In Vivo Structural Characteristics of the Femtosecond LASIK-Induced Opaque Bubble Layers With Ultrahigh-Resolution SD-OCT

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ABSTRACT

The authors report in vivo morphology of opaque bubble layers with ultrahigh-resolution anterior-segment optical coherence tomography (UHR-OCT) in 3 patients. Two patients were operated on with a 30-kHz IntraLase femtosecond laser (Abbott Medical Optics, Abbott Park, IL) and one patient was operated on with a 500-kHz VisuMax femtosecond laser (Carl Zeiss Meditec, Jena, Germany). UHR-OCT images from the patient operated on with the 500-kHz femtosecond laser revealed that the opaque bubble layer extended anterior to the flap dissection plane up to Bowman’s membrane. The lamellar flap dissection was incomplete in this patient. The opaque bubble layer in the patients operated on with the 30-kHz femtosecond laser extended posterior to the flap dissection plane and these patients experienced complete lamellar dissections with uncomplicated flap lifts. UHR-OCT imaging can be used to demonstrate the structural characteristics of OBL. It has the potential to be used to predict incomplete lamellar flap dissections in patients with opaque bubble layers. [Ophthalmic Surg Lasers Imaging 2010;41:S109-S113.]

INTRODUCTION

The femtosecond laser is a surgical tool used to prepare accurate, uniform, and predictable incisions in the cornea. The femtosecond laser separates the stromal lamellae by ultra-short wavelength energy that creates contiguous small bubbles expanding to form a resection plane. These interface gas bubbles are released when the flap is lifted; therefore, they do not interfere with the excimer ablation process. However, the gas bubbles sometimes break vertically through the corneal epithelium and diffuse into the corneal stromal lamellae, subconjunctival space, or even the anterior chamber. The opaque bubble layer is the accumulation of gas bubbles in the superficial layers of the stromal bed that form a diffuse opacity. These bubbles do not release when the flap is lifted and they can interfere with the flap creation or result in the blocking of iris-tracking during the excimer laser ablation. The histopathology of opaque bubble layers has not yet been described. Although opaque bubble layers may be visualized with Fourier-domain optical coherence tomography (OCT), the tissue resolution is not enough to demonstrate the in vivo detailed structural characteristics. Our group has developed a novel, custom-built, ultrahigh-resolution, spectral-domain anterior-segment optical coherence tomography (UHR-OCT) that can be used to demonstrate the structural characteristics of OBL.
used as a new imaging technique to visualize corneal tissue with an axial resolution of 3 µm. We report the in vivo structural characteristics of outer bubble layers with UHR-OCT.

CASE REPORTS

Case 1

A 43-year-old man with no previous ocular or medical history was scheduled for laser in situ keratomileusis (LASIK) with a 500-kHz VisuMax femtosecond laser (Carl Zeiss Meditec, Jena, Germany) for the treatment of myopia and astigmatism in both eyes. The manifest refraction was -1.75 +0.50 @ 180 in the right eye and -0.75 +0.25 @ 155 in the left eye. Best-corrected visual acuity was 20/20 in both eyes. Preoperatively, the central corneal pachymetry measurement (Orbscan; Bausch & Lomb, Rochester, NY) was 616 and 604 µm in the right and left eye, respectively. The corneal topography values (Corneal Topographer; Tomey, Nagoya, Japan) were 42.63 @ 31 and 42.33 @ 121 in the right eye and 42.57 @ 132 and 42.12 @ 42 in the left eye.

A small-size treatment pack was selected. The flap thickness parameter was set at 110 µm and the flap diameter setting was 7.9 mm. The other femtosecond laser settings were: side-cut angle of 110°, hinge angle of 35°, hinge position at 90°, spiral centripetal pattern, side-cut energy of 220 nJ, and spot energy of 220 nJ.

