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SHORT COMMUNICATION

Evaluation of Cyclophotocoagulation Effects with 1310-nm Contact Optical Coherence Tomography

M. Müller
Department of Ophthalmology, Medical University of Lübeck, Lübeck, Germany

C. Winter and G. Hüttmann
Institute for Biomedical Optics, Lübeck, Germany

H. Laqua and H. Hoerauf
Department of Ophthalmology, Medical University of Lübeck, Lübeck, Germany

ABSTRACT *Purpose*: The aim of this pilot study was to evaluate whether contact optical coherence tomography (OCT) allows visualization of the effects of cyclophotocoagulation. *Methods*: In this pilot study, transscleral contact OCT images (1310-nm wavelength) were generated prior to and immediately after conventional transscleral diode laser cyclophotocoagulation in three eyes of three patients who were suffering from uncontrolled glaucoma. *Results*: In the region of the ciliary body, transscleral contact OCT revealed two layers: (i) a superficial thick hyperreflective complex representing conjunctiva, the Tenon capsule, episclera, and sclera; and (ii) a thinner hyporeflective layer representing the ciliary body. The ciliary body could be differentiated from the overlying sclera by its marked drop in reflectivity. After cyclophotocoagulation, a marked increase of reflectivity in the treated area of the ciliary body was identifiable. After treatment, the distinct border between the hyperreflective scleral complex disappeared, and the region of the ciliary body appeared hyperreflective. The optical properties of the overlying sclera remained unchanged. On corresponding averaged A-scan images, scleral thickness appeared to be slightly increased, whereas ciliary body thickness remained unchanged. *Conclusions*: This pilot study demonstrates the capability of contact OCT for allowing visualization of changes in the ciliary body after transscleral cyclophotocoagulation (TSCPC). Further investigations are planned to clarify the complete significance of these data.

KEYWORDS ciliary body; cyclophotocoagulation; diode laser; ocular imaging; transscleral contact optical coherence tomography

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Correspondence: Maya Müller, M.D., University Eye Clinic, UK S-H, Campus Lübeck, Ratzeburger Allee 160, 23538 Lübeck, Germany.
E-mail: mayamueller@gmx.de

INTRODUCTION

Diode laser transscleral cyclophotocoagulation (TSCPC) is a destructive modality for treating glaucoma. Differences in transmission, reflection, and absorption of laser energy result from a variety of properties (e.g., degree of pigmentation and thickness of the overlying ocular tissues) and are responsible for a broad spectrum of coagulation effects of the ciliary body.[1] Because the effects

of the laser cannot be visualized at the time of application, delivery of safe and effective individual dosages of laser energy remains a major problem for any cyclodestructive treatment regimen as well as for lowering intraocular pressure. With recent developments in optical coherence tomography (OCT) technology, 1310-nm wavelength OCT offers deeper visualization of scleral tissue than was previously available.[2] To assess whether OCT is suitable for visualizing specific tissue reactions of the ciliary body immediately after TSCPC, we conducted a small-series pilot study to assess the efficacy of combined TSCPC/OCT.

MATERIALS AND METHODS

OCT System

Contact OCT images were generated using a modified experimental hand-piece (Heidelberg Engineering, Lübeck, Germany) based on the physical principles underlying OCT. With this device, differences in optical scattering between the various microstructures of the eye are able to be visualized. Instead of the common light source employed in conventional OCT systems (wavelength, $\lambda = 830$ nm), an infrared superluminescence diode (wavelength, $\lambda = 1310$ nm) (SLD-561; Superlum, Moscow, Russian Federation), with a coherence length of 20 μm and an energy output of 500 μW, was used. The advantage of the higher wavelength is that it provides deeper visualization into scleral tissue than that achieved by conventional (lower wavelength) OCT.[3,4] For the longer wavelength device, the acquisition time per image was 2 s. The reference arm optical delay, which determines the depth of the cross section, was 2.5 mm in air. Within the eye, the optical path is increased by the refractive index of the sclera. Thus, the axial depth of the image was reduced to ~1.8 mm and the axial resolution to 15.0 μm, depending on the optical properties of the measured tissue. The signal-to-noise ratio (SNR), which describes the quotient of the maximum signal and noise, was ~100 dB. The contrast of the system was verified by comparing the amplitude of an adjusted mirror (sample) to the standard deviation of noise. OCT images were generated in logarithmic gray scale. The resulting image represented a cross-sectional x/z diagram that was displayed online and recorded simultaneously. The scan length was 2 mm. The images displayed 200 × 600 (120,000) pixels, with a digitalization rate of 3.0 μm axially, and were not corrected for distortion (unscaled data). The contact OCT device was originally designed for dermatologic use; it has been previously described in more detail elsewhere.[5] The hand-piece, which comprises the OCT fiber, the scanning module, and the focusing optic, was adapted for ophthalmologic use by reducing its size and by modifying the tip spherically for increased transmission (via compression) through the sclera.[6]

