Prospective Long-term Evaluation of the Efficacy, Safety, and Stability of the Phakic Intraocular Lens for High Myopia

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Objective: To evaluate the safety, efficacy, predictability, and long-term stability of the Artisan Phakic Intraocular Lens (Ophtec BV, Groningen, the Netherlands) for the correction of high myopia.

Methods: Prospective analysis of 26 eyes from 15 patients who underwent placement of the Artisan lens for the correction of high and extreme myopia. The mean (SD) preoperative spherical equivalent was −12.30 (2.69) diopters (D) (range, −17.25 to −8.25 D).

Results: At 5 years, the mean (SD) manifest refraction was −0.37 (0.69) D, with 95% of eyes within 1 Diopter of attempted correction and 74% of eyes within 0.5 D of the attempted correction. Ninety-five percent of eyes achieved an uncorrected visual acuity of 20/40 or better and 74% achieved an uncorrected visual acuity of 20/20 or better. No eyes experienced a loss of 1 or more lines of best-corrected visual acuity. Sixteen percent of eyes gained 2 or more lines of best-corrected visual acuity. From preoperative measurements, the mean endothelial cell density decreased by 14.05% at 5 years postoperatively.

Conclusions: Placement of the Artisan lens is predictable, stable, and effective at reducing high and extreme myopia 5 years after implantation. The rate of endothelial cell loss was significantly higher than has been reported in previous studies.

Arch Ophthalmol. 2008;126(6):775-781

The prevalence of myopia has been estimated at 25% with increasing trends toward surgical correction. The most widespread surgical procedure for the correction of myopia has been laser in situ keratomileusis. Laser in situ keratomileusis has been shown to be safe and effective for the surgical correction of myopia, but it carries a number of potential limitations in the treatment of eyes with high myopia (≥8.0 diopters [D]), including corneal ectasia, severe night glare, and worsened best-corrected visual acuity (BCVA). These concerns have prompted the expansion of refractive surgery options to include other procedures, such as photorefractive keratectomy, clear lens extraction, and phakic intraocular lens (IOL) implantation. Photorefractive keratectomy initially showed great promise, but recent studies citing poor long-term stability of BCVA and visual disturbances from excess corneal ablation and smaller optical zones have blunted enthusiasm for photorefractive keratectomy, which uses older, conventional excimer lasers. Newer excimer lasers and wavefront-guided ablations have shown promise, and there is renewed interest in performing surface ablation for high myopia. Clear lens extraction has also been employed for many years for the correction of high myopia but has some significant complications limiting its widespread adoption, the primary concern being an increased risk of retinal detachment.

Several categories of phakic IOLs, including angle-supported anterior chamber lenses, posterior chamber lenses, and iris-fixated lenses, are available. The most promising type of phakic IOL is the iris-fixated lens. Originally designed in 1978 to correct aphakia, the iris-fixated lens was modified by Jan Worst into a biconcave structure to correct myopia (the Worst-Fechner claw lens). This was later converted into a convex-concave configuration and approved by the US Food and Drug Administration (FDA) in 2004. To date, the Artisan Phakic IOL (Ophtec BV, Groningen, the Netherlands) is the only FDA-approved, iris-fixated lens in the United States. While the other 2 IOL models resulted in complications of glaucoma, pupillary ovalization, and cataracts, the novel location of the iris-fixated lens implies that eyes may be prone to corneal endothelial
damage. While short-term results of endothelial conservation have been promising, more long-term data are necessary. This study presents 5-year data on the safety, efficacy, predictability, and long-term stability of the Artisan Phakic IOL.

### METHODS

The initial study group consisted of 26 eyes from 15 consecutive patients who underwent surgical implantation of an Artisan Phakic IOL for the correction of high myopia between 1999 and 2000 as part of a prospective, nonrandomized, multicenter, FDA clinical trial. Of the original group, a subset of 19 eyes from 12 patients were evaluated 1 to 6 days, 2 to 3 weeks, 4 to 8 weeks, 4 to 6 months, 1 year, 2 years, 3 years, 4 years, and 5 years after implantation. Comparisons of preoperative and postoperative clinical data were also made for all eyes. Institutional review board approval was obtained from the Stanford University Medical Center.

