Multiple regression analysis in nomogram development for myopic wavefront laser in situ keratomileusis: Improving astigmatic outcomes

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PURPOSE: To describe and evaluate a new multiple regression–derived nomogram for myopic wavefront laser in situ keratomileusis (LASIK).

SETTING: Moorfields Eye Hospital, London, United Kingdom.

DESIGN: Prospective comparative case series.

METHODS: Multiple regression modeling was used to derive a simplified formula for adjusting attempted spherical correction in myopic LASIK. An adaptation of Thibos’ power vector method was then applied to derive adjustments to attempted cylindrical correction in eyes with 1.0 diopter (D) or more of preoperative cylinder. These elements were combined in a new nomogram (nomogram II).

RESULTS: The 3-month refractive results for myopic wavefront LASIK (spherical equivalent ≤11.0 D; cylinder ≤4.5 D) were compared between 299 consecutive eyes treated using the earlier nomogram (nomogram I) in 2009 and 2010 and 414 eyes treated using nomogram II in 2011 and 2012. There was no significant difference in treatment accuracy (variance in the postoperative manifest refraction spherical equivalent error) between nomogram I and nomogram II (P = .73, Bartlett test). Fewer patients treated with nomogram II had more than 0.5 D of residual postoperative astigmatism (P = .0001, Fisher exact test). There was no significant coupling between adjustments to the attempted cylinder and the achieved sphere (P = .18, t test).

CONCLUSIONS: Discarding marginal influences from a multiple regression–derived nomogram for myopic wavefront LASIK had no clinically significant effect on treatment accuracy. Thibos’ power vector method can be used to guide adjustments to the treatment cylinder alongside nomograms designed to optimize postoperative spherical equivalent results in myopic LASIK.

Financial Disclosure: No author has a financial or proprietary interest in any material or method mentioned.

available on most excimer laser platforms, using the equation

\[
\% \text{ boost/deboost} = \frac{(1 - a)}{a} \times 100
\]

The dioptric value of the intercept constant (b) can then be subtracted from the target sphere for each subsequent treatment to move the regression line closer to the ideal (attempted MRSE change = achieved MRSE change) position. The task then is to reduce the residual variance or scatter of data points around the regression line.\(^2\)\(^3\)

Many factors other than attempted MRSE change might influence the achieved MRSE change values in LASIK. These include optical zone size,\(^4\)\(^5\) age,\(^4\) and higher-order aberrations (HOAs).\(^6\)\(^8\) We recently described a LASIK nomogram development method based on multiple regression analysis designed to take into account factors other than the attempted MRSE change.\(^9\) Briefly, this approach derives a regression equation that can be used as for simple linear regression to steer percentage adjustments to overall treatment energy (%boost or deboost) based on the slope coefficient for the 4.0 mm pupil wavefront refraction spherical equivalent (WRSE); however, dioptric adjustments to the target sphere are calculated individually for each eye by subtracting the sum of the weighted additional factors plus the intercept constant from the multiple regression equation. In our initial iteration of nomogram development for myopic wavefront LASIK based on this approach, we found that the MRSE minus the 4.0 mm pupil WRSE, maximum pupil minus 3.0 mm pupil WRSE, and central pachymetry were statistically significant additional influences on the achieved MRSE change. We then calculated and applied dioptric adjustments to the target postoperative MRSE for each eye treated using the equation

\[
\text{Dioptic adjustment} = -1 \times |0.444|
\]

\[
\times (\text{MRSE} - 4.0 \text{ mm pupil WRSE}) + 0.206
\]

\[
\times (\text{Max pupil} - 3.0 \text{ mm pupil WRSE}) + 0.0018
\]

\[
\times (\text{central corneal pachymetry in microns}) - 0.87
\]

– target postoperative sphere

We found that customizing the dioptic adjustment to the target postoperative MRSE for each eye using this multiple regression-derived nomogram during treatment planning significantly reduced residual variance in postoperative MRSE results in comparison with an earlier consecutive case series treated using the same myopic wavefront LASIK Customvue platform (version 3.67) treatment planning software, a Wavescan aberrometer, and the Customvue S4 IR excimer laser (all Abbott Medical Optics, Inc.). A similar approach can be applied using most commercially available excimer laser platforms, and the principle of using multiple regression analysis to take into account factors other than the attempted MRSE when planning treatments is equally applicable to nonwavefront-guided LASIK.