At the beginning of the flap creation, a dense opaque bubble layer appeared starting at the flap edge and extending toward the center of the cornea. It enlarged faster than the spiral pattern of the femtosecond laser (Figs. 1A, 1B, and 1C). UHR-OCT imaging was performed before the flap was lifted. UHR-OCT images revealed that the opaque bubble layer was located between the Bowman’s membrane and the mid-stroma (Fig. 2). The flap interface could clearly be identified in the periphery. However, in the area of the dense opaque bubble layer, which appears as bright hyperintense opacities, the flap interface is not visualized as clearly. After imaging of the opaque bubble layer was completed, flap lifting was initiated. The attempt was unsuccessful due to incomplete lamellar dissection over the area of the opaque bubble layer that resulted in a torn corneal flap (Fig. 1D). Flap preparation for the left eye and excimer laser ablation was aborted. The flap was repositioned and a bandage contact lens was placed over the cornea. Topical prednisolone acetate 1% (Pred Forte; Allergan Inc., Irvine, CA) and a fourth generation fluoroquinolone (Vigamox; Alcon Laboratories, Fort Worth, TX) were prescribed four times daily for 1 week following surgery. The prednisolone was then slowly tapered over 1 month. At postoperative week 3, the patient had mild photophobia with a best-corrected visual acuity of 20/20 in his right eye.

Case 2

A 36-year-old man with no past ocular or medical history had LASIK with a 30-kHz IntraLase laser (Abbott Medical Optics, Abbott Park, IL) flap creation for the treatment of myopia and astigmatism. The manifest refraction was -9.00 +1.25 @ 140 in the right eye and -9.00 +1.75 @ 40 in the left eye. Best-corrected visual acuity was 20/20 in both eyes. Preoperatively, the
central corneal pachymetry measurement was 508 and 505 µm in the right and left eye, respectively (Orbscan). The corneal topography values were 45.12 @ 117 and 43.46 @ 27 in the right eye and 45.31 @ 58 and 43.74 @ 148 in the left eye (Corneal Topographer).

The flap thickness parameter was set at 110 µm for both eyes. The flap diameter settings were 8.8 mm in the right eye and 8.9 mm in the left eye. The other parameters were: raster energy of 1.9 µJ; 11 µm/9 µm spot/line separation; hinge position at 90°, with hinge angle of 45°; side-cut energy of 2.3 µJ, with side-cut angle of 70°.

During flap creation in the left eye, a hard opaque bubble layer appeared at the superior half of the cornea, close to the hinge of the flap. Before the flap was lifted, UHR-OCT images of both corneas were obtained. In the right eye, there were small areas of diffuse opaque bubble layer displayed along with the flap interface. It is interesting to note that none of the lesions expanded into the surrounding corneal stroma in the right eye (Fig. 3A). In the left eye, a dense opaque bubble layer was located between the interface and the mid-stroma (Fig. 3B). In this case, none of the bubbles extended above the flap interface.

After the imaging was completed, the flap was lifted and excimer laser ablation was performed. In the left eye, there was increased resistance to flap lifting in the area of the OBL, but the flap was lifted without any complications. Wavefront-guided excimer photoaerlation with the Visx S4 (Abbott Medical Optics) targeting emmetropia was uneventful. Topical prednisolone acetate 1% (Pred Forte) and moxifloxacin (Vigamox) were prescribed four times a day for 1 week following surgery. On postoperative day 1, uncorrected visual acuity was 20/25 in both eyes. Slit-lamp examination was unremarkable.

Case 3

A 26-year-old man with no past ocular or medical history had LASIK with 30-kHz IntraLase laser flap creation for the treatment of myopia and astigmatism. The manifest refraction was -2.00 +0.50 @ 370 in the right eye and -2.25 +0.75 @ 390 in the left eye. The best-corrected visual acuity was 20/20 in both eyes. Preoperatively, the central corneal pachymetry measurement was 598 and 581 µm in the right and left eye, respectively (Orbscan). The corneal topography values were 43.12 @ 89 and 41.30 @ 179 in the right eye and 43.18 @ 84 and 41.19 @ 174 in the left eye (Corneal Topographer).

The flap thickness parameter was set at 110 µm for both eyes. The flap diameter settings were 9.1 mm in the right eye and 9.1 mm in the left eye. The other parameters were: raster energy of 1.9 µJ; 11 µm/3 µm spot/line separation; hinge position at 90°, with hinge angle of 45°; side-cut energy of 2.3 µJ, with side-cut angle of 70°.

During flap creation in the left eye, a hard opaque bubble layer appeared in the superior half of the cornea. Flap lifting and excimer laser ablation was performed.
without any complications. UHR-OCT images were taken immediately after the surgery was completed (Fig. 4A). In the left eye, the remaining opaque bubble layer and the bubbles of the side pocket were present in the mid-stroma (Fig. 4B). Interestingly, there were no bubbles located around the flap interface. Topical prednisolone acetate 1% (Pred Forte) and moxifloxacin (Vigamox) were prescribed four times a day for 1 week following surgery. At postoperative 1 month the uncorrected visual acuity was 20/20 in both eyes.

