Vitreoretinal Surgery Assisted by the 193-nm Excimer Laser

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Purpose. Ablating and cutting vitreoretinal membranes using a 193-nm excimer laser-based microsurgical system.

Methods. A 193-nm microsurgical system enables delivery of the beam into a fluid medium to cut preretinal and subretinal membranes. Two patients with proliferative diabetic retinopathy and one patient with proliferative vitreoretinopathy were treated with this new device.

Results. Gentle ablation and cutting of the preretinal and subretinal membranes without exerting any traction on or apparent damage to the neighboring tissue was achieved.

Conclusions. The technology is applicable to a variety of intraocular vitreoretinal surgical procedures. Invest Ophthalmol Vis Sci. 1997;38:1825–1829.

Proliferative vitreoretinopathy is the most common cause of failure in surgical procedures designed to treat retinal detachment. The pathogenesis of proliferative vitreoretinopathy involves proliferation of various cell types forming contractile membranes on the anterior and the posterior surfaces of the detached retina. The removal of these membranes requires precise surgical intervention. The current procedures of choice for the removal of such membranes are mechanical segmentation, peeling, or delamination. The mechanics of membrane removal are such that a degree of traction is usually exerted on the tissue that can damage the internal limiting layer and cause iatrogenic tears and bleeding.[1]

To circumvent the associated problems of mechanical membrane removal, several approaches have been investigated to accomplish tractionless removal of vitreoretinal membranes, using various types of lasers.[2–6] The approach of using the CO_2[2] and Holmium:YAG[3] lasers that are strongly absorbed in water causes collateral effects of the laser on the surrounding healthy tissue. In both these cases, the retina was damaged when the laser probe was located ~1.5 to 2 mm from the retinal surface. In the first application of the Erbium:YAG laser (in a normal spiking mode)[4] to vitreoretinal membrane cutting, the retina was also damaged at approximately the same distance as it was in the previous studies. Recent research on the application of this laser to vitreoretinal membrane removal,[5] using tips of improved configuration, generated data of considerably better quality. Membranes that were in contact with the retina and those located ~0.2 mm and 0.5 mm from the retina were cut with these tips. Thermal damage or hemorrhage of the retina was detected in 7 of the 18 cuts.[5] The 308-nm XeCl excimer laser was also reported able to cut vitreoretinal membranes,[6] but this wavelength is hazardous to cornea, lens, and retina.[7] As a result, these approaches have failed to achieve their objective of replacing mechanical instrumentation with laser removal of the interfering membranes.

Another technology, that of dielectric breakdown by a tightly focused laser beam, has also been tried for vitreoretinal membrane photodisruption. A picosecond Neodymium:YAG laser was focused by a high numeric aperture lens placed in front of the eye.[8] The membranes were cut successfully, but the retinal injuries were frequently detected up to 2 mm from the focal point of the laser. However, these injuries were detectable only in experiments in vivo using fluorescein angiography. The retinal damage was probably a result of laser absorption in the retinal pigment epithelium under the irradiated area,[8] because a significant part of the radiation penetrates through the focal spot of the laser beam and reaches the underly-

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ing tissue. In addition, the laser beam cannot be tightly focused in the peripheral part of the eye globe, which complicates, or makes impossible, the application of such a technique in these areas. Furthermore, the noninvasive nature of this procedure has no advantage for retinal membranes, because the actual removal of the cut membranes requires an invasive procedure.

We have developed a microsurgical system based on the 193-nm ArF excimer laser.[9,10] In the past, the application of this laser has been limited to such relatively dry tissues as the cornea, because of its complicated delivery problems in transmission through optical fibers[11] and through biologic fluids. We have resolved these problems by designing an articulated arm and a specialized tip that permit the transmission of the 193-nm radiation in the eye and allow the tip to reach almost all regions of the eyeball. In preliminary studies with animal models, we demonstrated precise and reproducible cutting of membranous tissue in the fluid environment of an eye in vivo.[10]

Herein we describe the first applications of this device to three patients with vitreoretinal proliferative disease in whom intravitreal, preretinal, and subretinal membranes were ablated with the 193-nm excimer laser.

METHODS

All patients described were treated according to the tenets of the Declaration of Helsinki after written, informed consent was obtained.