In addition to dioptic adjustments to the target postoperative sphere, dioptic adjustments to the target cylinder are available on most refractive excimer lasers. After optimization of the achieved MRSE, the next logical target for nomogram development is to reduce the postoperative refraction cylinder.

Standard refractive reporting charts describe astigmatic results in terms of dioptic cylinder power without reference to the cylinder axis (absolute cylinder).\(^9\) Absolute cylinder results do not distinguish between undercorrection and overcorrection. For example, reducing the absolute cylinder from 2.0 diopters (D) preoperatively to 1.0 D postoperatively could represent a 50% undercorrection if the axis of the preoperative cylinder and postoperative cylinder are the same, or a 50% overcorrection if the axes are 90 degrees apart. Vector analysis, in which polar coordinates are transformed to coordinates described by orthogonal vectors in Cartesian space using double-angle plots,\(^10\) overcomes this difficulty. Using this method, the distance between the preoperative and postoperative cylinder coordinates, calculated using the rules of vector subtraction, defines the achieved cylinder change. Scatterplots of the attempted cylinder change (the preoperative absolute cylinder) versus the achieved cylinder
change can then be used to guide dioptric adjustments to the cylinder in LASIK treatment planning.

Using the power vector notation of Thibos et al., the cylinder component of a spherocylindrical lens is described independent of the sphere by 2 Jackson cross-cylinder vectors (J0 and J45) at 45 degrees (90 degrees in a double-angle plot). Here, we describe the application of this method to pretreatment cylinder adjustment alongside a second iteration of our multiple regression analysis-derived nomogram for refining the treatment sphere in myopic wavefront LASIK. Results for the new nomogram incorporating cylinder adjustments (nomogram II) are compared with results in consecutive cases treated with the earlier nomogram (nomogram I).³

PATIENTS AND METHODS

The project design was reviewed by the Moorfields Research Governance Committee and approved as a prospective audit project. In accordance with the Declaration of Helsinki, informed consent information given to all patients included a lay explanation of the limitations of treatment accuracy, the possible need for repeat treatment, and the use of nomogram adjustments in treatment targeting.

Treatment Details

Eligibility for LASIK was determined using standard criteria.²,³ Aberrometry was performed using a Wavescan aberrometer (software version 3.67). A minimum of 3 scans per eye were taken, alternating between right eyes and left eyes, after up to 5 minutes of dark adaptation or adjustment of ambient lighting with the aim of attaining scans with a 7.0 mm pupil. Pharmacologic pupil dilation was not used. Aberrometric refraction findings were refined by manifest refraction in office-lighting conditions. Cycloplegic refraction was used to croscheck for accommodation in cases with a large disparity between the manifest refraction and the aberrometric refraction or in which accommodation was suspected based on pupil movement during aberrometry. Single scans were selected as a basis for treatment after reviewing Hartmann-Shack and infrared camera images. Criteria taken into account in scan selection included image quality, image centration, wavefront diameter (largest diameter, closest to measured pupil diameter), and regularity of the array of centroid markers within the perimeter of qualifying spots. Treatment programming, performed using Customvue treatment planning software (version 5.22), included a 5% (nomogram I) or 9% (nomogram II) treatment energy boost in all cases based on regression analysis of earlier results. The treatment energy boost is a percentage adjustment to default optical zone (6.0 mm) or blend zone (8.0 mm) diameters were made. Variation in the time between flap elevation and the commencement of treatment (and therefore tissue hydration) was minimized by locking the pupil and iris-tracking mechanism before flap elevation when possible; interface gas bubbles were used as a guide to depth (z-axis) focus. Microscope light and ambient room light levels were minimized during eye-tracking engagement and laser treatment to help patients maintain good fixation.

