
Correlation between ultraviolet radiation level and the incidence of late-onset corneal haze after photorefractive keratectomy

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ABSTRACT

Purpose: To investigate the correlation between environmental changes in ultraviolet (UV) radiation levels and the incidence of late-onset cornea haze (LOCH) after photorefractive keratectomy (PRK).

Setting: SynsLaser Clinic, Tromsø, Norway.

Methods: The study comprised 404 eyes that had myopic PRK and photoastigmatic refractive keratectomy from February 1996 through July 1998. The high latitude (70° N) of the observation site provided “natural laboratory” conditions to look at the occurrence of LOCH with high and low UV-radiation levels, which occurred during summers and winters, respectively. The diagnostic criterion for LOCH was acute haze of grade ≥ 2 occurring between 4 and 12 months postoperatively.

Results: The follow-up ranged from 12 to 41 months. Of the 314 eyes that met the inclusion criteria, 11 developed LOCH when the environmental UV-radiation level was high. No eye developed LOCH when the level was low. The correlation between a high level of environmental UV radiation and the occurrence of LOCH was statistically significant ($P = .001$).

Conclusion: Environments with high UV-radiation levels may increase the risk of LOCH after PRK in eyes with moderate to high myopia. Use of UV-protective eyewear should be encouraged during the first year after PRK. *J Cataract Refract Surg* 2001; 27: 404–410 © 2001 ASCRS and ESCRS

The term *corneal haze* has been used since 1988 and has been applied to describe corneal transparency decrease after photorefractive keratectomy (PRK).¹ Corneal haze is one of the most important short- and long-term complications of PRK, and its incidence and intensity increase in eyes treated for higher degrees of refractive error.² In vivo investigation of the structures

responsible for corneal haze after PRK reveals a bright layer of subepithelial deposit that gradually develops at the epithelial–stromal junction; this starts 1 week postoperatively, increases to a peak level between 1 and 3 months, and declines slowly thereafter.³ Such timing is characteristic of the onset and duration of “regular” haze after PRK. However, Meyer and coauthors⁴ describe 5 eyes that developed corneal haze much later, and Lipshitz and coauthors⁵ define a so-called late-onset corneal haze (LOCH) as an acute haze starting 4 to 12 months after excimer laser ablation; ie, at the time regular post-

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PRK haze has subsided. Figure 1 shows the acute onset, late timing, and high intensity of LOCH, as well as its discontinuity with regular post-PRK haze.

Biological factors, such as healing type and hormone status, as well as external factors, such as oral contraceptives, mechanical trauma, wind, sand, and ultraviolet (UV) exposure, have been described as risk factors for haze after PRK.⁶ Experimental animal studies have shown a correlation between post-PRK haze and UV-B exposure. These studies demonstrate that UV-B exposure after PRK in rabbit eyes exacerbates and prolongs the stromal healing response, manifested by increased keratocyte numbers, extracellular vacuolization, and deposition of disorganized collagen in the anterior stroma.⁷ Naranjo-Tackman reported cases of significant haze that appeared 6 months or later after PRK for high myopia among patients who lived in high mountain regions or in the coastal regions of Mexico, areas known for high UV-radiation levels (H.W. Singer, "Late Onset Haze Could Be Linked to UV Rays," Ocular Surgery News International, March 1997, page 16). Anecdotal clinical evidence of UV radiation and haze has been reported since 1995.

The present study was initiated after some of our PRK patients developed acute haze, grade 2 to 3, 5 to 7 months postoperatively and revealed a common history of significant exposure to sunlight shortly before the occurrence of haze. The observational retrospective clinical study looked at the correlation between the environmental UV-radiation level and the occurrence of LOCH after PRK. To our knowledge, this is the first clinical

study of the relationship between UV radiation and post-PRK haze.