Inclusion criteria included axial myopia from −5.0 to −20.0 D, anterior chamber depth (ACD) of 3.2 mm or greater, a scotopic pupil diameter shorter than the lens optic size (5-6 mm depending on the lens used), and an endothelial cell density (ECD) of at least 2000 cells/mm². Exclusion criteria included chronic systemic disease, collagen vascular disease, anterior segment pathology, prior corneal/intraocular surgery, glaucoma, and preexisting corneal, lenticular, or retinal pathologic features likely to alter vision.

The preoperative examination included measurement of uncorrected visual acuity (UCVA), BCVA, Jaeger visual acuity, and manifest and cycloplegic refractions and slitlamp biomicroscopy. Goldmann applanation tonometry, fundus examination, and corneal topography. The goal of all of the operations was emmetropia. The ECD was determined by manual counting before and after the operation with a specular microscope (Topcon SP-1000 and SP-2000P Non-Contact Specular Microscope; Topcon Corp, Tokyo, Japan) using 3 consecutive endothelial images. The ECD for each eye was calculated by averaging the 3 consecutive ECD measurements.

A single surgeon (E.E.M.) performed all the procedures in a manner similar to that described elsewhere. The van der Heijde formula, which uses the mean corneal curvature, ACD, and spherical equivalent of the patients’ cycloplegic correction, enabled calculation of the phakic IOL’s power. The Artisan Phakic IOL has a convex-concave UV light–absorbing polymethyl methacrylate optic available with diameters of either 6 mm (for IOL powers from −5.0 D to −15.0 D) or 5 mm (for IOL powers from −5.0 D to −20.0 D). The lens is positioned in the anterior chamber and held in place by fixation of the haptics to the midperipheral iris stroma, creating a bridge over the optical axis. For this study, two 5-mm optic lenses (model 206) and twenty-four 6-mm optic lenses (model 204) were used. The lens is 8.5 mm in overall length with 0.8 mm of vault.

Statistical analysis was performed using Microsoft Excel 2003 (Microsoft Corp, Seattle, Washington). Paired t test or analysis of variance (ANOVA) was used for parametric comparisons. P ≤ .05 was considered statistically significant. Values are given as mean (SD).

### PATIENT POPULATION

Seventeen eyes were from women and 9 were from men. The mean preoperative age was 43.0 (7.62) years (range, 32-56 years). Population characteristics are listed in Table 1. The baseline parameters for all 26 eyes were a mean spherical power of −11.81 (2.93) D (range, −17.00 to −6.75 D), a mean cylindrical power of −0.98 (0.95) D (range, −3.75 to 0.00 D), and a mean spherical equivalent of −12.30 (2.69) D (range, −17.25 to −8.25 D). The mean ACD was 3.87 (0.34) mm (range, 3.2-4.5 mm), and the mean intraocular pressure was 15.5 (1.9) mm Hg (range, 12.0-20.0 mm Hg). The mean preoperative ECD was 2481 (291) cells/mm² (range, 2045-3246 cells/mm²). The mean power of the implanted phakic IOL was −12.73 (2.36) D (range, −9.0 to −17.0 D). The mean preoperative pupil size was 5.5 (0.6) mm (range, 5-6 mm).