The postoperative treatment regimen comprised unpreserved topical levofloxacin 0.3% and dexamethasone 0.1% every 2 hours for 1 week with topical fluorometholone 4 times a day for the succeeding 2 weeks and unpreserved topical lubricants as required.

Nomogram II: Sphere Adjustment

A sample of 222 consecutive eyes treated with nomogram I from the series we reported earlier was reanalyzed using Minitab 15 statistical processing software (Minitab, Inc.) after tabulation of the following indices in an Excel spreadsheet (Microsoft Corp.): 3-month postoperative and preoperative sphere, cylinder, axis, patient age, sex, 4.0 mm pupil wavefront spherical equivalent; maximum pupil minus 3.0 mm WRSE, and central corneal pachymetry. Best subsets and stepwise multiple regression modeling were applied as previously described to derive the following regression equation used for calculation of pretreatment adjustments to the target postoperative sphere for each eye treated with nomogram II (Table 1):

Dioptric adjustment to attempted treatment sphere = \(-1 \times [0.422 \times (\text{MRSE} - 4.0 \text{ mm pupil WRSE}) + 0.024] - \text{ target postoperative sphere}\)

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Partial Correlation Coefficient</th>
<th>Adjusted (R^2)</th>
<th>(P) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0 mm WRSE</td>
<td>1</td>
<td>98.2</td>
<td>.000</td>
</tr>
<tr>
<td>MRSE – WRSE</td>
<td>0.421</td>
<td>98.6</td>
<td>.000</td>
</tr>
<tr>
<td>Max – 3.0 mm WRSE</td>
<td>–</td>
<td>–</td>
<td>&gt; .15</td>
</tr>
<tr>
<td>Pachymetry</td>
<td>–</td>
<td>–</td>
<td>&gt; .15</td>
</tr>
</tbody>
</table>

4.0 mm WRSE = 4.0 mm pupil wavefront refraction spherical equivalent; Max = 3.0 mm WRSE = Maximum pupil minus 3.0 mm pupil wavefront refraction spherical equivalent; MRSE = WRSE = manifest refraction spherical equivalent minus 4.0 mm pupil wavefront refraction spherical equivalent; pachymetry = central corneal thickness; WRSE = wavefront refraction spherical equivalent

*Stepwise multiple regression analysis of 222 consecutive eyes treated with wavefront-guided myopic LASIK using nomogram I. In this analysis, only 4.0 mm WRSE and MRSE – WRSE remained as significant influences (threshold \(P < .15\).
The underlying boost to overall treatment energy calculated at 9% was applied fully for patients treated using nomogram II, whereas a more conservative 5% boost was applied to patients treated using nomogram I. Changes to the overall treatment energy (%boost/deboost) were applied to all cases in each nomogram iteration with a user default setting in the numeric entry field marked “nomogram adjustment” in the Customvue 5.22 treatment planning software.

**Nomogram II: Cylinder Adjustment**

The 3-month postoperative manifest refraction cylinder results in 132 consecutive eyes with a preoperative manifest refraction cylinder equal of 1.0 D or more treated using nomogram I were tabulated against the preoperative manifest refraction cylinder values in the same eyes in an Excel spreadsheet. All degree values for axis were converted to radians to enable trigonometric functions in Excel. The Jackson cross-cylinder value for achieved cylinder change was then calculated as described by Thibos et al.:

