Unilateral Rainbow Glare After Uncomplicated Femto-LASIK Using the FS-200 Femtosecond Laser

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ABSTRACT

PURPOSE: To report a case of rainbow glare following femtosecond laser-assisted LASIK (femto-LASIK) with the Wavelight FS-200 femtosecond laser (Alcon Laboratories, Inc., Fort Worth, TX).

METHODS: A patient was treated bilaterally for myopia with femto-LASIK using the FS-200 femtosecond laser. Postoperatively, he complained of rainbow glare in his right eye.

RESULTS: Three months postoperatively, the induced grating pattern (hyperreflective spot-like zones corresponding to the surgeon-programmed spot and line separation distance of the FS-200 femtosecond laser) was demonstrated with confocal microscopy at the level of the flap interface in the right eye.

CONCLUSIONS: This is the first report of rainbow glare following femto-LASIK with the FS-200 femtosecond laser documented with in vivo confocal microscopy.

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Rainbow glare is a mild optical side effect of femtosecond laser-assisted LASIK (femto-LASIK). It was first described in 2008 by Krueger et al. using the 15-kHz IntraLase femtosecond laser (IntraLase Corp., Irvine, CA).[1] The cause of the rainbow glare was defined as the diffraction of light from the grating pattern created on the back surface of the LASIK flap after femtosecond laser exposure. The patients reported seeing a spectrum of colored bands radiating from a white-light source when viewed in a dark environment, as in a nighttime setting. The first study describing rainbow glare[1] found an incidence of 19.07% with an older IntraLase laser model. The study also examined a newer model of the laser, which included an increasing numerical aperture of the focusing optics, resulting in a smaller working distance under the cone. The incidence of rainbow glare with this model decreased to 2.32%. A subsequent study reported an incidence of rainbow glare of 5.8% with a newer generation model (IntraLase FS 60 kHz).[2] We report the first case of rainbow glare with a different femtosecond laser platform (FS-200 Wavelight; Alcon Laboratories, Inc., Fort Worth, TX), in which the visual symptoms were correlated with the histopathology findings.

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Dr. Gatinel is a lecturer and Dr. Saad is a consultant for Acufocus Inc. The remaining authors have no financial or proprietary interest in the materials presented herein.

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CASE REPORT

A 28-year-old man was referred to our office for the management of visual symptoms without loss of uncorrected distance visual acuity in the right eye after bilateral uneventful femto-LASIK. He had undergone uncomplicated bilateral LASIK at a private refractive surgery center for full correction of myopia with astigmatism 3 months prior to presentation.

The flap and the excimer laser parameters used for the LASIK correction were retrieved from the patient's medical records at the private center. A FS-200 Wavelight femtosecond laser was used to create superiorly hinged 9-mm flaps followed with excimer laser ablation using the EX-500 excimer laser **AQ1**. The corrections entered in the EC-500 laser software were -3.75 -0.50 × 62° in the right eye and -3.75 -0.50 × 68° in the left eye. One day postoperatively, uncorrected distance visual acuity was 20/30 in the right eye and 20/20 in the left eye. One month postoperatively, uncorrected distance visual acuity was 20/20 in both eyes.

The FS-200 laser settings were identical in both eyes, with a planned interface depth of 100 µm and a flap diameter of 9.5 mm. The bed spots and line separation was 7.5 µm, and the energy 0.8 µJ. The image taken by the FS-200 laser camera immediately after the completion of the laser flap creation demonstrated a subtle raster pattern created by the cavitation bubbles on the right cornea; this was not observed on the left cornea (**Figure 1**).