Diode Laser Specifications

Using the contact fiber optic G-probe (IRIS-Endoprobe), an infrared diode 810-nm laser (IRIS Medical Oculight SLx, IRIDEX Corporation, Mountain View, CA, USA) (range 1.5–2.5 W and 1.5 s) was applied perpendicularly to the scleral surface, at a distance of 1.5 mm from the limbus.

Surgical Procedure

Transscleral contact OCT measurements and TSCPC were performed immediately before and after TSCPC on three patients suffering from uncontrolled glaucoma. Informed consent was obtained from all patients. The study was approved by the ethics committee of our university. Prior to this treatment, no other ciliary destructive procedures had been performed. Measurements and treatments were accomplished under general anesthesia; pupils were undilated.

RESULTS

With 1310-nm contact OCT, a section of the pars plicata of the ciliary body could be visualized. In contrast with noncontact transscleral OCT, neither the overlying conjunctiva nor any other superficial layer was discernible (Fig. 1A). With the contact OCT system, two layers could be differentiated in the region of the ciliary body: (i) a superficial thick, hyperreflective complex representing conjunctiva, the Tenon capsule, episclera, and sclera; and (ii) a thinner, hyporeflective layer representing the outer part of the ciliary body in the area of the pars plicata. The ciliary body could be differentiated from the overlying sclera by a marked drop of reflectivity, owing to the fact that the sclera is highly reflective. Such reflectivity is a result of the inhomogeneous distribution of variable-diameter collagen fibrils of the sclera, in contrast with the soft and less dense structure of the ciliary body (Fig. 2A). Increasing the pressure on the hand-held contact system did not allow improved visualization of deeper structures, nor