\[
J_{0 \text{pre}} = \left(-\frac{C_{\text{pre}}}{2}\right) \cos 2\alpha_{\text{pre}} \\
J_{45 \text{pre}} = \left(-\frac{C_{\text{pre}}}{2}\right) \sin 2\alpha_{\text{pre}} \\
J_{0 \text{post}} = \left(-\frac{C_{\text{post}}}{2}\right) \cos 2\alpha_{\text{post}} \\
J_{45 \text{post}} = \left(-\frac{C_{\text{post}}}{2}\right) \sin 2\alpha_{\text{post}} \\
J_{\text{CC achieved}} = \sqrt{\left(J_{0 \text{post}} - J_{0 \text{pre}}\right)^2 + \left(J_{45 \text{post}} - J_{45 \text{pre}}\right)^2}
\]

where \(C\) is the dioptric value of the cylinder, \(\alpha\) is the cylinder axis in radians, \(\sqrt{\text{SQRT}}\) is the square root, \(J_{\text{CC}}\) is the Jackson cross cylinder, and \(J_{\text{CC achieved}}\) is the dioptric value for the surgically induced refractive change (Jackson cross cylinder).

A scatterplot of the attempted cylinder versus achieved cylinder (absolute cylinder) was then created (Figure 1, top) using

\[
\text{Attempted cylinder} = C_{\text{pre}} \\
\text{Achieved cylinder} = 2 \times J_{\text{CC achieved}}
\]

A variety of regression line options were then fitted to the scatterplot. Inspection of \(R^2\) values for each regression equation showed that simple linear regression provided the best fit (highest \(R^2\) value). A clear trend toward undercorrection was evident. Based on this, a 0.1 D correction was added to the attempted cylinder for each 1.0 D increase in preoperative cylinder (Table 2) for eyes treated with nomogram II.

**Statistical Comparison of Nomogram I and Nomogram II**

Graphic and descriptive data presentation was prepared in Excel. Except where indicated, Minitab 15 was used for all analyses. Data from consecutive eyes treated with each nomogram were summarized descriptively using standard reporting charts for refractive surgery and plots of attempted correction versus achieved astigmatic correction. The Bartlett test was used to determine whether variance in the postoperative MRSE error differed between groups. Using a threshold of 0.5 D to define clinically significant residual postoperative astigmatism, a 2-tailed Fisher exact test was used to determine whether there were significantly more patients with more than 0.5 D postoperative astigmatism in either group. Simple linear regression analysis, using a \(t\) test comparing the slope to zero to generate a \(P\) value in a scatterplot of preoperative cylinder adjustment versus postoperative
MRSE, was used to examine whether there was any coupling between cylinder adjustment and the achieved refraction sphere.

RESULTS

After exclusions (Table 3), data from 414 eyes treated with myopic wavefront LASIK in 2011 and 2012 with nomogram II were available for analysis. These data were compared with 299 eyes treated in 2009 and 2010 in a dataset previously described for nomogram I. The age and sex profile and ranges of attempted myopic and cylindrical correction were similar in both groups (Table 4).

Refractive and visual results for nomogram I and nomogram II are presented in the standard format in Figure 2 and summarized in Table 4. Visual results were similar; however, more eyes treated with nomogram I had an uncorrected distance visual acuity (UDVA) at the 20/16 or better level (Figure 2, A and B) both preoperatively and postoperatively. There was no significant difference in treatment accuracy (variance in the postoperative MRSE error) between nomogram I and nomogram II ($P = .73$, Bartlett test; Figure 2, E and F). The ratio of overcorrection to undercorrection was well balanced for nomogram II, in which a 9% boost was applied, whereas a trend toward undercorrection was evident for patients treated with nomogram I (Figure 2, G and H).

Fewer patients treated with nomogram II had more than 0.5 D residual postoperative astigmatism ($P = .0001$, Fisher exact test; Figure 2, I and J), and there was a reduced trend toward undercorrection of astigmatism in patients treated with nomogram II (Figure 1).