Patients and Methods

The study comprised 404 eyes that had myopic PRK and photoastigmatic refractive keratectomy from February 1996 through July 1998 at the SynsLaser clinic in Tromsø, Norway. Evaluation before surgery included uncorrected visual acuity, best spectacle-corrected visual acuity, cycloplegic refraction, tonometry, computerized videokeratography, slitlamp and dilated fundus examinations, scotopic pupillometry, and tear-film function assessment. The exclusion criteria were younger than 18 years; chronic eye disease such as cataract, glaucoma, uveitis, keratoconus, and dry-eye syndrome; as well as general diseases such as diabetes and autoimmune diseases.

The Compak 200 (LaserSight Technologies) flying-spot excimer laser with a 1.0 mm beam diameter was used in all procedures. Unpreserved chloramphenicol and diclofenac eyedrops were administered 30, 15, and 5 minutes preoperatively. Unpreserved oxybuprocaine eyedrops were administered prior to epithelial removal with the Amoils epithelial scrubber. The ablated optical zone varied from 5.5 to 7.0 mm, with a tapered transition zone of 1.0 to 1.5 mm, amounting to a total ablation diameter of 6.5 to 8.5 mm. After laser ablation, the cornea was hydrated with 2.5 mL of chilled balanced salt solution (BSS®) and a bandage contact lens (Biomedics 55, American Hydron) was applied.

Unpreserved diclofenac was used 4 times the first postoperative day, while the mixture of dexamethasone and chloramphenicol eyedrops was used 4 times daily the first month. Dexamethasone eyedrops were used from 1 to 3 months postoperatively and were tapered individually depending on the amount of myopia corrected and the amount of regression, haze, or both. The bandage contact lens was removed at 3 to 5 days, after reepithelialization had been confirmed biomicroscopically.

Regular follow-up examinations were performed by the surgeon at 1 day, 1 week, and 1, 3, 6, and 12 months. All patients were urged to report any loss in quality of vision, and those who did were examined thoroughly within a few days.

The inclusion criteria for the study were observation time of 12 months or longer; haze of grade 1 or lower at

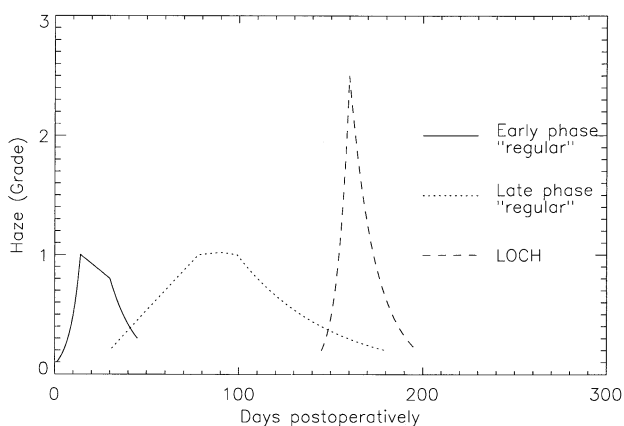


Figure 1. (Stojanovic) Grade of different types of haze versus days postoperatively (schematic).

the 3 month postoperative examination (to avoid possible misdiagnosis of prolonged regular post-PRK haze); discontinuation of local steroids within 3 months of surgery (to avoid their possible preventive effect on haze)^{2,8}; patients remaining in the observation area during the first 12 months postoperatively (to avoid a UV environment different from the one for which there was quantitative data).

The diagnostic criterion for LOCH was acute haze of grade 2 or higher starting 4 months or later after PRK. A scale from 0 to 4 was used to quantify the haze: 0 = clear cornea; 0.5 = trace of opacity; 1 = mild, not affecting refraction; 2 = moderate, with difficult refraction; 3 = opacity that prevents refraction; 4 = unable to view anterior chamber.⁹

The geographical position of the observation site (SynsLaser Clinic, Tromsø, Norway), latitude 70° N, is characterized by an uneven distribution of sunlight between the light summers and dark winters. During the light season (May to July), the sun is above the horizon for 24 hours, while in the dark season (November to January), the sun is below the horizon for 24 hours. These settings provide “natural laboratory” conditions that make it possible to look for the occurrence of LOCH in an environment with significant seasonal variations.