In the early postoperative period, the patient complained about colored radiating haloes extending laterally and vertically around bright light sources. These disturbances were seen with the right eye only. The greatest perceived spectral intensity was noted when bright white light sources were visualized in a dark environment or uniform background. The patient volunteered to draw his subjective visual perception as he was watching an illuminated white bulb at a distance of 1 meter. Using image-creation software, the patient drew six lateral and two vertical equally spaced chromatic bands (**Figure 2**). Each radiating band contained

A

Treatment Parameters (Standard)

Ablation

Abl. Zone	Max. Depth	Min. Pachy	Res. Stroma
9.0 mm	56 um	542 µm	386 µm

Flap

Diameter	Thickness	Side Cut Angle	Canal Width	Canal Length Offset
9.5 mm	100 µm	70°	1.3 mm	0.9 mm

Hinge

Position	Length	Angle	Width
90°	3.5 mm	43°	0.3 mm

Laser separations

Bed Cut		Side Cut	
Spot Separations	Line Separations	Spot Separations	Line Separations
7.5 µm	7.5 µm	5.0 µm	3.0 µm

Measured Data

Pulse Energy Bed Cut	Pulse Energy Side Cut	Suction Time	Device Temperature
0.8 µJ	0.8 µJ	81.0 s	25.0 °C

Treatment Data

Treatment Progress	Treatment Breaks	x-Offset	y-Offset
100 %	0	-0.20 mm	0.20 mm

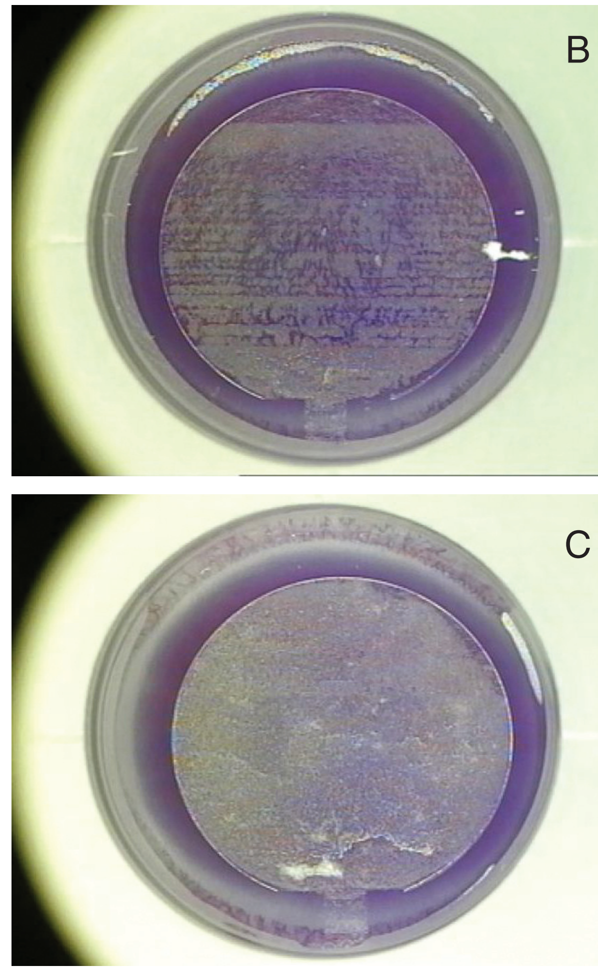

Figure 1. (A) Energy and spot parameters used for the right and left eyes flap creation with the FS-200 femtosecond laser (Alcon Laboratories, Inc., Fort Worth, TX). Snapshots of the (B) right and (C) left eyes taken right after the completion of the interface creation is evocative of a raster shot pattern on the right eye.

a typical colored rainbow spectrum, which extends from violet-blue closer to the light source to red at its outermost extent.