A model 103 MSG Lambda Physik (Gottingen, Germany) ArF excimer laser with 193-nm wavelength and a ~20-nsec pulse duration was used. The laser beam was directed with a specially designed articulated arm.[9,10] The excimer laser probes, with outer diameter of 1.5 mm and tip diameter 0.28 ± 0.03 mm, were inserted through the sclerotomy in all procedures. The total energy transmitted through the tips was calibrated before the sterilization by an Ophir DGX energy meter (Jerusalem, Israel) with an 03AP head. In all surgical procedures, the total energy was 0.12 ± 0.02 mJ/pulse. For effective ablation and cutting, it was necessary to touch the tissue gently with the laser tip during the surgical procedure.

RESULTS

The three patients described illustrate different techniques of vitreoretinal surgery with the ArF laser-based microsurgical system: direct ablation or removal, gentle lift with tangential cutting, and cutting of subretinal membrane fibers through small holes created in the retina.

Patient 1

A 61-year-old woman, with known diabetes of 15 years' duration, had proliferative diabetic retinopathy. She underwent panretinal photocoagulation with the argon laser and thereafter had several episodes of recurrent vitreous hemorrhage in the right eye. Preoperative examination revealed that visual acuity in the right eye was limited to perception of hand movements only. A mature cataract and dense intravitreal hemorrhage completely obscured the fundus. Echographic examination showed an attached retina with epiretinal membranes in the posterior pole.

Under general anesthesia, the cataract was removed by phacoemulsification, and a pars plana vitrectomy was performed. After the vitreous was cleared, we could observe an attached retina, a pale optic disc, and an epiretinal fibrous tissue remnant (1.5 mm × 1 mm) in the posterior pole. We decided to remove this tissue to prevent a traction retinal detachment from developing. We chose the excimer laser to remove the membrane by direct ablation at a repetition rate of 10 to 20 Hz (Fig. 1). The laser probe was passed over the tissue, in near contact, scalping the tissue layer by layer. It took several scans before the tissue was completely removed. In spite of the very close location of the fibrous clump to the retina, no apparent damage in the underlying retina was detected after tissue removal (Fig. 2). The technique enabled us to remove such tissue without pulling the retina and thus prevented a retinal break.

At a follow-up visit 14 months after the procedure, the visual acuity in the patient's right eye had recovered to 20/500, and the retina was attached.

Patient 2

A 65-year-old woman had proliferative diabetic retinopathy for 20 years. During the last 5 years, she had undergone panretinal photocoagulation by argon laser in both eyes, but her vision had declined. Examination revealed no light perception in the right eye because of neovascular glaucoma, whereas the vision in her left eye was limited to perception of hand movements because of mature cataract and tractional retinal detachment.

Under general anesthesia, she underwent a phacoemulsification procedure and pars plana vitrectomy. After the vitrectomy was completed, a large fibrovascular epiretinal membrane covering the posterior pole and a traction-localized retinal detachment were revealed (Fig. 3). Removing such a large membrane by "direct ablation" as described in the first patient is very time consuming. Therefore a gentle-lift technique was employed. The large membrane was first segmented into five parts by passing the laser tip over the membrane from the edge of the optic disc

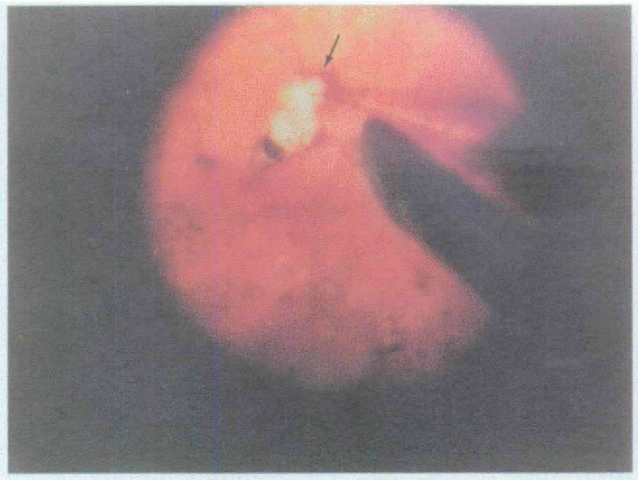

FIGURE 1. Patient 1. Epiretinal fibrous tissue remnant (*arrow*) in patient with proliferative diabetic retinopathy before ablation by excimer laser. Laser tip is touching the tissue. The shadow of the tip can be seen on the retinal surface.

