred in only 1 (0.6%) of 164 LASIK cases in this series, 1 case had final BSCVA of 20/30, 1 case was 20/25, and the remainder were ⩾20/20. Furthermore, as shown in Table 2, this series surpassed all suggested FDA safety and effectiveness targets for laser refractive procedures so it appears to be at least visually representative of outcomes expected with LASIK.

A search of the literature was performed to obtain other LASIK studies with similar time frames, preoperative myopia, and/or laser software as used in the present LASIK group. The clinical outcomes of these published LASIK cases are listed in Table 3. The rate of complications is less in many of these studies[9-17] compared to the present LASIK group, which includes 6.7% DLK, 1.8% striae, and 0.6% ectasia, although it should be noted that many of the comparable studies had relatively small patient populations.

The typical incidence of DLK, striae, and ectasia after LASIK was also investigated. A review of the peer-reviewed literature found the rate of DLK after LASIK to range from 0.4% to 29%.[18-27] The largest investigation was by Stulting et al,[21] who reported an incidence of 0.4% DLK from 15,119 LASIK cases from 1995 to 2002. Another large retrospective study of 2711 LASIK eyes found an incidence of 1.3% developing DLK, including mild DLK cases.[18] Hoffman et al[19] reported 4% with DLK, with 0.7% progressing to grade 3 DLK, from 1000 consecutive LASIK cases.

A single-center study of 980 consecutive LASIK cases found an incidence of 5.3% DLK, yet this rate reduced after modification to their sterilization techniques.[25] Yuhan et al[24] also reported an incidence of 11% DLK in 92 LASIK cases; however, with an alteration in cleaning procedures and fluids the rate dropped to 2%. The largest incidence was reported by Levinger et al[27] in which 7 (29%) of 24 eyes had grade I to II DLK. It was found that after wiping new microkeratome blades with 100% alcohol the DLK incidence decreased.

The etiology of the 6.7% DLK incidence in the pres-

TABLE 3

Comparison of ICL to Standard LASIK Clinical Outcomes in the Literature (Low to Moderate Myopia)

Study	Sanders (2006) (Current Series)		Twa et al (2005)[9]	
Laser/software	ICL	VISX Star S3	VISX Star S3	B&L Technolas 217A Laser
Date of surgery	11/98 to 9/00	5/01 to 6/02	4/02 to 11/02	4/02 to 11/02
Preop myopia (range) (D)	−3.00 to −7.88	−3.00 to −7.88	−2.13 to −6.00	−1.50 to −7.00
Preop MRSE (D)	−6.01±1.4	−6.01±1.33	−3.81±1.20	−3.88±1.30
Preop astigmatism (D)	+0.58±0.56	+0.74±0.66	⩽3.00	⩽3.00
Follow-up (mo)	6	6	6	6
Study design	Case-control study		Prospective randomized clinical trial	
No. of eyes	161	162	30	30
Results				
Adverse events/complications	See text	See text	None reported	None reported
BSCVA (% ⩾20/20)	95	85	–	–
Loss of BSCVA ⩾2 lines (%)	0	1	0	0
Loss of BSCVA ⩾1 line	5	14	10	10
Improvement of BSCVA ⩾2 lines (%)	3	3	–	–
Improvement of BSCVA ⩾1 line (%)	44	15	10	36.7
Change in BSCVA (mean line change)	+0.45±0.72	+0.03±0.65	–	–
Mean MRSE	−0.09±0.31	−0.33±0.65	–	–
UCVA (⩾20/15) (%)	25	11	–	–
UCVA (⩾20/20) (%)	63	49	77	77
UCVA (⩾20/40) (%)	99	95	100	100
Predictability – attempted vs achieved				
±0.50 D	85	67	83.3	83.3
±1.00 D	97	88	96.7	100
Stability of MRSE (1 to 6 mos)				
±0.50 D	93	82	–	–
±1.00 D	99	97	–	
Re-treatment	–	9.1	–	–

ICL = Implantable Collamer Lens, MRSE = manifest refraction spherical equivalent, BSCVA = best spectacle-corrected visual acuity, UCVA = uncorrected visual acuity, NA = not applicable

ent LASIK group is unknown. Diffuse lamellar keratitis remains an enigmatic condition following otherwise successful LASIK surgery. The condition appears to be multifactorial with no single etiology. Reports have shown that surgeons can help minimize the risk for this condition by decreasing possible surgical trauma or epithelial defects, as well as paying meticulous attention to cleaning procedures, especially that of microkeratomes, their blades, sterilizers, and reservoirs.