Photorefractive keratectomy was performed throughout the observation period; ie, during dark and light seasons. A theoretical model was developed to quantify the relevant environmental UV radiation during the critical postoperative period. This model allowed us to associate a certain amount of environmental UV radiation with each date of surgery and divide the actual surgeries into 2 groups: 1 with a high risk of receiving a significant amount of postoperative UV radiation and 1 with a low risk. Finally, the incidence of LOCH in these groups was compared.

As a basis for the calculations, the UV index values for Tromsø, Norway, provided by the Norwegian Institute for Air Research, were used. The UV index is the UV radiation hitting a horizontal surface at sea level for 1 hour between 11:30 AM and 12:30 PM. It is measured daily and is expressed in units of hJm^{-2} . The UV index, shown in Figure 2, varies from day to day due to cloud conditions, ozone layer, and atmospheric conditions, but the major variations occur from summer to winter because of the high latitude of the observational site. As

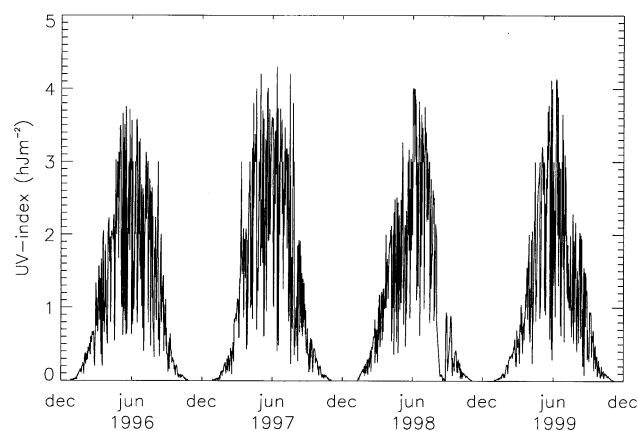


Figure 2. (Stojanovic) UV index for Tromsø, Norway, for each day from January 1996 through December 1999.

the UV index does not include reflected radiation, it was multiplied by a factor of 16 in the period from November 1 through May 31, when snow is omnipresent in the area, giving an enhanced UV index. This correction was done because the cornea of a person observing snow-covered terrain is exposed to UV radiation that is approximately 16 times greater than the cornea of a person observing the same terrain without snow cover.¹⁰

To quantify the risk of a PRK-treated cornea of receiving a high UV dose, a theoretical quantity called the UV risk (UVR) was introduced. This is defined by

$$\text{UVR}(op) = \sum_{i=op+120}^{i=op+365} \text{UV}_{\text{enh}}(i) \frac{365 - (i - op)}{365 - 120} \quad (1)$$

where i represents the day, which is numbered consecutively from 1 on December 21, 1995, and op represents the day of the surgery. For example, $\text{UVR}(43)$ represents the UV risk for an eye treated on day 43, February 1, 1996. Since the UV radiation does not appear to have a significant cumulative damaging effect on the cornea¹¹ and the LOCH by definition does not appear until 4 months postoperatively, 120 days was chosen as the lower limit in the formula above. Three hundred sixty-five days postoperatively was chosen as the upper limit, since there have been very few cases of significant post-PRK haze reported after this time. This gives an interval of 8 months, considered critical for the development of LOCH. It was also assumed that after PRK, corneal integrity is gradually restored and the cornea becomes less vulnerable to UV radiation over time. The last factor

in equation 1 is therefore an attenuating function decreasing linearly from unity at 120 days to zero at 365 days postoperatively.

By introducing a normalizing constant

$$C = \frac{1}{1095} \sum_{op=0}^{op=1095} UVR(op) \quad (2)$$

where 1095 is the number of days in the observation period, a dimensionless quantity, UV risk factor (UVRF), has been defined by

$$UVRF(op) = \frac{1}{C} + UVR(op) \quad (3)$$

Since the interval in the calculation of UVRF is 8 months, ie, shorter than 1 year, the UVRF will depend on the date of surgery, as shown in Figure 3. Since C is the average of UVR in the 3 year period, a UVRF greater or lower than unity means a higher or lower than average risk of high UV exposure, respectively.¹² Hence, the actual surgeries could be grouped into high and low UVRF groups.