FIGURE 2. Condition of patient 1 after removal of epiretinal fibrous tissue. No apparent damage can be observed on the retina under the removed clump.

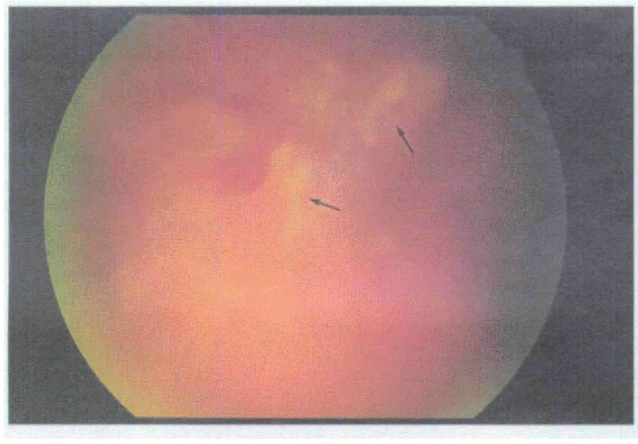

FIGURE 3. Patient 2. Proliferative diabetic retinopathy with fibrovascular membranes (*arrows*) covering the posterior pole and preretinal bleeding.

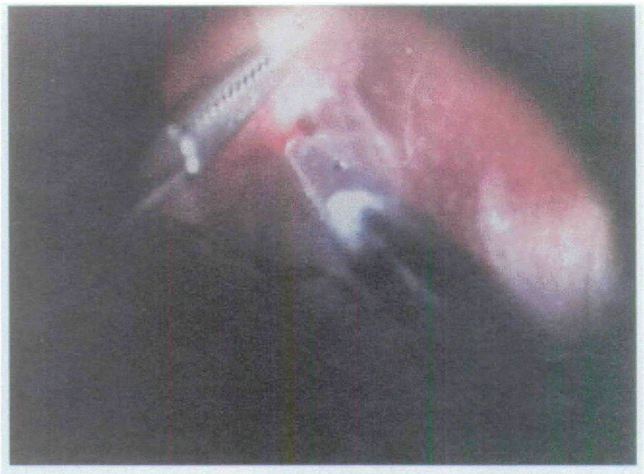

FIGURE 4. Patient 2. Excimer laser cutting the fibrotic connections between the membrane and the retina.

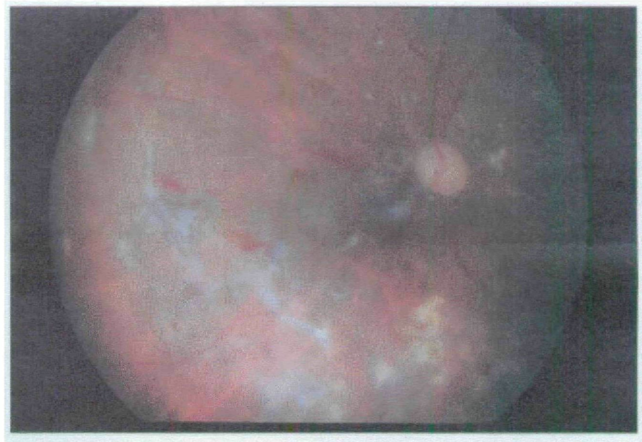

FIGURE 5. Patient 2. One month after ablation of preretinal membranes with the excimer laser.

FIGURE 6. Patient 3. Cutting of a subretinal fibrotic band and the overlying retina with the laser tip. The arrow indicates where the fibrotic band was cut.

to the peripheral areas of the retina and performing full-thickness cuts in the membrane. The edges of the small, segmented membranes were gently lifted up by forceps, revealing the fine fibrotic connections attaching the retina to the membrane. The laser tip was brought into near contact with these fine connections (Fig. 4) and cut with a few laser pulses, thereby fully releasing the membrane, which could then be removed with forceps or a vitrectome without associated retinal damage. Because there was no retinal tear, silicone oil or gas exchange was not needed. The operation was completed by argon endolaser.