Ocular and corneal wavefront measurements were obtained using the OPD SCAN III (Nidek, Gamagori, Japan). Left and right anterior axial curvature maps showed a central flattened zone without significant irregularities: high-order aberrations root mean square were 0.45 and 0.41 µm in the right and left eyes, respectively. Confocal microscopy of the right and left corneas were obtained using the HRT II confocal microscope equipped with the Rostock corneal module **AQ1**. The acquired two-dimensional image is defined by 384 × 384 pixels covering an area of 400 × 400 µm with lateral digital resolution of 1 µm/pixel and digital depth resolution of 2 µm/pixel. At approximately 40 µm below the epithelium basal layer on the right cornea, hyperreflective spots appeared in an equidistant horizontal arrangement, measuring only a few microns (**Figure 3**). The horizontal and vertical distances between these zones matched the distance between spots and lines programmed in the FS-200 laser (7.5 µm). Thus, the aspect found strongly suggested that it corresponded to tissular response to the femtosecond laser impacts. It was not possible to identify whether these presumed impacts were exactly located at the posterior side of the flap.

DISCUSSION

Rainbow glare is an optical side effect after LASIK primarily caused by the diffraction of light. It is believed to be caused by the grating pattern created on the back surface of the LASIK flap after femtosecond laser exposure.[1,2] A diffraction grating is an optical component

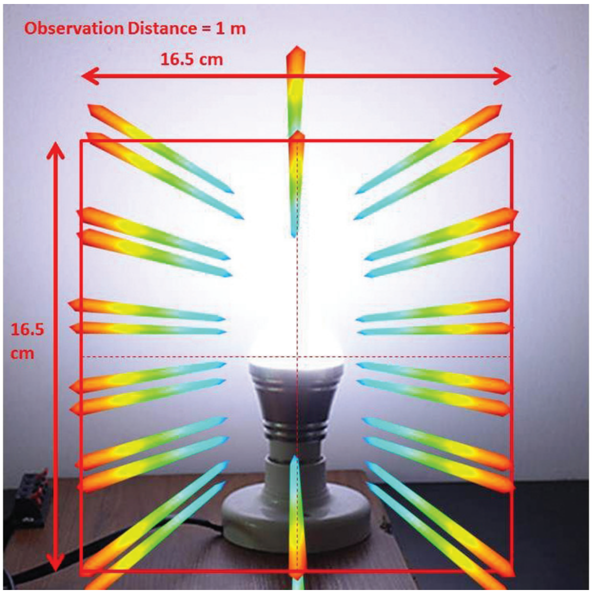

Figure 2. Illustration offered by the patient reporting symptoms of rainbow glare in his right eye. Six bands of color are seen around each side of a white light source.

with a periodic structure, which splits and diffracts light into several beams travelling in different directions. The directions of these beams depend on the spacing of the grating and the wavelength of the light, so that the grating acts as the dispersive element.[3] As the incident light is refracted and diffracted by the cornea on the way from its source to the fovea, the gratings created by the femtosecond laser spots are of 'transmission' type. The diffracted light is composed of the sum of interfering wave components, and the intensity of the pattern created on the retina is the result of the combined effects of interference and diffraction. A diffraction grating has a 'zero-order mode' (where $m = 0$), in which there is no diffraction and a ray of light behaves according to the laws of refraction. The relationship between the grating spacing and the angles of the incident and diffracted beams (non-zero order modes, $m \geqslant 1$) of light is known as the grating equation. When light is normally incident on the grating, the diffracted light will have maxima at angles θ_m given by this equation: $d \sin \theta_m / \lambda = |m|$, where θ_m is the angle between the diffracted ray and the grating's normal vector, d is the distance from the center of one slit to the center of the adjacent slit, and m is an integer representing the propagation mode of interest. When looking at a white-light source positioned at a distance of 1 m in a dark environment, our patient noted the spectral bands for red extended from a distance of 85.0 mm. Using the previous equation and $\lambda = 640$ nm, we calculated a grating pattern spacing of 7.90 µm,