Results

The mean follow-up was 23.2 months \pm 8.3 (SD) (range 12 to 41 months). The inclusion criteria were satisfied in 314 of the 404 eyes. The mean age of the patients was 31.2 \pm 9.3 years (range 19 to 76 years), and the mean spherical equivalent (SE) correction was -4.66 ± 2.11 diopters (D) (range -1.25 to -11.50 D; 242 eyes [77%] had $|SE| < 6.0$ D and 72 [23%] had

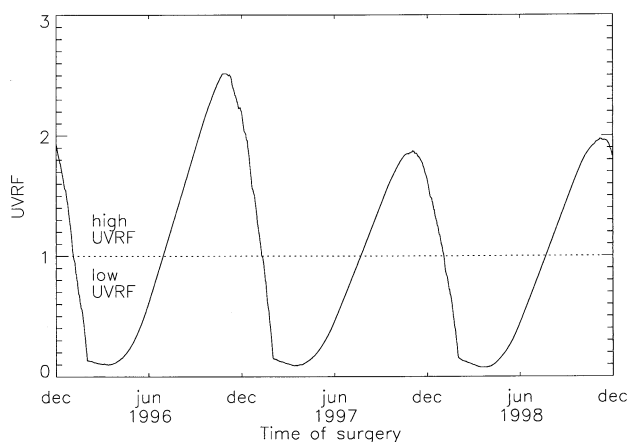


Figure 3. (Stojanovic) Ultraviolet risk factor versus time of surgery. The surgeries having a UVRF higher than unity belong to the high-UVRF group and vice versa.

$|SE| \geq 6.0$ D). The mean haze grade at 3 months was 0.44 ± 0.36 (range 0.0 to 1.0). One hundred seventy eyes were in the high UVRF group and 144, in the low UVRF group.

Five to seven months postoperatively, 11 eyes (4%) developed haze of grade ≥ 2 (Table 1). At 3 months, these eyes had the same demographic and clinical data as the other eyes except for higher preoperative myopia ($|SE| \geq 6.0$ D in all but 1 eye). At the time LOCH was diagnosed, the haze was grade 2 to 3. At the same time, regression occurred (mean SE dropped from $+0.1$ to -1.8) and best corrected visual acuity (BCVA) decreased (mean loss of 2.1 lines). Nine of the 11 eyes had a history of abundant exposure to sunlight in the week before the diagnosis of LOCH. All 11 eyes were in the high UVRF group.

Figure 4 shows the relationship between UVRF and the occurrence of LOCH, and it shows that LOCH cases are concentrated near the apex of the UVRF curve and that the LOCH cases are generated from the procedures in the high-UVRF group.

The occurrence of LOCH in 11 eyes in the high-UVRF group and no occurrence among eyes in the low-UVRF group provided the basis for the statistical analysis. A significant correlation between high UVRF and the occurrence of LOCH ($P = .001$) was found. The 2-tailed Fisher exact test was used.

Discussion

The influence of the environmental UV-radiation level on the incidence of LOCH was investigated. A theoretical model was developed and a quantity, UVRF, that gives a measure for the risk of receiving a significant UV dose introduced. It must be emphasized that this does not represent a measure of the actual postoperative UV exposure for each eye, which would require an experimental study with individual dosimetry.^{13,14}

An experimental study in which the UV-radiation levels are measured on the exposed cornea, eg, with contact lenses with UV-dosimetry capabilities, would exclude unknowns such as each patient's type of activity, use of protective eyewear and hats, individual anatomy of orbita and eyebrows, squinting, and aversion reflex. However, this would introduce a new set of unknown variables such as the effect of dosimetry contact lenses on PRK-treated corneas, while other possibly associated en-

Table 1. Eleven eyes that developed LOCH.

