Treatment of Hyperopia with Contact Ho:YAG Laser Thermal Keratoplasty

Catharina A. Eggink, MD; Yavuz Bardak, MD; Marinus H.M. Cuypers; August F. Deutman, MD

ABSTRACT

PURPOSE: To evaluate the effectiveness, safety, and stability of contact Ho:YAG laser thermal keratoplasty for low to moderate hyperopia.

METHODS: Fifty-five hyperopic eyes of 39 patients were treated with a Technomed contact Ho:YAG laser; 25 eyes were treated a second time. Treatment parameters were 1 octagonal ring of 8 spots with a treatment diameter of 6 mm, 7 mm, or 8 mm. Efficacy of the Ho:YAG laser treatment was evaluated after 6 months, comparing 3 treatment zone diameters. Stability and efficacy after 12 months was evaluated comparing 7-mm and 8-mm treatment zone diameters.

RESULTS: Mean reduction of spherical equivalent refraction after 6 months was not statistically significantly different between the 6-mm or 7-mm diameter zones: 1.42 (±1.30) D versus 2.22 (±0.44) D. An 8-mm diameter treatment zone was significantly less effective, 1.12 (±0.47) D. Longer follow-up did not show stability: mean reduction of spherical equivalent manifest refraction was 1.58 (±0.45) D for the 7-mm diameter treatment zone and 0.82 (±0.61) D for the 8-mm diameter treatment zone after approximately 12 months. Retreatment had a limited additive effect. No clinically significant loss of spectacle-corrected visual acuity was reported. No eyes lost more than 1 line of visual acuity.

CONCLUSION: Contact Ho:YAG laser thermal keratoplasty corrected hyperopia up to 2.50 D, but predictability was poor and a regression of initial effect occurred. Instability of refraction persisted to 1 year after surgery. [J Refract Surg 1999;15:16-23]

Thermal keratoplasty was first described by Lans. Laser thermal keratoplasty (LTK) has been used for the treatment of refractive errors. Laser thermal keratoplasty changes the anterior corneal curvature by heat-induced shrinkage of collagen fibers. The amount of change depends on the parameters of LTK treatment, including clear zone size, number, size, and pattern of spots, number of pulses at each spot, and pulse energy.

In LTK treatment, laser energy can be delivered to the cornea by a contact or a noncontact mode. We used a Technomed contact Ho:YAG laser, in which the laser energy is applied to the cornea by making contact between the energy emitting probe and the cornea.

In this retrospective study, we report clinical results to evaluate the effectiveness, stability, and safety of contact Ho:YAG LTK for low to moderate hyperopia. We compared the effect of treatment on 3 clear zones (6, 7, or 8-mm diameter) and evaluated the stability of the treatment in a 1 year follow-up treatment group using clear zone diameters of 7 mm and 8 mm. The effect of retreatment was also examined.

PATIENTS AND METHODS

Contact Ho:YAG LTK for hyperopia up to +5.00 diopters (D) was evaluated on 55 consecutively treated eyes of 37 patients (22 male, 15 female, mean age 54 ± 9 years; range 24 to 69 years) treated between December 1993 and September 1996. Patients with more than 1.00 D of refractive astigmatism were excluded.

Following the first treatment, 23 eyes underwent a second LTK treatment. The second LTK procedures were carried out in eyes in which 1.00 D or more of hypermetropia remained after stabilization, provided the patient wished to improve their
refractive situation. Major indications for treatment were unwillingness to wear spectacles for distance and intolerance to contact lenses.

A stable refraction for one-half year was required before LTK. Patients stopped soft contact lens use for at least 2 weeks before baseline measurement and hard contact lens use for at least 3 weeks. A complete ophthalmic examination was performed before treatment and postoperatively at approximately 1.5 months (range 1 to 3 mo), 6 months (range 3 to 9 mo), and 12 months (range 9 to 24 mo). LTK was not performed on patients with previous ocular surgery, ocular trauma, corneal disease, cataract, glaucoma, or macular diseases.

LTK was performed after being sure that there was no ocular pathology and no use of wound healing delaying agents such as corticosteroids or cytotoxic agents. Informed consent was obtained from all patients.