**DISCUSSION**

We have demonstrated in vivo structural characteristics of opaque bubble layers with UHR-OCT. The use of this new imaging technique allowed us to perform in vivo, noninvasive, morphological analysis of the cornea. Tissue resolution of UHR-OCT gave us the opportunity to get high-quality images of the cornea simulating the living biopsy of the tissue. This technique has the potential to be used in all clinical conditions generating structural changes in the cornea. To the best of our knowledge, this is the first study in the literature to describe in vivo structural characteristics of opaque bubble layers with UHR-OCT.

There are two different types of opaque bubble layers. The early (hard) type opaque bubble layer has a more dense appearance and develops at the plane of laser pulses. The late (diffuse) type of opaque bubble layer has a more transparent appearance and occurs after the laser dissection has been completed through a particular area. Both types of opaque bubble layers have a bright white appearance in UHR-OCT. However, the density and the distribution of the lesions in the corneal stroma are found to be different.

A VisuMax femtosecond laser system does not use a side-pocket due to its lower energy use and minimal compression of the cornea. The minimal spot energy (pulse energy of less than 1 uJ) and rapid firing rate (repetition rate of 500 kHz) results in decreased production of bubbles and permits the femtosecond laser to remain ahead of the expanding opaque bubble layer. However, in our first case the OBL expanded faster than the femtosecond laser. The UHR-OCT images demonstrated that the gas particles reached from mid-stroma up to Bowman’s membrane in the area of the dense opaque bubble layer. The flap interface was not visualized due to the dense opacities of the opaque bubble layer. This finding has never been reported before as a contraindication to proceeding with the flap lifting. As a result, the surgery was continued and resulted in a torn flap. Our experience suggests that opaque bubble layers located above the flap interface may be a sign of an undissected flap zone. This pattern of opaque bubble layers on an UHR-OCT image may be a contraindication to flap lifting and result in termination of surgery. Performing a second pass could be considered as another alternative to complete the lamellar flap dissection.

In cases 2 and 3, the UHR-OCT images showed different structural characteristics of the opaque bubble layer with the 30-kHz IntraLase laser. In case 2, the opaque bubble layer was located between the flap interface and the mid-stroma. Although the opaque bubble layer had a dense pattern in some areas, there was no involvement of the corneal stroma above the flap interface. In the fellow eye, most of the diffuse opaque bubble layer was located around the flap interface. In case 3, the scanning was performed after the laser ablation was completed. The opaque bubble layer that remained after surgery was located at the level of mid-stroma. Once again, no bubbles were identified at the flap interface just minutes after the excimer laser ablation was performed.

Opaque bubble layer incidents with high vacuum femtosecond lasers have been reported to occur mainly below the corneal flap interface. It has been suggested that the generated gas bubbles are under high pressure due to corneal compression and high vacuum. Because the corneal lamellae interweave more extensively in the layers of the anterior cornea, the bubbles created will travel the pathway of least resistance and migrate deep into the stroma or the side pocket when under high pressure. With the VisuMax laser, the suction apparatus does not compress the cornea as it does with the IntraLase femtosecond laser system. This property gives VisuMax the advantage over high vacuum systems by allowing the patient to maintain vision and relatively lower intraocular pressure during treatment. However, this feature may also allow gas bubbles to travel anterior to the flap interface, potentially increasing the risk of incomplete flap dissection in patients with hard opaque bubble layers.

Incisions from previous corneal surgeries such as LASIK, radial keratotomy, or penetrating keratoplasty and thin flaps can also cause gas bubbles to dissect through the anterior stroma. These bubbles can block
the focused femtosecond laser light and result in an incomplete flap. This phenomenon is similar to our experience with the patient in case 1. However, lack of previous scarring in this patient suggested that this complication may be a result of intrinsic characteristics of a low vacuum femtosecond laser system.

Our study demonstrates that UHR-OCT can be used as a noninvasive technique to image opaque bubble layer characteristics and to observe the in vivo stromal distribution of the opaque bubble layer during femtosecond-assisted refractive surgery. UHR-OCT imaging may be used to guide the surgeon and prevent flap complications related to opaque bubble layers.

REFERENCES