Number	Age (Years)	Sex	3 Months Postop				At Time of LOCH Diagnosis				UV History	UVRF Level
			Preop SE (D)	Haze Grade	SE (D)	BSCVA	Months Postop	Haze Grade	SE (D)	BSCVA		
1	36	F	-7.25	0.75	+1.50	20/25	7	2.0	+0.13	20/40	Skiing	High
2	36	F	-6.75	0.50	-0.13	20/20	5	3.0	-0.25	20/40	Snow scooter	High
3	29	M	-7.38	0.50	-1.00	20/30	5	2.5	-3.00	20/80	Snow scooter	High
4	28	F	-6.00	0.50	+0.50	20/20	4	2.0	-1.62	20/30	Fishing	High
5	43	M	-2.25	0.25	+0.13	20/15	5	2.5	-1.50	20/40	?	High
6	28	F	-8.38	0.50	-1.32	20/20	5	2.5	-3.75	20/40	Skiing	High
7	29	M	-8.88	0.50	+0.25	20/40	5	2.0	-0.37	20/25	Snow scooter	High
8	23	F	-6.38	0.50	+0.50	20/25	7	2.0	-2.25	20/40	Fishing	High
9	30	M	-10.50	1.00	+0.50	20/25	5	2.0	-1.25	20/30	?	High
10	23	M	-10.25	0.25	+0.87	20/25	5	2.5	-2.12	20/30	Sunbathing	High
11	45	F	-8.75	1.00	+0.87	20/20	5	3.0	-4.12	20/50	Sunbathing	High

LOCH = late-onset corneal haze; SE = spherical equivalent; BSCVA = best spectacle-corrected visual acuity; UVRF = ultraviolet risk factor

vironmental factors such as temperature changes, moisture, dust content, and wind, as well as endogenous factors such as the patient's hormonal status and healing response would have to be addressed.⁶

Seasonal variations in body functions manifested by sleep disorders, changes in eating patterns, body-weight variations, and seasonal affective disorders appear to be more prevalent at higher northern latitudes.¹⁵⁻¹⁷ Photopic stimuli, or the lack of these, may affect the regulation of the circadian pacemaker and, therefore, the

diurnal pattern of hormonal secretions.¹⁸ Seasonal level variations in pineal hormone melatonin appear to influence the seasonal changes in immune functions.¹⁹ The seasonal fluctuations in central serotonin transmission have been proposed for the pathophysiology of seasonal affective disorders.^{20,21} It is not known whether the seasonal variations in body functions influence the development of LOCH.

In our model, we used an enhancement factor of 16 for the UV index for January through June because of the reflected UV radiation. This factor was based on research data.¹⁰ We also used an attenuating function that decreases the enhanced UV index linearly from 4 to 12 months postoperatively. It is not known how corneal susceptibility to UV radiation decreases with time after PRK, and our assumption of the linear decrease might be considered somewhat arbitrary. However, we have tried other types of attenuating functions without losing the significance of the results. We therefore feel that our model is reasonably sound and that our assumptions are valid.

Because the LOCH is, by definition, significant haze (grade ≥ 2) and occurs acutely in clear corneas (after the regular postoperative haze has subsided⁵), its diagnosis is easy and unambiguous. We initially considered a clinical study of early regular haze (during the first 3 months after PRK). However, this would have required high accuracy of subjective assessment of

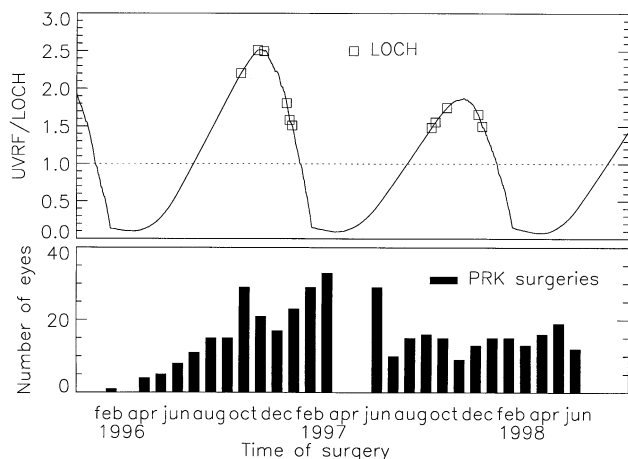


Figure 4. (Stojanovic) The curve at the top shows UVRF as a function of the date of surgery. The squares represent cases of LOCH. The bars at the bottom represent the number of eyes treated in each month. The time scale is the same in both.

minute variations in haze grade, which we considered to be an almost impossible task. Besides, local steroid treatment, which is very common during this period, could have prevented an increase in haze^{22,23} and that would have made the results of studying possible UV influence on haze even more uncertain.

