Pilocarpine in the Management of Overcorrection After Radial Keratotomy

Eduardo Laranjeira, MD; Kurt A. Buzard, MD, FACS

ABSTRACT

BACKGROUND: Induced hyperopia is a potential complication of radial keratotomy with few effective treatments. We report the results of a retrospective study to evaluate the effectiveness of pilocarpine in the treatment of eyes overcorrected by radial keratotomy.

METHODS: Sixteen eyes of 14 patients, from a consecutive pool of 200 eyes who underwent radial keratotomy, had hyperopia. The patients were subsequently treated with topical pilocarpine. The patients were treated from 3 to 14 weeks (mean, 8.3 weeks).

RESULTS: The mean time of diagnosis of hyperopia was 3 weeks after the surgery (range, 1 to 12 weeks). The mean spherical equivalent of the manifest (fogging) refraction was +1.92 diopters (D) (range, +0.75 D to +5.00 D) and the keratometric power ranged from 31.26 D to 41.66 D (mean, 38.05 D). Mean uncorrected visual acuity before the treatment with pilocarpine was 20/50. After the treatment with pilocarpine, the mean spherical equivalent refraction was -0.31 D (range, -1.76 D to +0.50 D). The mean keratometric power was 38.32 D (range, 34.87 D to 43.12 D), with a mean uncorrected visual acuity at 20/25. The patients were followed for 8 to 49 weeks after treatment without pilocarpine (mean, 21 weeks). The mean spherical equivalent refraction and keratometric readings after that period were -0.71 D (range, -2.25 D to +0.25 D) and 38.33 D (range, 36.12 D to 43.12 D), respectively. All eyes in this study had more than 1.00 D of reduction of hyperopia at the conclusion of the study.

CONCLUSION: Pilocarpine effectively reduced overcorrections after radial keratotomy. After termination of treatment, the steepening of corneal curvature was maintained. [J Refract Surg. 1996; 12:382-390.]

A significant complication following radial keratotomy is overcorrection and the induction of hyperopia. This may appear in the immediate postoperative period or even years after the procedure. The PERK study reported an 11% incidence of overcorrections greater than +1.00 diopter (D) 1 year after surgery, an increased incidence (17%) of overcorrections 4 years after the procedure, and 23% at 10 years after the procedure. The increased incidence of overcorrection in the years following radial keratotomy has been termed "hyperopic shift." Arrowsmith and Marks reported 33% with overcorrections of more than 1.00 D at 5 years. Deitz et al noted that overcorrections of greater than 1.00 D occurred in 31% of patients 4 years after surgery. Because this technique exhibits a hyperopic shift with time, some surgeons have achieved a lower overcorrection rate by using four incisions, shorter incisions, or intentionally undercorrecting the initial radial keratotomy.

Many different approaches have been used to treat this complication. The medical management of eyes overcorrected by radial keratotomy include contact lens, antiglaucoma medications, and hypertonic agents. Contact lens fitting following radial keratotomy is more difficult than in normal eyes. After the surgery, there is a substantial change in the corneal topography with flattening of the central cornea and steepening of the paracentral cornea. Hofmann et al reported a 56% success rate in fitting rigid gas-permeable contact lenses after radial keratotomy. The incidence of neovascularization in postoperative radi-
Table 1

Results of Pilocarpine Treatment of Eyes With Overcorrection After Radial Keratotomy