The procedure was performed under topical anesthesia (tetraacaine 1.0 %). After insertion of a lid speculum, the eye lids were kept open until the corneal surface was dry. Centration was obtained by using the fixation device of the Summit excimer laser delivery system. The center of the pupil and the clear zone were marked on the cornea with a circular corneal marker. With an 8-incision radial keratotomy marker, 8 spots were defined at the intersection of the circular and radial marks.

In all eyes, we used a Technomed Ho:YAG laser (Holmium 25, Technomed, Baesweiler, Germany, 20 mJ/pulse, 25 pulses, repetition rate of 15 Hz, wavelength of 2100 nm, pulse duration of 1 ms, optic fiber diameter of 550 nm) to apply 8 spots with a treatment zone diameter of 6 mm, 7 mm, or 8 mm. The laser beam was delivered via a quartz fiberoptic handpiece brought into contact with the cornea.

The clear zone diameter size was adjusted for each patient to produce a change in central corneal curvature that matched the patient’s required refractive correction indicated by the spherical equivalent manifest refraction. The algorithm was determined according to Seiler and colleagues.

In our study, a 6-mm diameter clear zone was applied to treat 4.00 to 5.00 D of hyperopia, a 7-mm diameter clear zone for 2.00 to 4.00 D, and an 8-mm diameter clear zone to treat up to 2.00 D. If a second LTK was applied at the same zone, the new laser spots were placed in between the previous ones. Tobramycin eye drops were given until all epithelial defects healed.

Subjective manifest refractive measurements and visual acuity were obtained using phoropter and standard Snellen charts. Visual acuity was recorded in decimal fraction. Intraocular pressure was measured by applanation tonometry. Spectacle-corrected visual acuity, spherical equivalent manifest refraction, and refractive astigmatism were measured. Mean change (reduction) in spherical equivalent refraction was obtained by subtracting the postoperative spherical equivalent from the preoperative spherical equivalent.

Surgically-induced astigmatism was calculated using vector analysis, as described by Waring. An induced cylinder (calculated by vector analysis) of 1.00 D or more was considered clinically significant.

To describe the effectiveness of LTK on the 3 different clear zone diameters, results are described for a group of eyes with a minimum 3 month follow-up (mean 5.5 mo). All eyes treated with a 6-mm diameter clear zone were retreated before reaching the 12 month follow-up time period because of disappointing effect in relation to the expected effect. Data for 39 eyes of 28 patients were available for this analysis.

The second group consisted of 28 eyes of 19 patients with a minimum 9-month follow-up. This group was analyzed to draw conclusions about the effect and stability of LTK on 7 or 8-mm diameter clear zones. Six-month follow-up was available on 16 eyes that underwent a retreatment.

RESULTS

Three treatment groups were defined according to the treatment zone diameter of the LTK: 6-mm treatment group, 7-mm treatment group, and 8-mm treatment group.

Mean spherical equivalent refraction and refractive change, as well as the amount of induced astigmatism of the 6-mm, 7-mm, and 8-mm diameter groups for the first treatment are given in Table 1.

Table 2 shows 1-year follow-up data on 11 eyes of the 7-mm LTK group and 17 eyes of the 8-mm LTK group to assess the efficacy and stability during this time period.

The effect of a second treatment is shown in Table 3, which presents data on 16 eyes with 6-month follow-up.

Efficacy of Ho:YAG LTK at 6 Months

To evaluate the efficacy of Ho:YAG LTK comparing 3 different treatment zone diameters, data were available on 6 eyes in the 6-mm diameter group, 14 eyes in the 7-mm diameter group, and 19 eyes in the 8-mm diameter group. These 39 eyes belonged to 28 patients, mean age 57 years (range 43 to 69 yr).