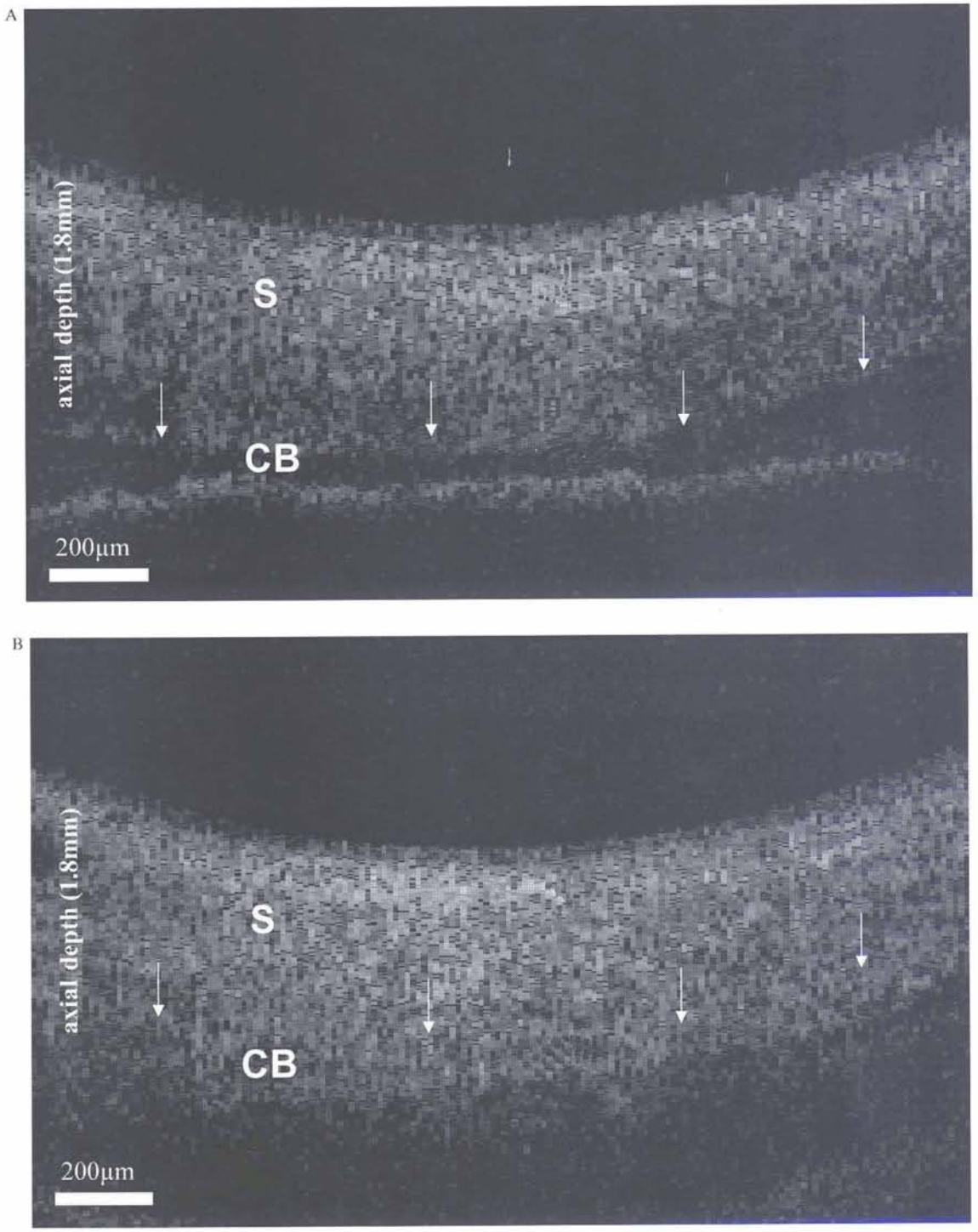

FIGURE 1 Transscleral contact OCT image (1310 nm, 100 Hz, 200 scans, 2.0 × 1.8 mm). (A) Immediately before TSCPC: hyperreflective scleral layer, hyporeflective ciliary body layer. (B) Immediately after TSCPC: hyperreflectivity of ciliary body region. At an exposure duration of 1.5 s, the laser power was 2000 mW. S, sclera; CB, ciliary body; arrows, sclera–ciliary body crossover.