### SPHERICAL EQUIVALENT REFRACTION

The study eyes have been followed up for a mean of 4.42 years (3 eyes for <1 year, 2 eyes for 1 year, 2 eyes for 3 years, and 19 eyes for 5 years). Five eyes (19.3%) were lost to follow-up owing to patient relocation or unavailability, while 2 (7.7%) were lost to follow-up owing to

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**Table 1. Baseline Characteristics of Patients Receiving a Phakic Intraocular Lens Implant**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>43.0 (7.62)</td>
</tr>
<tr>
<td>Sex, M/F</td>
<td>9/17</td>
</tr>
<tr>
<td>No. of bilateral cases</td>
<td>11</td>
</tr>
<tr>
<td>6-mm optic lens, No.</td>
<td>24</td>
</tr>
<tr>
<td>5-mm optic lens, No.</td>
<td>2</td>
</tr>
<tr>
<td>Implanted lens power, D</td>
<td>−12.73 (2.36)</td>
</tr>
<tr>
<td>Spherical power, D</td>
<td>−11.81 (2.93)</td>
</tr>
<tr>
<td>Cylindrical power, D</td>
<td>−0.98 (0.95)</td>
</tr>
<tr>
<td>Spherical equivalent, D</td>
<td>−12.30 (2.69)</td>
</tr>
<tr>
<td>ACD, mm</td>
<td>3.87 (0.34)</td>
</tr>
<tr>
<td>IOP, mm Hg</td>
<td>15.5 (1.9)</td>
</tr>
<tr>
<td>ECD, cells/mm²</td>
<td>2481 (291)</td>
</tr>
</tbody>
</table>

**Abbreviations:** ACD, anterior chamber depth; D, diopters; ECD, endothelial cell density; IOP, intraocular pressure.
complications related to the implantation. The preoperative spherical equivalent and its stability postoperatively is shown in Figure 1. There was a mild statistically insignificant hyperopic shift of +0.07 (0.13) D for all eyes from postoperative year 1 to the last visit.

The mean preoperative spherical equivalent refraction was −12.30 (2.69) D (range, −17.25 to −8.25 D). Mean postoperative spherical equivalent refraction was −0.44 (0.56) D (range, −2.00 to −0.38 D) at 1 year, −0.38 (0.78) D (range, −2.63 to −0.50 D) at 3 years, and −0.37 (0.69) D (range, −2.625 to 0.875 D) at 5 years. There was no statistically significant difference among values postoperatively (ANOVA, \( P = .86 \)) (Table 2). The deviation of the achieved vs the intended refractive correction was calculated. After 1 year, 16 of 23 (69.6%) eyes were within 0.5 D of the desired refraction, 21 of 23 (91.3%) eyes were within 1.0 D, and all eyes were within 2.0 D. After 3 years, 15 of 19 eyes (78.9%) were within 0.5 D of the desired refraction, 17 (89.5%) were within 1.0 D, and 17 (89.5%) were within 2.0 D, with the remaining eye undercorrected owing to progressive myopia since lens implantation (Table 3 and Figure 2).

Astigmatism decreased from 0.98 (1.0) D preoperatively to 0.61 (0.8) D, 0.50 (0.6) D, and 0.50 (0.4) D at years 1, 3, and 5, respectively.

For all eyes, the goal was emmetropia. Attempted corrections averaged −12.59 (2.78) D, while the last visit achieved a mean correction of −12.22 (2.64) D. There was a moderately strong correlation between attempted and achieved corrections with an \( R^2 \) of 0.94 (Figure 2). Predictability, defined as achieved divided by attempted spherical equivalent, is presented in Table 2 and Figure 3 and was 0.97 (0.05) D for all eyes at 5 years.

### Table 2. Spherical Equivalent Refraction and Predictability at Preoperative and Follow-up Visits

<table>
<thead>
<tr>
<th>Visit</th>
<th>No. of Eyes</th>
<th>Spherical Equivalent Refraction, Diopters</th>
<th>Mean (SD)</th>
<th>Range</th>
<th>( P ) Value&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preoperative</td>
<td>26</td>
<td>−12.30 (2.69)</td>
<td></td>
<td>−17.25 to −8.25</td>
<td></td>
</tr>
<tr>
<td>Postoperative follow-up</td>
<td>23</td>
<td>−0.44 (0.56)</td>
<td></td>
<td>−2.00 to −0.38</td>
<td>.89</td>
</tr>
<tr>
<td>1 y</td>
<td>20</td>
<td>−0.38 (0.78)</td>
<td></td>
<td>−2.63 to −0.50</td>
<td></td>
</tr>
<tr>
<td>3 y</td>
<td>19</td>
<td>−0.37 (0.69)</td>
<td></td>
<td>−2.625 to 0.875</td>
<td>.65</td>
</tr>
<tr>
<td>5 y predictability&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19</td>
<td>0.97 (0.05)</td>
<td></td>
<td>0.84 to 1.11</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Comparing spherical equivalent refraction with value at 1 year postoperatively.