In the 6-mm diameter group (6 eyes), mean pre-operative spherical equivalent manifest refraction
### Table 1
Refractive Data After Ho:YAG LTK from Baseline to 6 Months

<table>
<thead>
<tr>
<th>Treatment Diameter (No. eyes)</th>
<th>Baseline and Time (mo) After Ho:YAG LTK (mean)</th>
<th>Mean Spherical Equivalent Manifest Refraction (D)</th>
<th>Reduction of Spherical Equivalent Refraction (D) (SD)</th>
<th>Vectoral Change in Astigmatism (D) (SD)</th>
<th>No. Eyes with &gt;1 D Vectoral Change in Astigmatism (% of Total Eyes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 mm (6)</td>
<td>Baseline 1.5 (1.1)</td>
<td>3.96 (0.50)</td>
<td>2.35 (1.48)</td>
<td>1.25 (0.96)</td>
<td>3 (50)</td>
</tr>
<tr>
<td></td>
<td>6 (3.6)</td>
<td>1.60 (1.18)</td>
<td>1.42 (1.30)</td>
<td>0.88 (0.44)</td>
<td>3 (50)</td>
</tr>
<tr>
<td>7 mm (14)</td>
<td>Baseline 1.5 (1.4)</td>
<td>2.88 (0.53)</td>
<td>2.76 (0.53)</td>
<td>0.96 (0.54)</td>
<td>5 (36)</td>
</tr>
<tr>
<td></td>
<td>6 (6.4)</td>
<td>0.12 (0.70)</td>
<td>2.22 (0.44)</td>
<td>0.74 (0.55)</td>
<td>5 (36)</td>
</tr>
<tr>
<td>8 mm (19)</td>
<td>Baseline 1.5 (1.5)</td>
<td>1.60 (0.62)</td>
<td>1.78 (0.71)</td>
<td>0.76 (0.42)</td>
<td>5 (26)</td>
</tr>
<tr>
<td></td>
<td>6 (5.3)</td>
<td>-0.22 (0.75)</td>
<td>1.12 (0.47)</td>
<td>0.67 (0.44)</td>
<td>4 (21)</td>
</tr>
</tbody>
</table>

### Table 2
Refractive Data After Ho:YAG LTK from Baseline to 1 Year

<table>
<thead>
<tr>
<th>Treatment Diameter (No. eyes)</th>
<th>Baseline and Time (mo) After Ho:YAG LTK (mean)</th>
<th>Mean Spherical Equivalent Manifest Refraction (D)</th>
<th>Reduction of Spherical Equivalent Refraction (D) (SD)</th>
<th>Vectoral Change in Astigmatism (D) (SD)</th>
<th>No. Eyes with &gt;1 D Vectoral Change in Astigmatism (% of Total Eyes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 mm (11)</td>
<td>Baseline 1.5 (1.4)</td>
<td>2.94 (0.31)</td>
<td>2.73 (0.49)</td>
<td>0.85 (0.35)</td>
<td>4 (36)</td>
</tr>
<tr>
<td></td>
<td>6 (6.6)</td>
<td>0.22 (0.50)</td>
<td>2.22 (0.50)</td>
<td>0.51 (0.29)</td>
<td>0 (0)</td>
</tr>
<tr>
<td></td>
<td>12 (13.3)</td>
<td>0.67 (0.53)</td>
<td>1.58 (0.45)</td>
<td>0.83 (0.59)</td>
<td>4 (36)</td>
</tr>
<tr>
<td>8 mm (17)</td>
<td>Baseline 1.5 (1.4)</td>
<td>1.58 (0.51)</td>
<td>1.74 (0.76)</td>
<td>0.54 (0.37)</td>
<td>2 (12)</td>
</tr>
<tr>
<td></td>
<td>6 (5)</td>
<td>-0.16 (0.62)</td>
<td>1.05 (0.40)</td>
<td>0.59 (0.42)</td>
<td>2 (12)</td>
</tr>
<tr>
<td></td>
<td>12 (12.1)</td>
<td>0.55 (0.50)</td>
<td>0.82 (0.61)</td>
<td>0.57 (0.44)</td>
<td>4 (24)</td>
</tr>
</tbody>
</table>