<table>
<thead>
<tr>
<th>Eye</th>
<th>Sex</th>
<th>Age (yrs)</th>
<th>Clear Zone Diameter (mm)</th>
<th>Spherical Equivalent Refraction (D)</th>
<th>Mean Keratometric Power (D)</th>
<th>Concentration (%)/Duration (wk) of Pilocarpine Treatment</th>
<th>Time After Cessation of Pilocarpine (wk)</th>
<th>Spherical Equivalent Refraction (D)</th>
<th>Mean Keratometric Power (D) at Final Observation</th>
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<tr>
<td>1</td>
<td>M</td>
<td>44</td>
<td>3.50</td>
<td>-4.50</td>
<td>43.25</td>
<td>4/11</td>
<td>16</td>
<td>-0.25</td>
<td>38.87</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>35</td>
<td>3.25</td>
<td>-4.50</td>
<td>45.25</td>
<td>11/2</td>
<td>32</td>
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<td>41.50</td>
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<tr>
<td>3</td>
<td>F</td>
<td>39</td>
<td>3.00</td>
<td>-7.75</td>
<td>44.56</td>
<td>2/3</td>
<td>16</td>
<td>-0.75</td>
<td>40.87</td>
</tr>
<tr>
<td>4</td>
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<td>46</td>
<td>4.00</td>
<td>-3.00</td>
<td>45.62</td>
<td>2/15</td>
<td>lost to follow up</td>
<td>lost to follow up</td>
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</tr>
<tr>
<td>5</td>
<td>M</td>
<td>42</td>
<td>3.75</td>
<td>-3.75</td>
<td>42.74</td>
<td>4/9</td>
<td>16</td>
<td>plan0</td>
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<tr>
<td>6</td>
<td>F</td>
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<td>3.50</td>
<td>-4.75</td>
<td>42.56</td>
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<td>16</td>
<td>-0.25</td>
<td>37.50</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>47</td>
<td>3.00</td>
<td>-7.25</td>
<td>43.62</td>
<td>2/12</td>
<td>12</td>
<td>-1.00</td>
<td>34.87</td>
</tr>
<tr>
<td>8</td>
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<td>-7.50</td>
<td>43.12</td>
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<td>49</td>
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<td>16</td>
<td>-0.87</td>
<td>43.12</td>
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<td>-7.00</td>
<td>42.93</td>
<td>1/7</td>
<td>36</td>
<td>-0.50</td>
<td>37.25</td>
</tr>
<tr>
<td>12</td>
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<td>12</td>
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<tr>
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<td>-6.75</td>
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<td>47</td>
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</tr>
<tr>
<td>15</td>
<td>M</td>
<td>41</td>
<td>3.25</td>
<td>-5.75</td>
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<td>M</td>
<td>44</td>
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<td>-7.50</td>
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<td>38.33</td>
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<tr>
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This article describes the results of the treatment of overcorrections following radial keratotomy by using pilocarpine, a topical ocular miotic. A possible mechanism of action is suggested in relation to corneal wound healing and the average refraction and keratometric readings before and after the treatment are described.

**PATIENTS AND METHODS**

Sixteen eyes of 14 patients (9 men and 5 women) who had undergone radial keratotomy were subsequently treated with pilocarpine to correct an overcorrection. These patients represented an 8% incidence of overcorrection in a population of 200 consecutive radial keratomies. All surgeries were performed by one surgeon (K.A.B.) over a period of 2 months (January and February) in 1993. The ages ranged from 35 to 53 years (mean, 44 years). The spherical equivalent of the manifest refraction before surgery ranged from -2.00 D to -7.75 D (mean, -5.64 D). The preoperative keratometric readings had a range of 42.56 D to 45.62 D (mean, 43.80 D). The diameter of the clear zone had a range of 3.00 to 5.00 mm (mean, 3.37 mm). All surgery consisted of eight-incision radial keratotomy extending to within 1.00 mm of the limbus. The diamond knife was set at 100% of the thinnest paracentral reading of the pachymetry. The procedures were performed with the two-step technique, described elsewhere. To decrease the rate of
of overcorrections in patients over age 40, the incisions were made intentionally slightly shallow by using the American technique with the knife set at 100% of thinnest paracentral thickness. When there was a doubt between two optical zones to correct the refractive error in the nomogram, the larger one was chosen. Table 1 lists the patient data before the surgery and after treatment with pilocarpine.