Pretreatment cylinder adjustment had no significant effect on posttreatment MRSE results (Figure 3).

DISCUSSION

This study evaluated a second iteration (nomogram II) of a multiple regression analysis–based nomogram for myopic wavefront LASIK incorporating a simple method of refining astigmatic results and a simplified calculation of preoperative adjustment to the treatment sphere. Refractive results were better in patients treated with nomogram II. Postoperative astigmatism was reduced with the application of a 10% dioptric addition to the treatment cylinder, and the balance of undercorrections and overcorrections was improved by the application of an additional 4% overall treatment energy boost. We could not find corresponding improvements in postoperative UDVA.

Calculation of the dioptric adjustment to the treatment sphere in nomogram II was simplified without clinically significant loss of treatment accuracy. Age and maximum pupil minus 3.0 mm pupil WRSE dropped out as statistically significant influences (Table 1), leaving the difference between manifest and aberrometric refraction (MRSE minus the 4.0 mm pupil WRSE) as the only remaining modifier for the treatment sphere in addition to the percentage boost based on the WRSE. Although age and maximum pupil minus 3.0 mm pupil WRSE were found to be

<table>
<thead>
<tr>
<th>Table 2. Astigmatism adjustment applied in nomogram II.</th>
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<tbody>
<tr>
<td><strong>Preop Manifest Refraction</strong></td>
</tr>
<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>0 to 0.99</td>
</tr>
<tr>
<td>1 to 1.99</td>
</tr>
<tr>
<td>2 to 2.99</td>
</tr>
<tr>
<td>3 to 3.99</td>
</tr>
<tr>
<td>4 to 4.99</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. Cases excluded from analysis.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exclusion Criterion</strong></td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>Lost to follow-up</td>
</tr>
<tr>
<td>CTK</td>
</tr>
<tr>
<td>Ectasia</td>
</tr>
<tr>
<td>LINE syndrome</td>
</tr>
<tr>
<td>Cataract</td>
</tr>
<tr>
<td>Amblyopia</td>
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</tbody>
</table>

$\text{CTK} = \text{central toxic keratopathy; LINE} = \text{LASIK} = \text{induced neuroepitheliopathy}$

Table 4. Myopic LASIK results: nomogram I versus nomogram II.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nomogram I</th>
<th>Nomogram II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes (n)</td>
<td>299</td>
<td>414</td>
</tr>
<tr>
<td>Patients (n)</td>
<td>165</td>
<td>215</td>
</tr>
<tr>
<td>Year of treatment</td>
<td>2009 to 2010</td>
<td>2011 to 2012</td>
</tr>
<tr>
<td>Mean age (y)</td>
<td>39.9 ± 9.0</td>
<td>37.6 ± 9.7</td>
</tr>
<tr>
<td>Mean attempted sphere (D)</td>
<td>4.1 ± 2.2</td>
<td>4.0 ± 2.1</td>
</tr>
<tr>
<td>Mean attempted cylinder (D)</td>
<td>0.83 ± 0.65</td>
<td>0.85 ± 0.74</td>
</tr>
<tr>
<td>Mean MRSE error (D)</td>
<td>−0.19 ± 0.32</td>
<td>−0.04 ± 0.34</td>
</tr>
<tr>
<td>Variance</td>
<td>0.102</td>
<td>0.106</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.983</td>
<td>0.978</td>
</tr>
<tr>
<td>$\leq ±1.0 \text{D of target SE} (%)$</td>
<td>98</td>
<td>99</td>
</tr>
<tr>
<td>$\leq ±0.5 \text{D of target SE} (%)$</td>
<td>88.3</td>
<td>90.8</td>
</tr>
<tr>
<td>UDVA* ≥ 20/20 (%)</td>
<td>84.2</td>
<td>83.8</td>
</tr>
<tr>
<td>UDVA* ≥ 20/40 (%)</td>
<td>99.5</td>
<td>99.4</td>
</tr>
</tbody>
</table>