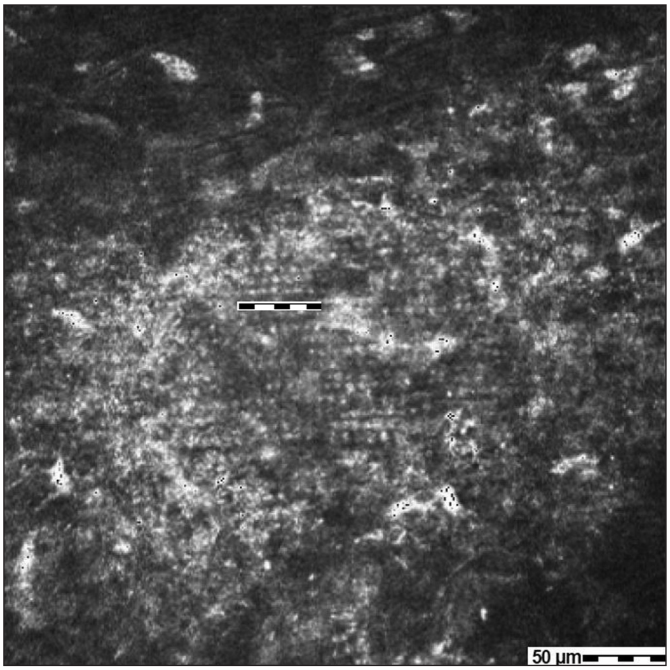

Figure 3. Observation of hyperreflective zones in an equidistant arrangement, measuring only a few microns at the 3-month examination of the right eye of the patient. This aspect is highly evocative of the tissular response of the femtosecond laser impacts at the posterior side of the flap: the spacing of the impacts is approximately 7 to 8 μm because 6 to 7 consecutive impacts can be counted along a linear distance of 50 μm (HRT II image **AQ1**; original magnification 400 × 400 μm).

which is close to the programmed value of spot separation (7.50 µm), and corresponds to the spacing dimensions observed on confocal microscopy.

One morphologic study has reported the presence of a raster pattern at the interface after femto-LASIK flap creation,[4] but others failed to demonstrate such pattern at the interface level[5,6] or at the back of the flap.[7]

Using in vivo confocal microscopy, similar hyperreflective spots have been observed after LASIK in asymptomatic eyes in which flaps were created with the IntraLase femtosecond laser.[8] These features, which disappeared between day 7 and month 2, were attributed to tissular response of the femtosecond laser impacts at the posterior side of the flap. In our patient, these images were still visible 3 months after femtosecond laser surgery.

The quality of the focused beam and numerical aperture of the focusing optics appears to be the most significant factor in minimizing the diffractive dispersion of light that leads to this symptom.[1,2] In previous studies, the relationship between length of time from a service call and the incidence of rainbow glare emphasized the importance of a proper maintenance and alignment of the optical components used to focus the beam. Although we could not have access to this information, it is intriguing that the occurrence of the rainbow glare symptoms was unilateral, despite identical energy and spot separation parameters for the right and left eyes. The image taken by the FS-200 camera after the interface creation was suggestive of a raster pattern for the shot delivery in the right eye (**Figure 1B**), whereas it was not apparent in the left eye (**Figure 1A**). How this immediate appearance after the interface creation relates to the occurrence and persistence of the symptoms of our patient remains to be elucidated. The presence of hyperreflective shot pattern in the right eye and its absence in the left eye confocal microscopy examination reinforces the hypothesis that the uniform array of periodically aligned photodisruption defects acts as a likely source of the grating pattern, resulting in diffractive light scatter.

We report the first case of rainbow glare occurring after femto-LASIK using a FS-200 femtosecond laser. The case was documented with in vivo confocal microscopy images evocative of a diffractive pattern created by the raster spot pattern and consecutive tissular response arrangement. Even with the latest advances in femtosecond laser technology, rainbow glare remains a possible optical side effect. Consequently, further investigation is necessary to evaluate its clinical impact and effect on the visual function, and to better understand the factors contributing to it.

AUTHOR CONTRIBUTIONS

Study concept and design (DG); data collection (EG, DG, HR, AS); analysis and interpretation of data (DG); drafting of the manuscript (DG); critical revision of the manuscript (EG, DG, HR, AS); administrative, technical, or material support (DG, AS); supervision (DG)

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AUTHOR QUERIES

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