Another search of the peer-reviewed literature reported the incidence of flap striae after LASIK to range from 1.1% to 3.5%.[28-32] The variety of causes of flap striae include misalignment of the corneal flap after

	Seward et al (2003)[10]		Giaconi & Manche (2003)[11]	
	VISX Star S3	Autonomous LADARVision	VISX Star S3	VISX Star S2
	—	—	—	—
	−3.10 to −6.00	−3.10 to −6.00	−1.75 to −11.25	−1.50 to −11.25
	−4.73±0.86	−4.43±0.93	−4.74±2.24	−4.65±2.17
	6	6	3	3
	Retrospective single center cohort		Retrospective case-control study	
	49	50	47	47
	None reported	None reported	Resolving central island 4.3%	2.1%
	–	–	–	–
	0	0	0	4.3
	0	0	–	–
	0	0	–	–
	0	0	–	–
	0	0	–	–
	–	–	−0.27±0.09	−0.19±0.53
	–	–	–	–
	–	–	63.9	68
	–	–	95.7	91.4
	88	80	76.6	72.3
	–	–	95.7	91.5
	96 (3 to 6 mo)	90 (3 to 6 mo)	–	–
	–	–	–	–
	18	22	–	–

flap replacement, flap desiccation and contraction during laser ablation, flap wrinkling during stretching, movement of the corneal flap on the first postoperative day, or the tenting effect of the corneal flap over the ablated stromal bed.[33] The present LASIK series had three (1.8%) eyes with striae, yet all cases resolved quickly. Striae are relatively uncommon; nevertheless, careful flap handling and positioning can prevent many striae.

Review of the LASIK literature for ectasia incidence was also performed. Many of the studies had small to medium patient populations (from 15 to 300 LASIK cases) with no report of ectasia,[34-43] although the study with the largest patient population of 2873 LASIK cases reported an ectasia incidence of 0.66% (19 cases).[44] The present LASIK group reported 1 (0.6%) case with ectasia. Ectasia has no single etiology, and cases with no apparent risk factors have been found to develop ectasia. To minimize ectasia incidence, careful screening of patients should exclude those with preexisting keratoconus/forme fruste keratoconus, abnormal topography, and thin corneas.

The improvement in predictability of the ICL at 6 months over the LASIK procedure (LASIK: 67% ±0.50 D and 88% ±1.00 D compared to ICL: 85% ±0.50 D and 97% ±1.00 D) is not unexpected as it is more accurate to manufacture the exact correction required in a HEMA material than to ablate the correction onto corneal tissue, which is then subject to tissue healing. The improvement in predictability is especially dramatic in view of the fact that 9.1% of the LASIK cases required enhancement surgery within the first 6 months postoperatively compared to none of the ICL cases and astigmatism was treated routinely in the LASIK cases, whereas only spherical correction was attempted with the ICL. Similarly, a more rapid stability of refractive outcome would be expected with the ICL compared to a LASIK procedure because the 3-mm clear corneal incision used in the ICL implantation is known from its use in cataract and IOL surgery to have a minimal effect on refraction[45,46] whereas corneal refractive changes with LASIK would be expected to take longer to stabilize.

The cases were not matched with regard to preoperative astigmatism. Although significantly less preoperative cylinder was observed in the ICL versus LASIK groups, there was significantly less postoperative cylinder in the LASIK group as cylinder was corrected whereas only spherical correction was attempted in the ICL group. The LASIK group would have been expected to have better postoperative UCVA based on the larger degrees of uncorrected astigmatism in the ICL group; however, postoperative UCVA was better in the ICL group. This could have been a result of the enhanced predictability in the ICL group and/or possibly due to the improved image quality with the ICL versus the LASIK group due to less postoperative higher order aberrations.[47]

It should be mentioned that data collected as part of routine follow-up as seen in the LASIK group may not have been encouraged to read the maximum lines of

TABLE 3 CONTINUED

Comparison of ICL to Standard LASIK Clinical Outcomes in the Literature (Low to Moderate Myopia)

Study	Balazsi et al (2001)[12]	Fraunfelder & Rich (2004)[13]	
Laser/software	B&L Technolas 217 Planoscan	NIDEK EC-5000	Alcon LADARVision4000
Date of surgery	October 1997 to May 1998	May to December 2001	
Preop myopia (mean/range) (D)	−0.50 to −7.00	−1.00 to −10.00	−1.00 to −10.00
Preop MRSE (mean/range)(D)	−4.01±1.59	−4.25±1.83	−4.86±2.67
Preop astigmatism (D)	⩽2.50	⩽4.00	⩽4.00
Follow-up (mo)	6	6	6
Study design	Prospective single center trial	Retrospective review	
No. of eyes	236	54	60
Results			
Adverse events/complications	None reported	None reported	None reported
BSCVA (⩾20/20) (%)	–	–	–
Loss of BSCVA ⩾2 lines	0	–	–
Loss of BSCVA ⩾1 line	11.3	–	–
Improvement of BSCVA ⩾2 lines	8	–	–
Improvement of BSCVA ⩾1 line	45.1	–	–
Change in BSCVA (mean line change)	–	–	–
Mean MRSE	+0.02±0.64	–	–
UCVA (⩾20/15) (%)	–	–	–
UCVA (⩾20/20) (%)	81.9	50	41.7
UCVA (⩾20/40) (%)	94.6	87	85
Predictability – attempted vs achieved			
±0.50 D	73	61.2	55
±1.00 D	91	90.8	80
Stability of MRSE (1 to 6 mo)			
±0.50 D	89 (3 to 6 mo)	–	–
±1.00 D	99 (3 to 6 mo)	–	–
Re-treatments	None	–	–