Mean time of diagnosis of overcorrection was 3 weeks after the surgery (range, 1 to 12 weeks). All refractions were performed by a certified ophthalmic technician and confirmed by K.A.B. using the manifest refraction with a formal fogging technique. The overcorrection ranged from +0.75 D to +5.00 D (mean, +1.92 D). The mean keratometry reading at the time of diagnosis in the overcorrected group was 36.05 D (range, 31.25 D to 41.00 D). The mean uncorrected visual acuity in the overcorrected group was 20/50 (range, 20/20 to 20/400).

Before the treatment with pilocarpine, direct and indirect ophthalmoscopy were done with every patient. None of the eyes presented with retinal pathology. Most of the eyes were treated initially with pilocarpine 1% four times daily (Table 2). This dose was increased or decreased according to the refraction and the tolerance of the patient to pilocarpine treatment (maximum dose: pilocarpine 4% four times daily). Complaints related to pilocarpine treatment ranged from brow aches and transient visual disturbances to significant photophobia. This was treated by discontinuing the pilocarpine drops and switching to pilogel ointment, which seemed to be generally better tolerated. In some eyes, pilocarpine gel was added at night to enhance the pharmacologic effect, which seemed to work in several eyes.

During the treatment, the retina, refraction, and vision were checked on a weekly basis. The refraction and vision testing was done with medication on
the day of treatment and continued until the patient demonstrated a minus spherical equivalent, at which time the treatment was discontinued.

**RESULTS**

The time of treatment with pilocarpine ranged from 3 to 14 weeks (average, 8.2 weeks). The mean uncorrected visual **acuity** after the treatment was 20/25 (range, 20/20 to 20/70). All eyes had a reduction of at least 1.00 D of the spherical equivalent refrac-

The spherical equivalent refraction after the treatment ranged from -2.25 D to +0.25 D (mean, 0.71 D). The patients were arbitrarily divided into two groups according to age: Group I (between 35 and 45 years) and Group II (between 46 and 55 years). The average spherical equivalent refraction on the treatment was -0.19 D in Group I and -0.38 D in Group II (Table 3). Figures 1 and 2 show the results of spherical equivalent refraction after treatment; the spherical equivalent refraction showed a tendency toward...
myopic shift. Some eyes (eg, eye 16) needed a longer time to have an improvement of the overcorrection. Eyes 3, 6, and 10 had a better response to pilocarpine, and needed the medication just for 3 weeks. Comparing the two age groups, older patients had the highest amount of overcorrection (Table 3). However, in this group, the results seemed to be better than in the younger patients, with good stability. The eyes between 35 and 45 years show variation of the spherical equivalent refraction in the first month of treatment. This response may be related to the effect of pilocarpine on accommodation, which is higher in younger patients. The mean change in manifest refraction in the myopic direction was 2.20 D (Group I: 1.62 D; Group II: 2.78 D), ranging from 1.00 D to 5.00 D. The mean uncorrected visual acuity after the treatment was very similar in both groups: 20/25 in Group I and 20/30 in Group II.

A steepening of corneal curvature with pilocarpine treatment was observed in all patients. The keratometric readings after the treatment ranged from 34.87 D to 43.12 D (average, 38.33 D). The
average keratometry reading was 38.15 D in Group I and 38.48 D in Group II (Figs 3 and 4). Both groups showed a progressive steepening of corneal curvature during the first month of treatment. The variability of spherical equivalent refraction was not noted in the keratometric readings of the youngest patients, with an evolution similar to that of Group II. The mean steepening in keratometric readings was 2.18 D (Group I: 1.78 D; Group II: 2.57 D), ranging from 0.06 D to 6.00 D.