Corticosteroids have a therapeutic effect on haze,²² but it is not known whether they have a preventive effect, acting as a shield postoperatively.²³ We chose to exclude eyes that were treated with steroids for longer than 3 months.

The incidence of LOCH in our study (which used a small-beam laser) was 4%, which is higher than the incidence (1.8%) in the study reported by Lipshitz and coauthors,⁵ in which a broad-beam laser was used. The lower incidence could be accounted for by the following: First, since the amount and incidence of regular post-PRK haze are higher with broad-beam lasers, some of the LOCH cases might have been masked by protracted severe cases of regular postoperative haze. Second, topical steroid treatment that was extended beyond 3 months might have prevented the development of some of the LOCH cases. On the other hand, if UV exposure is one of the causes of LOCH, a possible explanation for a higher incidence of LOCH in our cohort may be found in the lifestyle of the population in the north of Norway. After long, dark winters, many people spend hours cross-country skiing in the sun. Indeed, 7 of our 11 cases of LOCH had a history of abundant exposure to sunshine in connection with leisure activities in the snow during Easter and early spring.

Both Meyer and coauthors⁴ and Lipshitz and coauthors⁵ found that late-onset haze primarily affects patients treated with PRK for moderate and high myopia. This was true in our study, which shows a statistically significant correlation between the occurrence of late haze and corrected myopia ≥ 6.0 D.

Immediately after their haze had been detected, the 11 LOCH cases received local treatment with dexamethasone 1% eyedrops for at least 2 weeks. Four of them did not respond satisfactorily and were treated with transepithelial phototherapeutic keratectomy, with a total ablation depth of 60 to 80 μm . All 11 cases eventually regained the lost lines of BCVA, and their regression mostly reversed.

Concurrently with the PRK procedures in this study, we treated 60 cases using laser in situ kerato-

mylectomy (LASIK) and none showed any sign of LOCH even if their date of surgery placed them in the high-UV-risk group. This could imply that LASIK-treated eyes have a higher threshold for UV-radiation damage, possibly due to the intact epithelium and Bowman's membrane.

Several studies have investigated adjunctive treatment to reduce corneal haze after PRK. Interferon alpha 2b,²⁴ TGF beta,²⁵ as well as mitomycin-C²⁶ seem to reduce the amount of haze after PRK.

Ringvold²⁷ investigated the UV-filtering effect of vitamin C in the corneal epithelium of various species. He found that diurnal animals showed a higher ascorbate concentration in the corneal epithelium than nocturnal species. The highest ascorbate concentration was found in the corneal epithelium of the reindeer, which is exposed to extremely high doses of UV radiation during the spring from the reflection from the snow. This observation has been interpreted as an environmental adaptation protecting the eye from UV radiation.²⁸

Conclusions

In our study, we found no cases of LOCH when the environmental UV-radiation level was low, while a significant number of cases were found when the UV-radiation level was high. Our results suggest that an environment with a high UV-radiation level might increase the risk of LOCH in eyes with moderate to high myopia.

Ultraviolet-protective eyewear should be worn during the first year after PRK, especially when there is a danger of high UV exposure (reflection from snow or water, high altitude, low latitude, and the hole in the ozone layer).

Ringvold²⁹ recommends that PRK patients start taking 1000 mg of vitamin C daily, 2 weeks preoperatively and 2 weeks postoperatively. During the first postoperative year, the same daily dose should be taken whenever patients are exposed to abundant UV radiation.

Patients with moderate and high myopia should be advised to choose LASIK surgery instead of PRK, since there is no evidence of any significant risk of development of LOCH after LASIK. At high latitudes, if LASIK is contraindicated, PRK should be performed between May and November to minimize the risk of harmful UV exposure.

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