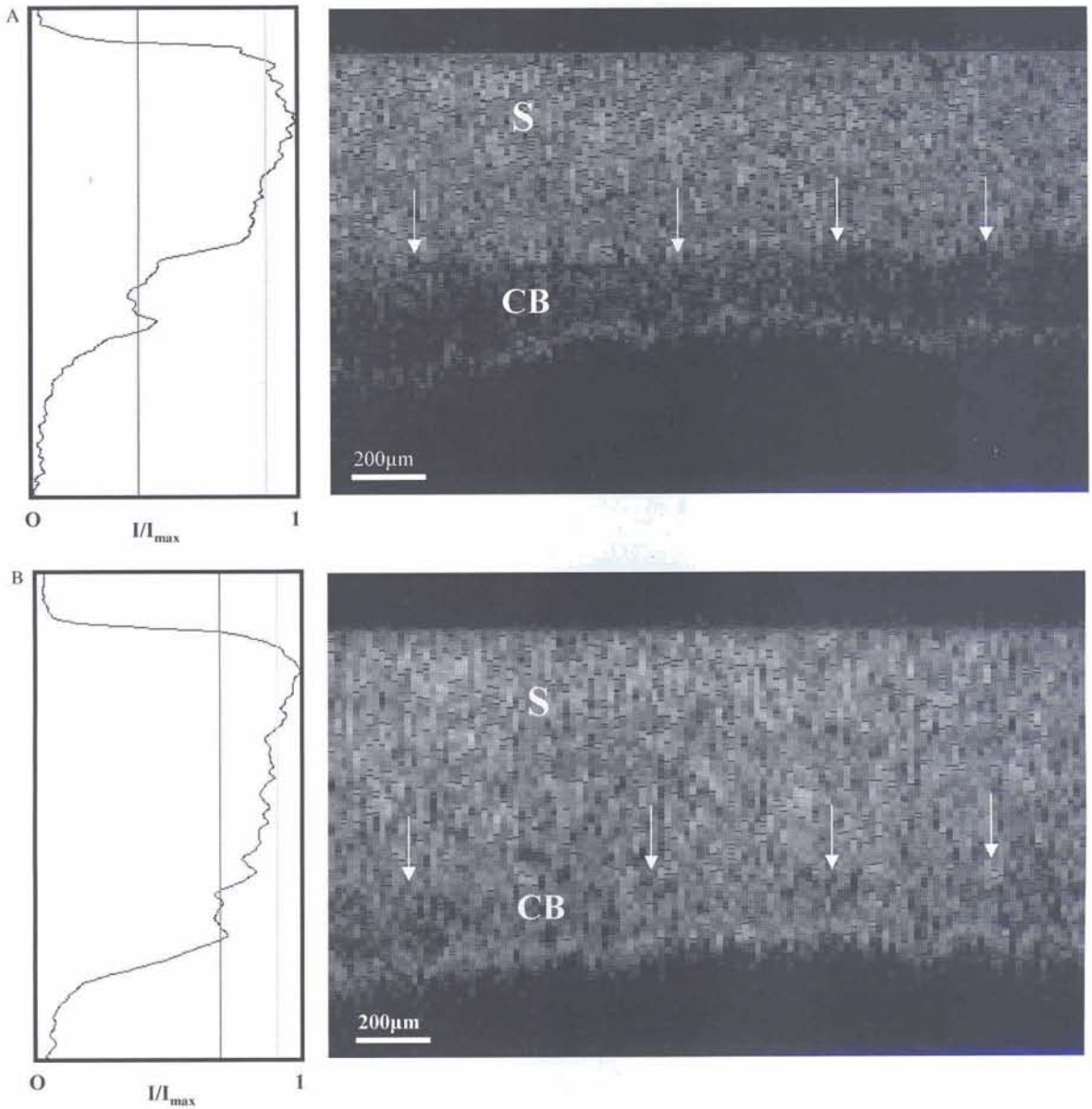

FIGURE 2 Surface-aligned partial image and corresponding normalized averaged A-scan. Graphs are normalized to maximum intensity. (A) Immediately before TSCPC. (B) Immediately after TSCPC, showing a marked increase of signal intensity in the ciliary body region after treatment. Right line: Averaged intensity within sclera, showing a broadening of scleral plateau. Left line: Averaged intensity within ciliary body. At an exposure duration of 1.5 s, the laser power was 2000 mW. S, sclera; CB, ciliary body; arrows, sclera–ciliary body crossover.

did releasing the pressure allow for superficial layer differentiation. Due to limited signal intensity and limited penetration depth, no additional structures (e.g., zonular fibers or peripheral lens elements) could be identified. The concave shape of the surface was caused by depressing the spherical glass-surfaced applicator onto the sclera.

After cyclophotocoagulation, a marked increase of reflectivity in the treated area of the ciliary body was identifiable, whereas reflectivity of the untreated region remained unchanged (Fig. 1B). A distinct border, located between the hyperreflective scleral complex and the hyporeflective ciliary body, was present prior to TSCPC but disintegrated and nearly disappeared after

treatment. The ciliary body region became hyperreflective. The optical properties of the overlying sclera remained unchanged. The distinct demarcation between the sclera and the ciliary body complex was no longer discernible after treatment (coagulated area). The corresponding averaged A-scan (Fig. 2) shows a broadening of the scleral plateau. This is due, presumably, to a slight increase in scleral thickness. In contrast, the dimensions of the ciliary body remained identical (i.e., its thickness was not increased after treatment). The hyperreflectivity of the treated area remained unchanged over the maximum real-time visualization of 120 s (Figs. 1B and 2B). In contrast to that which occurs in noncontact OCT, motion artifacts were negligible here.