<sup>b</sup> Achieved divided by attempted spherical equivalent.

### Table 3. Refractive Predictability After Phakic Intraocular Lens Implantation

<table>
<thead>
<tr>
<th>Refraction, Diopters</th>
<th>1 Year Postoperatively (n=23)</th>
<th>3 Years Postoperatively (n=20)</th>
<th>5 Years Postoperatively (n=19)</th>
</tr>
</thead>
<tbody>
<tr>
<td>±0.5</td>
<td>16 (69.6)</td>
<td>15 (75.0)</td>
<td>14 (73.7)</td>
</tr>
<tr>
<td>±1.0</td>
<td>21 (91.3)</td>
<td>17 (85.0)</td>
<td>18 (94.7)</td>
</tr>
<tr>
<td>±2.0</td>
<td>23 (100.0)</td>
<td>17 (85.0)</td>
<td>18 (94.7)</td>
</tr>
</tbody>
</table>

### Figure 2. Spherical equivalent refractive outcomes after Artisan Phakic Intraocular Lens (Ophtec BV, Groningen, the Netherlands) implantation at 1, 3, and 5 years postoperatively. After 5 years, 73.7% of eyes (n=14) were within 0.5 diopter (D) of the desired refraction and 94.7% of eyes (n=18) were within 1.0 D.

### Figure 3. Scatterplot demonstrating the refractive predictability of the spherical equivalent 5 years after Artisan Phakic Intraocular Lens (Ophtec BV, Groningen, the Netherlands) implantation in 19 eyes. Eighteen eyes (94.7%) were within 1.0 diopter (D) of the desired refraction. The line is the best-fit regression of all eyes.

### VISUAL ACUITY

Preoperative UCVA was less than 20/200 in all 26 eyes. At 1 year, 15 of 23 (65.2%) eyes achieved a UCVA of at least 20/20 and 20 of 23 (87.0%) eyes achieved a UCVA.
of at least 20/40. Of 20 eyes, 12 (60.0%) achieved a UCVA of 20/20 or better and 17 (85.0%) achieved a UCVA of 20/40 or better at 3 years. At 5 years, 14 of 19 (73.7%) eyes achieved a UCVA of 20/20 or better and 18 of 19 (94.7%) eyes achieved a UCVA of 20/40 or better.

Preoperatively, 19 of 26 (73.1%) eyes had a BCVA of 20/20 or better. At 1 year, 3 years, and 5 years postoperatively, 22 of 23 (95.7%), 17 of 20 (85.0%), and 18 of 19 (94.7%) eyes, respectively, achieved this acuity. After 1, 3, and 5 years, a BCVA of 20/30 or better was achieved in 23 of 23, 19 of 20 (95.0%), and 19 of 19 eyes, respectively. Postoperative BCVA was significantly better than preoperative values at 1 and 5 years (ANOVA, P < .01). Preoperative BCVAs and postoperative UCVAs are shown in Figure 4.

At 3 years, 1 patient developed a nuclear sclerotic cataract (UCVA, 20/400; BCVA, 20/160) prompting removal of her phakic IOL, and myopia progressed in another patient (UCVA, 20/100; BCVA, 20/30), worsening still at 5 years (UCVA, 20/250; BCVA, 20/25). Otherwise, no significant differences in UCVA or BCVA were noted at any time postoperatively. Best-corrected visual acuity remained the same or improved in 100% of eyes (n = 19) at 5 years. The efficacy index was 0.80 at 1 year, 0.43 at 3 years, and 0.63 at 5 years.