### Table 3
Refractive Data After Retreatment of Ho:YAG LTK from Baseline to 6 Months

<table>
<thead>
<tr>
<th>Treatment Diameter (No. eyes)</th>
<th>Baseline and Time (mo) After Ho:YAG LTK (mean)</th>
<th>Mean Spherical Equivalent Manifest Refraction (D)</th>
<th>Reduction of Spherical Equivalent Refraction (D) (SD)</th>
<th>Vectoral Change in Astigmatism (D) (SD)</th>
<th>No. Eyes with &gt;1 D Vectoral Change in Astigmatism (% of Total Eyes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 mm (5)</td>
<td>Baseline 1.5 (1.1)</td>
<td>2.35 (1.03)</td>
<td>1.23 (1.42)</td>
<td>1.37 (0.61)</td>
<td>4 (80)</td>
</tr>
<tr>
<td></td>
<td>6 (5.7)</td>
<td>1.13 (1.98)</td>
<td>0.33 (0.60)</td>
<td>1.22 (0.90)</td>
<td>2 (40)</td>
</tr>
<tr>
<td>8 mm (11)</td>
<td>Baseline 1.5 (1.0)</td>
<td>1.22 (0.80)</td>
<td>0.87 (1.20)</td>
<td>0.62 (0.58)</td>
<td>2 (18)</td>
</tr>
<tr>
<td></td>
<td>6 (5.6)</td>
<td>0.34 (0.88)</td>
<td>0.47 (0.51)</td>
<td>0.56 (0.51)</td>
<td>3 (27)</td>
</tr>
</tbody>
</table>

of 3.96 (+0.50) D was reduced to 1.60 (+1.18) D at the first follow-up examination (mean follow-up 1.1 mo). At the time of the second examination (mean follow-up 3.6 mo), mean spherical equivalent manifest refraction was 2.54 (+0.90) D. The initial reduction of 2.35 (+1.48) D decreased to 1.42 (+1.30) D after the second examination.

Considering the change in vector-corrected astigmatism at both postoperative time intervals, 3 of the 6 eyes in the 6-mm diameter group showed an induced cylinder of 1.00 D or more. The mean vector-corrected change in astigmatism decreased from
Figure 1: Achieved correction (reduction of spherical equivalent manifest refraction) at 6 months after Ho:YAG laser thermal keratoplasty.

1.25 (±0.96) D to 0.88 (±0.44) D.

In the 7-mm diameter LTK group (14 eyes), the mean preoperative spherical equivalent manifest refraction was 2.88 (±0.53) D. The mean reduction of spherical equivalent manifest refraction was 2.22 (±0.44) D after a mean time interval of 6.5 months. The mean induced astigmatism, calculated by vector analysis, decreased from 0.96 (±0.54) D to 0.74 (±0.55) D, with 6 of 14 eyes in the first and 3 of 14 eyes in the second time interval showing an induced cylinder of 1.00 D or more.

The 8-mm LTK group (19 eyes) with a preoperative mean spherical equivalent manifest refraction of 1.60 (±0.62) D showed a reduction of spherical equivalent refraction of 1.12 (±0.47) D after a mean 5.3 months follow-up. The vector analysis of the change in astigmatism showed a mean change in induced astigmatism of 0.76 (±0.42) D after 1.5 months and 0.67 (±0.44) D after 5.3 months. An induced astigmatism of 1.00 D or more was found in 5 of 18 eyes after 1.5 months and in 4 of 19 eyes after 5.3 months.

A scattergram (Fig 1) shows widely distributed data for reduction of spherical equivalent refraction after a mean follow-up of 5.3 months in the 3 treatment zone groups.

Concerning the efficacy of a 6-mm LTK versus a 7-mm LTK, there was not a significant difference in reduction of spherical equivalent refraction at 1.5 (Wilcoxon rank sum test: P = .3625) or 6 months follow-up (P = .0755). A 7-mm treatment zone produced a significant higher reduction of spherical equivalent refraction than an 8-mm LTK after 1.5 months (Wilcoxon rank sum test: P = .0011) as well as 6 months (P = .0001).

No significant differences were found in the amount of induced cylinder (as calculated by vector analysis) at all examinations between the 6-mm LTK group and the 7-mm LTK group, as well as between the 7-mm LTK and 8-mm LTK groups.

However, the risk of inducing cylinder of 1.00 D or more seemed higher in the 6-mm LTK group (where we found a clinically significant induced cylinder in 3 of 6 eyes) than in the 7-mm or 8-mm LTK group (as this was found in 3 of 14 eyes in the 7-mm LTK group and in 4 of 19 eyes in the 8-mm LTK group).

Stability and Efficacy of Ho:YAG LTK at 12 Months

Twenty-eight eyes of 19 patients (mean age 57.3 yr, range 49 to 67 yr) had a minimum follow-up of 9 months. Of these 28 eyes, 11 eyes had a treatment zone diameter of 7 mm, and 17 eyes had a treatment zone diameter of 8 mm.