DISCUSSION

During TSCPC, failure to visualize the ciliary body could not only result in inaccurate treatment localization but also might explain some of the variability in treatment response.[7,8] Thus, the ability to visualize structures is crucial for assessing effective and safe treatment parameters. The ciliary body has, so far, been imaged by ultrasound biomicroscopy (UBM).[9] The effects of laser have been judged by studies on animal eyes, human cadaver eyes, and living human eyes that were subsequently enucleated or imaged by UBM.[9,10] Several studies have reported the use of modified Miyake posterior photography or high-resolution black-and-white videography to study transscleral laser lesions.[11,12] These techniques revealed slow tissue shrinkage and whitening of the ciliary epithelium. A study by Lim et al. on rabbit ciliary body demonstrated blood perfusion immediately and 1 week after TSCPC.[13] These authors used high-frequency ultrasound imaging, which revealed ciliary body shrinkage and markedly diminished areas of blood flow.

Another method for collecting signals from the ciliary body was used on porcine and human cadaver eyes by Preussner, who measured reflections of transmitted energy from the posterior segment through the pupil.[14] With this technique, no direct, time-related correlation with the occurrence of the "pop" sound was demonstrable. The "pop" is an audible gross sign that indicates the maximum allowable energy levels for application to the eye.[1,15] Whereas histology–when used as a method for determining the effects of laser–is hampered by factors such as inflammatory reaction and time delay, OCT allows immediate analysis of reflectivity changes of the ciliary body. Correlation between transscleral contact OCT findings and anatomy is based on studies of human cadaver eyes and OCT anterior segment measurements.[5] The pronounced light scattering of the sclera is a well-known phenomenon.[6,16] The TSCPC effect from contact OCT revealed changes in reflectivity, but no increase in size. This may be explained by laser-induced thermal changes, which alter the alignment of tissue fibrils, thus increasing the reflectivity seen with contact OCT. While these latter effects were observed immediately after TSCPC, long-term TSCPC effects, as demonstrated histologically, include whitening of the ciliary body epithelium.[11] Contact OCT would then exhibit a sustained increase in reflectivity. Wirbelauer et al. used noncontact OCT for imaging scleral expansion bands in presbyopia.[16] This technique allowed for quantitative evaluation of intrascleral changes and enabled estimation of the distance from the scleral extension bands to the hyporeflective ciliary body region. Our measurements were homogeneous over the entire scan period. Thus, artifacts–such as probe impurity, degradation of the measuring system, and misalignment–are unlikely, as they would have produced miscellaneous irregularities over the scan length. Changes in reflectivity may also have been due to (i) time considerations, since there was a short (several seconds) time gap between treatment and post-CPC measurement, or (ii) slightly different measurement locations. Although we went to great lengths to remain at the exact treatment site, a slightly different measurement site cannot be completely ruled out because instruments were changed. To obviate this problem, it would be desirable to combine both instruments within one applicator. Further investigations are intended to combine these features.

With contact OCT, it may be possible to use the pattern of changes in reflectivity of the ciliary body as a hallmark of specific coagulation effects. Transscleral contact OCT may not only improve our understanding of tissue responses to TSCPC but also assist in monitoring the timing and extent of laser effects. This pilot study, although limited in patient number, has shown the capability of contact OCT when used to visualize TSCPC effects in the ciliary body after laser treatment. Further verification of this observation is needed, as repeated longitudinal measurements were not assessed in the current study. It remains to be proved if results of contact OCT after TSCPC correlate with tissue damage caused by the laser procedure; so far, no assumptions can be made whether contact OCT controls tissue

reaction or is capable of indicating changes in aqueous production.

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