$\text{Means ± SD}$

$\text{MRSE} = \text{mean refraction spherical equivalent; SE} = \text{spherical equivalent}$

$\text{UDVA} = \text{uncorrected distance visual acuity (monocular)}$

$\text{*Excludes monovision eyes, which were deliberately undertreated.}$
Figure 2. Visual and refractive 3-month postoperative outcomes for patients treated with nomogram I and nomogram II presented in the standard format (CDVA = corrected distance visual acuity; UDVA = uncorrected distance visual acuity).
Relationship between dioptic addition to the pretreatment cylinder (Table 2) and postoperative SE error for patients treated with nomogram II, showing a weak trend towards more hyperopic outcomes for patients with a larger pretreatment cylinder adjustment. This trend was not statistically significant ($P = .18$, $t$ test; $R^2 = 0.015$) (MRSE = manifest refraction spherical equivalent).

Figure 3. Relationship between dioptic addition to the pretreatment cylinder and postoperative SE error for patients treated with nomogram II, showing a weak trend towards more hyperopic outcomes for patients with a larger pretreatment cylinder adjustment. This trend was not statistically significant ($P = .18$, $t$ test; $R^2 = 0.015$) (MRSE = manifest refraction spherical equivalent).

Cylindrical values are heavily skewed toward the 0.0 to 1.0 D range in most myopic LASIK datasets. Repeatability of manifest refraction cylinder, and in particular cylinder axis values, is relatively low in this range.\textsuperscript{10} We therefore discarded eyes with a preoperative cylinder less than 1.0 D from our starting dataset for analysis of astigmatism. We used more than 0.5 D as a threshold for clinically significant postoperative astigmatism because retreatment would not normally be indicated for lower levels of postoperative astigmatism. Applying different thresholds using the same statistical test, fewer patients treated using nomogram II had more than 0.75 D ($P = .05$) and more than 1.00 D ($P = .045$) of astigmatism postoperatively.

We initially applied a 10% dioptic addition to the treatment cylinder based on vector decomposition of astigmatism without conversion to a Jackson cross-cylinder format.\textsuperscript{10} We then reanalyzed a larger dataset using the method presented here before continuing with a 10% addition to the treatment cylinder in nomogram II. The attractive theoretical feature of conversion to a Jackson cross-cylinder format, as described by Thibos et al.,\textsuperscript{11,12} is that the consideration of cylinder is separated mathematically from the consideration of the SE. Adjustments for cylinder based on this approach can therefore be used as a simple add-on to any nomogram to refine MRSE outcomes in myopic LASIK.

Although Jackson cross-cylinder values have the advantage of spherical neutrality, they are a less intuitive measure of astigmatism for most surgeons when reading plots of attempted change versus achieved refractive change. Accordingly, having derived the surgically induced refractive change to cylinder in a Jackson cross-cylinder format, we doubled it to convert back to an absolute cylinder value representing the achieved astigmatic change. Note that the slope of the regression line, which forms the basis for treatment adjustment, is not altered by this transformation as long as the attempted cylinder change is also plotted in an absolute cylinder format. This is simple to do because the aim in myopic LASIK is almost always to eliminate astigmatism. The attempted astigmatic change is therefore equal to the preoperative manifest refraction cylinder.

We found a more than 20% undercorrection of the cylinder (Figure 1, top); however, we applied only a 10% dioptic addition to the treatment cylinder in nomogram II. We have observed $R^2$ values in the range of 0.7 to 0.8 in linear regression analysis of astigmatic data using the method we describe here. This is lower, and confidence intervals are wider, than for similar analyses of attempted sphere versus achieved sphere in myopic LASIK in which $R^2$ values are typically 0.9 or more.\textsuperscript{7} We would therefore recommend a cautious iterative approach to pretreatment cylinder adjustment, applying small changes initially and reanalyzing results, rather than applying the full correction based on the slope constant and intercept for the scatterplot, as for optimization of the SE.\textsuperscript{3} Additional arguments for a cautious approach to cylinder adjustment include the risk for astigmatic overcorrection if adjustments to overall treatment energy are applied simultaneously, as in the 4% increase between nomogram I and nomogram II reported here, and the risk for spherical overcorrection if changes to the tissue removal pattern associated with changes in astigmatism for the laser platform used are not spherically neutral.