As shown in Table 2, the preoperative spherical
The mean reduction in spherical equivalent refraction was 2.73 (±0.49) D after a mean of 1.4 months, 2.22 (±0.50) D after 6.6 months, and 1.59 (±0.45) D after a mean interval of 13.3 months. The induced astigmatism calculated by vector analysis was still 0.83 (±0.59) D after 13 months, with 4 of 11 eyes showing an induced cylinder of 1.00 D or more. In the 8-mm LTK group (17 eyes) with a preoperative spherical equivalent refraction of 1.58 (±0.51) D, the mean spherical equivalent refraction diminished gradually from 1.74 (±0.76) D after 1.4 months to 1.05 (±0.40) D after 5 months, and to 0.82 (±0.61) D after 12 months. The vector-calculated change in astigmatism did not show significant change over time and was 0.57 (±0.44) D after 12 months, with 4 of 17 eyes showing 1.00 D or more of induced cylinder.

Figure 2 shows the individual data of eyes from the 7 and 8-mm LTK groups after 12 months follow-up, with the preoperative spherical equivalent refraction on the X-axis and the change in spherical equivalent refraction on the Y-axis.

Figure 3 depicts the effect of the LTK in the 7 and 8-mm LTK groups over time.

The statistically significant difference in efficacy between the 7-mm and 8-mm LTK groups found at 6 months was also found at 1 year (Wilcoxon rank sum test, P = .0007).

In both groups, no stability in mean spherical equivalent refraction was recorded at 12 months follow-up. The induced reduction decreased after 6 months and again after 12 months. In the 8-mm LTK group, however, the decrease from 6 months to 12 months was less than that in the 7-mm LTK group; reduction in hyperopia diminished by 28% in the 7-mm LTK group and by 22% in the 8-mm LTK group.

Retreatments

Retreatments were performed on 23 of the initial 49 eyes. Initial LTK in 6 eyes was performed with a 6-mm diameter treatment zone, 8 eyes had a 7-mm diameter treatment zone, and 9 eyes had an 8-mm diameter treatment zone. The mean time interval between the first and the second treatment was 8.3 months and ranged from 2.2 to 20.8 months. Sixteen eyes were available with a minimal follow-up time of 3 months and a mean follow-up time of 5.5 months.

Of these 16 eyes, the second LTK (the retreatment) was performed with a treatment zone diameter of 7 mm in 5 eyes (7-mm diameter retreatment group) and 8-mm diameter in 11 eyes (8-mm diameter retreatment group) (Table 3).

The limited effect of a second LTK was expressed by a reduction of 0.33 (±0.60) D in the 7-mm diameter retreatment group after a mean follow-up of 5.7 months and 0.47 (±0.46) D in the 8-mm diameter retreatment group after a mean follow-up of 5.6 months.

The mean induced cylinder (calculated by vector analysis) from the retreatment was 1.22 (±0.90) D in the 7-mm diameter retreatment group and 0.56 (±0.51) D in the 8-mm diameter retreatment group. Two of 5 eyes in the 7-mm diameter retreatment group and 3 of 11 eyes in the 8-mm diameter
retreatment group had induced astigmatism of 1.00 D or more.

**Safety of Ho:YAG LTK**

Concerning the visual acuity with spectacle correction, no clinically significant losses were reported. All eyes had a preoperative spectacle-corrected visual acuity of 0.8 or more. Of 28 eyes with a follow-up of 1 year, 7 eyes lost 1 line of spectacle-corrected visual acuity (1.0 to 0.8); no eye lost more than 1 line.

Immediately after LTK, the laser spot sites showed a conical opacity in the anterior corneal stroma of about four-fifths of the corneal thickness. An obvious central corneal curvature steepening and a loss of corneal epithelium at the laser spot sites were seen. Due to laser-induced epithelial defects, some patients expressed transient complaints of mild pain and photophobia, slight tearing, and foreign body sensation. These complaints resolved within 1 week. There were no visual complaints of halos or glare nor complications of recurrent erosions. Corneal opacities due to the laser spots decreased over time but they were still slightly visible by slit-lamp microscopy after 1 year. There was no significant anterior chamber inflammation seen postoperatively in any eye. There were no changes observed in any of the intraocular structures or the ocular adnexa.