INTRAOCULAR PRESSURE

Mean preoperative intraocular pressure for all 26 eyes was 15.5 (1.9) mm Hg (range, 12.0-20.0 mm Hg). It changed to 15.5 (1.6) mm Hg (range, 12.0-17.0 mm Hg [n = 23]), 16.1 (2.5) mm Hg (range, 11.0-20.0 mm Hg [n = 20]), and 15.9 (1.6) mm Hg (range, 12.0-18.0 mm Hg [n = 19]) at 1, 3, and 5 years postoperatively, respectively.

ECD AND ENDOTHELIAL CELL LOSS

The mean preoperative ECD was 2481 (291) cells/mm² (range, 2045-3246 cells/mm²). After 1, 3, and 5 years, the mean postoperative ECD was 2325 (396) cells/mm² (range, 1203-3018 cells/mm² [n = 21]), 2256 (370) cells/mm² (range, 1086-2634 cells/mm² [n = 20]), and 2156 (495) cells/mm² (range, 1087-2959 cells/mm² [n = 16]), respectively (Figure 5). Mean postoperative ECD was significantly lower than preoperative ECD (ANOVA, P = .01).

Endothelial cell loss was 7.18% at 1 year, 9.98% at 3 years, and 14.05% at 5 years, corresponding to an annual endothelial cell loss of 7.18% (17.28%) (range, −25.87% to 43.64%), 1.18% (3.83%) (range, −6.53% to 6.68%), and 3.15% (7.51%) (range, −11.15% to 19.06%) at 1, 3, and 5 years of follow-up, respectively (Table 1). When stratified by the diameter of the implanted phakic optic lens, the mean endothelial cell loss at 5 years postoperatively was 16.10% (21.00%) and −0.28% (10.02%) for optic lenses with diameters of 6 mm (n = 14) and 5 mm (n = 2), respectively. The difference observed between these 2 groups did not reach statistical significance (t test, P = .17). No significant correlation was found between the preoperative ACD and endothelial cell changes after 5 years (r² = 0.029).

COMPLICATIONS

There were no intraoperative complications for any of the eyes. Two eyes (7.7%) were lost to follow-up owing to complications following implantation of the phakic
IOLs. One eye (3.8%) developed 3+ nuclear sclerosis 3 years postoperatively necessitating phakic IOL explantation with simultaneous cataract extraction and IOL implantation and subsequent photorefractive keratectomy for residual astigmatism. We did not feel the nuclear sclerotic lens changes were a result of the placement of the phakic IOL. The second eye (3.8%) lost to follow-up developed severe visual glare and halos postoperatively, requiring explantation of the phakic IOL without complications. Other reported complications, such as iris retraction and atrophy,23 pupil ovalization,23,24 ocular hypertension, and retinal detachment,23 were not observed in our study cohort. No eyes in our study lost more than 2 lines of BCVA at 5 years (Figure 6).

This study sought to evaluate the 5-year stability, predictability, safety, and efficacy of the Artisan Phakic IOL for the correction of high myopia, for which there exists only 1 study of equal or longer duration to our knowledge.9 The 19 eyes from the 12 patients for whom we present this analysis represent 73% of the initial pool of 26 eyes from 16 patients who had undergone Artisan Phakic IOL implantation.

The dearth of long-term data on Artisan Phakic IOL implantation contrasts with the numerous studies evaluating short-term refractive outcomes.19-21,26-34 Despite entailing a significantly variable follow-up period (between 1 week to 2 years postoperatively), the stability of phakic IOLs is perhaps evinced in nearly every study’s avowal that at least 90% of eyes were within 1 D of the attempted correction at any postoperative instance. Multi-year studies (with a cumulative power represented by > 400 patients) demonstrate similar results, citing mean spherical equivalents at last visits almost always within 0.25 D of desired values several months postoperatively. Currently, the long-term data, albeit limited, show comparable constancy. The longest study to date, a 10-year retrospective report examining outcomes in 89 eyes from 49 patients who underwent phakic IOL implantation for high myopia, reported a mean spherical equivalent of −0.70 (1.00) D (range, −4.00 to 2.00 D), with 65.2% and 92.8% of eyes within 1.0 D and 2.0 D of attempted refraction, respectively.20 We report similar outcomes at 5 years with the slight undercorrection noted immediately postoperatively, ultimately proving beneficial in offsetting the subsequent modest, though anticipated,23 hyperopic shift.