Eyes 4 and 9 were lost to follow up. The mean follow up after stopping the treatment with pilocarpine was 21 weeks (range, 8 to 49 weeks). The average uncorrected visual acuity was 20/25 (range, 20/20 to 20/70). The spherical equivalent refraction during this follow up ranged from -2.25 D to +0.25 D (mean, -0.71 D). In Group I, it was -0.64 D and in Group II, -0.82 D. Figures 5 and 6 represent the evolution of spherical equivalent refraction without pilocarpine in Groups I and II, respectively. The mean keratometry reading during the same period was 38.33 D (range, 36.12 D to 43.12 D). Group I had an average keratometry of 39.12 D and Group II, 38.24 D (Figs 7 and 8, respectively). When comparing the results of
spherical equivalent refraction and keratometric readings during the follow up of 8 to 49 weeks, we observed a continued drift toward myopia and steepening of corneal curvature immediately after stopping pilocarpine without treatment, suggesting that corneal wound healing is continuing.

Table 3 shows comparative results for each group (younger versus older patients) at various times in the study. This data confirms the differences based on age discussed above. The cumulative findings of this study, summarized in Table 4, confirm the overall improvement of the individual cases discussed above.

**DISCUSSION**

Initial overcorrection and/or a progressive refractive hyperopic shift following radial keratotomy is a significant complication of the procedure. Hyperopia greater than +1.00 D has been reported in 3% to 22% of postoperative radial keratotomy eyes 1 year after the procedure.\(^1,3,5,7,14,15\) Progressive overcorrection, or hyperopic shift, of more than +1.00 D has also been documented at 10 years after the surgery: \(^2,3,18\) Arrowsmith, 33%; and \(^5\) Deitz, 31%.

Factors that may contribute to initial overcorrections include: improper selection of the clear zone, an
excessive number of radial incisions, excessively deep incisions, elevated intraocular pressure, unsuspected keratoconus, and poor wound healing which may be related to age, diabetes, and use of corticosteroids. Age has been shown to be an important factor in the incidence of overcorrections, requiring special adjustments and considerations to avoid initial overcorrections in the patients over age 40, which is supported in this study, with an average age of 44 years.

This study shows that pilocarpine, a topical ocular miotic, is effective in the treatment of radial keratotomy overcorrections. We hypothesize that pilocarpine may stimulate corneal wound healing. There was a reduction of hyperopia in all 16 overcorrected eyes. The mean spherical equivalent refractions before and after the use of pilocarpine were +1.92 D and -0.31 D, respectively. The mean change in refractive error toward myopia was 2.20 D. The highest spherical equivalent refraction after the treatment was +0.25 D. We found similar results in the keratometric readings with a range of steepening from 0.06 D to 6.00 (mean, 2.18 D). Most of the changes in refractive error and keratometric readings occurred in the first 3 to 4 weeks of treatment (Figs 1, 2, 3, and 4).

The mean visual acuity improved after the pilocarpine treatment. Before treatment, the mean uncorrected visual acuity was 20/50 (range, 20/20 to 20/400), and after treatment, the average was 20/25. One eye (12) had an uncorrected visual acuity worse than 20/40; however, 94.5% of the eyes had an uncorrected visual acuity of 20/40 or better. Eye 12 presented with a 20/70 uncorrected visual acuity after the treatment, probably because of his refraction (-1.75 D) after the treatment, due to the drift of spherical equivalent refraction toward myopia caused by pilocarpine. The results were similar during the period of 8 to 49 weeks without mediation with a mean uncorrected visual acuity of 20/25 (range, 20/20 to 20/80; Table 4), and 93% of the eyes with 20/40 or better. Eye 12 again presented with an undercorrected visual acuity worse than 20/40 (20/80) and with a spherical equivalent refraction of -2.25. This overcorrected patient became undercorrected with the treatment and the visual acuity can now be improved by means of an enhancement.

In comparing the two age groups, pilocarpine tended to produce a greater effect in older eyes when considering the results of refractive error (Table 3). The variation of the refractive error during the first weeks of treatment in Group I (Fig 1) might have been induced by the variation of accommodation caused by the miotic and is more pronounced in the younger age group. Both age groups are comparable when considering the results of keratometric readings and uncorrected visual acuity, which indicates that the pharmacologic suture effect is similar in different ages.