Improved refractive results were not accompanied by improved visual results for nomogram II in this study. We had expected the reduced astigmatism and reduced undercorrections to lead to improvements in postoperative UDVA in patients treated with nomogram II; however, more patients treated with nomogram I attained a UDVA of 20/16 or better.
Analyzing this surprising trend, we observed that preoperative corrected distance visual acuity (CDVA) was also better in the earlier group of patients treated with nomogram I and that the preoperative CDVA appeared to drop during the 18-month period in 2011 and 2012, during which the results for nomogram II were assessed. Refraction testing was performed by the same experienced optometrist using the same protocol throughout the study period for both nomogram I and nomogram II. Demographic indices for the comparator groups and the range of refractive errors treated were similar, although the rate of losses to follow-up was higher for patients treated with nomogram II. Visual acuity testing was performed using the Early Treatment Diabetic Retinopathy Study (ETDRS) logMAR acuity charts projected on a standard-resolution liquid crystal display using Test Chart 2000 software (Thomson Software Solutions). Although this system was correctly calibrated when installed, subsequent checks have showed changes in calibration that reduce letter size by approximately 10%. Although refractive results should not have been affected, this reduction in projected letter size would have led to underestimation of visual acuities for patients treated with nomogram II. Retrospectively, we were unable to determine the timing of this calibration error with any accuracy or whether it was a step change or a drift. We were therefore unable to apply a systematic correction to our acuity results based on the observed calibration error. Screen-based visual acuity testing charts have advantages over standard backlit charts including ease of switching between charts to prevent letter learning and adjustment of letter size to fit the available viewing distance. However, good correlation with measurements from standard backlit charts requires measures to minimize veiling reflective glare from the screen surface and accurate calibration of test type size, luminance, and contrast.15,16

Although we used ETDRS logMAR charts (5 letters per line) to measure visual acuity, a further limitation of our study is that we collected Snellen equivalent data, rounding up if 3 or more letters were read correctly on a line and down if 2 or fewer letters were read. More accurate discrimination between groups could have been achieved with scoring based on the number of letters read,17 rounding up or down only for descriptive data presentation in the standard format.9

Despite flaws in the visual acuity data, we believe improvements in astigmatic refractive results presented here represent proof of principle for a simple method of adjustment to enhance astigmatic results in myopic LASIK. This method can be applied in tandem with any nomogram development method for refining the treatment sphere. These data also show that removing marginal influences from a multiple regression-derived nomogram for myopic wavefront LASIK did not result in a clinically significant loss of treatment accuracy.

It is important to emphasize that although the methods for nomogram development described here are applicable to any laser system, the nomogram we derived is not. Surgeons wishing to adopt this approach, including those using a laser system identical to the one we used, should build from the ground up using their own refractive outcome data.

WHAT WAS KNOWN

- Multiple regression analysis can be used to account for factors additional to the attempted SE refraction change in the development of nomograms to enhance the accuracy of SE refraction outcomes for myopic wavefront LASIK.

WHAT THIS PAPER ADDS

- A simplified multiple regression-derived nomogram from which marginal influences were excluded did not diminish the accuracy of SE refraction results.

- Thibos’ power vector method, which considers astigmatism independent of the refraction SE, can be adapted to guide pretreatment adjustments, enhancing astigmatic results, and used in combination with nomograms designed to optimize the sphere.

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J CATARACT REFRACT SURG - VOL 41, MAY 2015

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