The aforementioned short-term studies show favorable outcomes regarding visual acuity, with all reports indicating at least 85% of implanted eyes demonstrating a postoperative BCVA of 20/40 or better and at least 60% of eyes gaining 2 or more Snellen lines of BCVA.19-21,26-34 Additionally, more than 80% of eyes in the studies demonstrated a UCVA of 20/40 or better (with preoperative UCVA generally ≈ 20/200). Safety is illustrated by nearly all studies reporting no loss of 2 or more Snellen lines of BCVA (the isolated studies reporting eyes with a loss of ≥ 2 Snellen lines were in the context of progressive age-related cataracts, which the authors claim were independent of the implanted lenses).19-21,26-34

Similarly, long-term results from a 10-year retrospective study reported 92.5% of eyes achieving a BCVA and 79.7% of eyes achieving a UCVA of 20/40 or better at last visit.5 They report 3.6% (n=2) of eyes losing more than 2 Snellen lines of BCVA, which they attribute to corneal dystrophy and cataract formation unrelated to the phakic IOL.

Our study reflected slightly better outcomes, with a BCVA of at least 20/40 achieved in 100% of eyes and no eyes losing 2 or more Snellen lines of visual acuity at 5 years. Given the anterior chamber location of the Artisan Phakic IOL, initial concerns were of putative endothelial damage.36 Of importance in interpreting ECD changes is the reported annual physiologic decline of 0.6% (0.5%) with accompanying increases in polymegethism and pleomorphism.35 There have been numerous, generally concor-

Table 4. Endothelial Cell Density (ECD) in Patients Receiving a Phakic Intraocular Lens Implant

<table>
<thead>
<tr>
<th>Visit</th>
<th>No. of Eyes</th>
<th>ECD, Cells/mm²</th>
<th>ECD Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (SD)</td>
<td>Mean (SD), %</td>
</tr>
<tr>
<td>Preoperative</td>
<td>26</td>
<td>2481 (291)</td>
<td>7.18 (17.28)</td>
</tr>
<tr>
<td>Postoperative follow-up</td>
<td>21</td>
<td>2325 (396)</td>
<td>9.98 (16.85)</td>
</tr>
<tr>
<td>1 y</td>
<td>20</td>
<td>2256 (370)</td>
<td>1086-2634</td>
</tr>
<tr>
<td>3 y</td>
<td>16</td>
<td>2156 (495)</td>
<td>1087-2959</td>
</tr>
<tr>
<td>5 y</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Comparing postoperative mean ECD with preoperative mean ECD.

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Figure 6. Lost and gained Snellen lines of best-corrected visual acuity after Artisan Phakic Intraocular Lens (Ophtec BV, Groningen, the Netherlands) implantation. After 1, 3, and 5 years, 0% (n=0), 5.0% (n=1), and 0% (n=0) of eyes lost more than 2 Snellen lines of BCVA, respectively.
The Artisan Phakic IOL appears to be predictable, effective, and stable for the correction of myopia in eyes with a spherical equivalent of −8.25 to −17.25 D. The ongoing endothelial loss demonstrated in our study is a potentially worrisome trend. We recommend caution in contemplating implantation of these phakic IOLs in young patients or those with compromised endothelial cell counts. Additional studies should address outcomes at even later postoperative times and disparity in the reported ECD changes and should more thoroughly characterize the corneal endothelium postoperatively.

Submitted for Publication: August 31, 2007; final revision received December 2, 2007; accepted December 16, 2007.

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Financial Disclosure: None reported.

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