Pilocarpine has a short- and long-term action. The short-term action is the constriction of the pupil and the accommodative spasm, which would reduce the hyperopia. Abramson et al31 described the average axial thickening of the lens 45 minutes after the instillation of pilocarpine 2% as 0.32 mm. They reported that volunteers experienced a 5.00 to 9.00 D stimulation of accommodation with pilocarpine. This effect disappeared 100 minutes after instillation. It could explain the improvement of visual acuity and symptoms of fluctuation of visual acuity observed in the patients during the first weeks of treatment; however, this action was observed only when the miotic was still being used and could not explain the maintenance of the results even 49 weeks after the conclusion of treatment. Another possible beneficial effect would be the lowering of the intraocular pressure. We think that this is not the principle mechanism of action of pilocarpine. In support of this position, the results with other antiglaucoma medications seem less than convincing. Maloney et al14 demonstrated that changes in intraocular pressure from 10 to 20 mm Hg do not significantly decrease the corneal curvature between 1 week and 6 months after surgery.

### Table 4

<table>
<thead>
<tr>
<th>Spherical Equivalent Refraction (D)</th>
<th>Range Spherical Equivalent (D)</th>
<th>Mean Keratometry (D)</th>
<th>Range Keratometry (D)</th>
<th>Mean Uncorrected Visual Acuity</th>
<th>Range Uncorrected Visual Acuity</th>
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<tr>
<td>Before pilocarpine</td>
<td>+1.92</td>
<td>0.75 to +5.00</td>
<td>36.05</td>
<td>31.25 to 41.00</td>
<td>20/50 to 20/400</td>
</tr>
<tr>
<td>During pilocarpine</td>
<td>-0.31</td>
<td>-1.75 to +0.50</td>
<td>38.32</td>
<td>34.67 to 43.18</td>
<td>20/30 to 20/70</td>
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<tr>
<td>After pilocarpine</td>
<td>-0.71</td>
<td>-2.25 to +0.25</td>
<td>38.33</td>
<td>34.87 to 43.12</td>
<td>20/25 to 20/80</td>
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We propose that the mechanism of action of pilocarpine, the long-term action, is related to corneal wound healing. Buzard has postulated that a delayed wound healing is the principle cause of radial keratotomy overcorrections. A practical, non-invasive means to monitor this complication is the photokeratometry. Breaking of mires over radial incisions is a sign of poorly healed incisions. We think pilocarpine appears to act as a pharmacologic suture pulling the incisions together early in the postoperative course. The miotic stimulates the wound healing and extrusion of the epithelial plug. This could be noted 8 to 49 weeks (mean, 21 weeks) after interruption of treatment. The average spherical equivalent refraction and keratometric readings during this period were -0.71 D and 38.33 D, respectively. Both of them were more myopic than the results immediately after stopping the treatment (Figs 5, 6, 7, and 8; Table 4).

We think that the initial overcorrection may indicate that the patient progresses with a hyperopic shift. Therefore, if the wound healing problem following radial keratotomy is promptly treated, the overcorrection observed years after surgery may be avoided. The treatment should be continued for a period of at least 3 to 4 weeks or until the patient becomes myopic again. The dose is adjusted according to the results and the tolerance of the patient to the medication, with a gradual reduction of the use as the hyperopia improves. Adding pilocarpine gel at night may be helpful for difficult cases.

Because of the risk of retinal detachment, it is essential to check the retina before using pilocarpine. This is a rare event and probably does not occur in eyes free of retinal pathology. If the patient presents any complaint suggestive of retinal detachment, the medication must be discontinued immediately. In this study, none of the eyes treated has developed this complication. Some patients may also complain about brow ache, visual disturbance, and photophobia, which may lead to reduction of the dose or even discontinuation of treatment.

Hyperopia is a serious postoperative complication of radial keratotomy. It is our clinical impression that eyes treated with pilocarpine early do better; therefore, it may be wise to begin treatment within a week or 2 of the initial surgery. Pilocarpine appears to be effective in the treatment of overcorrections following radial keratotomy, provided that therapy is maintained long enough.

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REFERENCES