ICL = Implantable Collamer Lens, MRSE = manifest refraction spherical equivalent, BSCVA = best spectacle-corrected visual acuity, UCVA = uncorrected visual acuity

UCVA or BSCVA as is usually mandated in a clinical study. This is a well-known study effect, especially at the higher visual acuity levels such as 20/20 and 20/15. Interestingly, the same trends in improved UCVA in the Visian ICL group were also seen at the 20/40 level.

The efficacy outcomes of similar LASIK series (ie, comparable time frames, preoperative myopia, and/or laser software to the current LASIK group) are listed in Table 3 and compared to the Visian ICL results. Three studies used the same laser software as the present LASIK group (VISX Star S3) and were treated for low to moderate myopia.[9-11] Twa et al[9] performed LASIK on 30 eyes for −2.00 to −6.00 D of myopia. When comparing the results to the present ICL group, the preservation and improvement of BSCVA was much better in the ICL series, although UCVA and predictability of refraction were comparable to the ICL results. Seward et al[10] used similar techniques on 49 eyes; the improvement in BSCVA did not compare to that of the ICL group (0% vs 44%; improvement ⩾1 line), yet the

Caster et al (2005)[14]	Goes (2005)[15]	Lin & Tsai (2005)[16]		Nuijts et al (2002)[17]
Alcon LADARVision4000	Zeiss Meditec MEL 80	Schwind Keratome Multiscan		B&L 217z Planoscan
May to October 2003	–	August 1999 to April 2002		–
≤−7.00	−1.00 to −8.25	–	–	−4.35±2.11/ −0.25 to −6.5
−3.62±1.9	−4.41±1.98	−5.36±0.67/ −4.00 to −5.90	−8.15±0.94/ −6.00 to −9.99	–
≤2.50	≤2.75	≤1.50	≤1.50	−1.02±1.08/≤4.00
3	12	6	6	6
Prospective study	Prospective consecutive series	Prospective study		Prospective study
20	68	98	110	12
–	Microstriae−7.4%	DLK−1%	Decentration 0.9%	None reported
95	–	–	–	100
0	0	2	1.8	0
–	–	4.1	4.5	0
–	13	–	–	8.3
–	67	–	–	41.7
–	–	–	–	–
−0.42	0.13±0.30	−0.56±0.90	−0.67±1.00	Sphere: 0.00±0.21
–	62	–	–	–
45	88	63	63	83
95	100	100	98	100
55	96	71 (at 12 mo)	61 (at 12 mo)	92
–	100	91 (at 12 mo)	82 (at 12 mo)	100
–	–	–	–	–
–	–	–	–	–
None	None	Performed after 6 mo if needed		None

predictability and stability of refraction were comparable to the ICL series (88% vs 85% and 96% vs 93%, respectively). Finally, Giaconi et al[11] performed LASIK for the treatment of −1.75 to −11.00 D of myopia (−4.74±2.24 D MRSE); the results were comparable to the ICL series in regards to uncorrected vision, yet the ICL group showed better predictability (±0.50 D, 76.6% vs 85%).

Several other studies[9-17] are also presented in Table 3 with similar preoperative myopia and/or surgical time frames as in the present LASIK group; however, different laser systems were used.

Of all the reports, Lin and Tsai[16] showed the most similar preoperative MRSE (−5.36±0.67 D vs −6.01±1.33 D) and with a similar time frame. Comparison of the 98 LASIK cases to the ICL group showed that preservation of BSCVA and achieved UCVA were comparable; however, the ICL had better predictability of refraction (±0.50 D: 85% vs 71%; ±1.00 D: 97% vs 91%).

In reviewing the LASIK literature, it is difficult to compare studies to the present ICL and LASIK groups because of the variation in the range of preoperative myopia, laser/software systems, the time frame of the study, and incomplete clinical information. The value of case-matching the ICL and LASIK populations for a more precise comparison is important.

In summary, this matched population comparison of LASIK and ICL cases demonstrated that the ICL performed better than LASIK in almost all measures of safety, efficacy, predictability, and stability of refraction, supporting the ICL as an effective alternative to standard LASIK for the range of myopia studied. Although this large case-control study produced significant results, further investigation may include a prospective, randomized study design to optimize the accuracy of the comparison between these two refractive surgery techniques.

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