Mean preoperative intraocular pressure was 15.2 ± 4.1 mmHg (range 11 to 20 mmHg) and mean intraocular pressure at the last examination was 14.9 ± 3.8 mmHg (range 12 to 20 mmHg). This difference was not statistically significant.

All patients were satisfied with improvement in their vision without glasses or with their reduced dependence on optical correction.

**DISCUSSION**

There are no published reports that compare the clinical effect of applying Ho:YAG laser energy to the cornea using 3 different clean zone diameters. Our study shows that contact Ho:YAG LTK can correct up to about 2.50 D of hyperopia by using a single ring of 8 treatment spots and above mentioned laser parameters.

The clear zone diameter affects refractive outcome. Six-millimeter diameter zone treatment (considering the mean achieved change in spherical equivalent refraction) results in a mean effect not significantly different from a 7-mm diameter zone treatment. The individual data show a larger range of effect after a 6-mm clear zone treatment than after a 7-mm clear zone treatment, indicating better predictability of the latter.

Using a 7-mm diameter zone treatment, a higher reduction in mean spherical equivalent refraction can be achieved than with an 8-mm diameter clear zone.

Koch and colleagues treated 15 eyes with noncontact Ho:YAG LTK by using 8 spots on a 6-mm diameter zone. In this clinical study, the postoperative mean reduction of spherical equivalent refraction was 0.90 (±0.59) D at 6 months and 0.79 (±0.65) D at 12 months. In their US FDA Phase IIA clinical study, they present 18 eyes treated by noncontact Ho:YAG LTK with 8 spots on a 6-mm diameter zone with a mean reduction in spherical equivalent refraction of 0.53 (±0.36) D at 6 months and 0.55 (±0.33) D at 12 months. A report on the 2-year follow-up of the same 18 eyes showed no significant regression between 1 and 2 years.

In our study, applying 8 spots on a 6-mm diameter clear zone, the mean reduction of spherical equivalent refraction was 2.35 (±1.48) D at 6 months. We used the contact Ho:YAG, which produces higher average temperatures than a noncontact procedure. The difference between our results and the results of the aforementioned study may be due to the difference between the contact and noncontact methods. We couldn’t await a longer term result of the 6-mm diameter LTK, as the effect of the LTK didn’t fulfill the expectations of the treatment: preoperative spherical equivalent refraction exceeded the effect and a significant amount of hyperopia remained.

Although Koch and colleagues claim a stable effect of a single 6-mm diameter zone LTK between 6 and 12 months and even up to 2 years, Tutton and colleagues describe a 50% regression at 2 years after LTK (two-zone LTK). We could not demonstrate stability of effect between 6 and 12 months follow-up in the 7-mm and 8-mm LTK groups.

A primary LTK procedure is more effective for reduction of spherical equivalent refraction than a repeat LTK procedure. Other studies do not report on retreatments. However, 2-ring (16 spots) treatments are reported to be more effective than treatment with one ring: 1.48 (±0.58) D versus 0.53 (±0.33) D.

In our study, safety of the procedure has been expressed by the absence of significant changes in spectacle-corrected visual acuity. Others have performed endothelial cell counts as well as glare and contrast sensitivity testing. Koch (using a non-contact Ho:YAG laser device) showed that no significant endothelial cell density changes occurred after LTK up to 12 months postoperatively. He reported...
slight changes in outcome in contrast sensitivity testing, but no significant loss of contrast sensitivity and unchanged glare test measurements.\textsuperscript{11}

We conclude that contact Ho:YAG LTK is a safe technique, and that it can reduce hyperopia in one or two procedures. The effect is dependent on the diameter of the circle on which the laser spots are applied. We recommend a 7-mm diameter clear zone because a 6-mm diameter clear zone produces no statistically significant different effect, but does have a higher chance of inducing astigmatism.

Using 8 spots, the 8-mm diameter treatment should be reserved for lower amounts of refractive correction. The 7-mm diameter treatment produces a slightly greater effect. Disadvantages are regression over time and low predictability of the effect.

It is probable that a retreatment has less additive effect to a primary LTK than a double zone (16 spots) LTK in one phase.

REFERENCES