In follow-up examination 14 months later, the retina was flat (Fig. 5), and the patient's visual acuity in the treated eye was 20/600.

Patient 3

A 62-year-old man with myopia underwent a circling–buckling procedure with cryopexy for retinal detachment in his left eye. Four months later he appeared with total retinal detachment in that eye. Examination revealed total retinal detachment, with subretinal bands forming a triangular pattern in the midperiphery retina and peripheral retinal folds causing tractional retinal detachment. No retinal break was seen.

Under general anesthesia, he underwent a pars plana vitrectomy followed by heavy fluid (decalin) injection into the posterior pole to flatten it and to stabilize the retina. The peripheral retina remained detached because of the subretinal bands. To cut these bands the laser tip was brought in proximity to the point in the retina at which the subretinal bands were located. Using a few pulses of the laser, a small hole approximately 0.4 mm in diameter was made in the retina, and the underlying bands were cut (Fig. 6). When the tension of the bands was released, the retina immediately flattened.

The peripheral retinal folds were treated by passing the laser tip through the space between the folds where the fine, transparent epiretinal membranes were located. The membranes were ablated with low energy without visible damage to the retina itself, and the wrinkled retina was freed. Once the retina was free, heavy fluid–silicone oil exchange was performed to complete the flattening of the retina.

In follow-up examination 13 months after the operation, the retina was still attached, and the patient's visual acuity was 20/200.

DISCUSSION

Ideally, a technique for the removal of epiretinal membranes should avoid undue displacement of the retina and thermal or other damage in the surrounding tissues. Today, even with the finest intraocular instrumentation, mechanical traction of the epiretinal tissue can induce complications.

The unique capabilities of the ArF laser microsurgical instrument that we have developed allows tissue to be cut and removed in a gradual and controlled manner without tissue displacement. The mechanism of such tissue cutting is associated with the generation of fast-expanding cavitation bubbles. The dynamics of these bubbles have been studied in model systems,[12] and the results have shown[10] that the 193-nm excimer laser is capable of cutting retinal tissue in vivo to a depth of approximately 25, 50, and 120 μm/pulse when the total energy at the ablating tip is varied in the range of 0.075, 0.11, and 0.17 mJ/pulse, respectively, for a tip diameter of 0.25 mm. Epiretinal membranes were cut with approximately the same pulse rate as the retina.[10]

The biologic medium screens the tissue from the 193-nm radiation caused by absorption when the tip is held at some distance from the surface. This screening effect determines[1] the minimum distance allowed for operation of the laser without damaging the underlying tissue while holding the tip in near contact with the tissue during the cutting.[13] At a distance from the tip to the tissue surface exceeding 60 μm, cavitation bubbles are not generated at the energies used in these surgical procedures; thus, no cutting occurs.[13] This feature provides the surgeon with good distance control for the cutting of vitreoretinal membrane. Concerning possible photochemical effects of the laser on the underlying retina after tissue removal, results of studies in vitro have shown[13] that, beyond 250 μm from a cellular surface, no alterations even in the cellular membrane permeability are seen.

Three techniques of vitreoretinal surgery with the ArF excimer laser were demonstrated. First, a method of "direct ablation," which causes the lowest degree of trauma to the underlying tissue. In this method, dissection and removal could be done in a precise manner with the removal depth depending on the laser energy. With such a technique, layer-by-layer removal could be accomplished.

Second, a gentle-lift technique was applied to areas of large and thick membranes that were adhering tightly to the retina and in which direct ablation would be time consuming. In this procedure, the laser probe was applied first to segment the large membrane. Then, the small membrane segments were lifted gently while the fibrotic connections attaching the membrane to the retina were cut tangentially with the laser, as an additional precaution against retinal injury.

Third, a method of subretinal membrane cutting was employed to cut subretinal bands through small holes made in the retina. The diameter of these holes slightly exceeded the tip diameter that was, in our patient, ~0.28 mm. For this method, especially fine tips can be used to decrease the dimensions of the retinal damage.

During the application of the laser in all the patients there were no observable anatomic effects indicating inadvertent retinal damage, hemorrhage, and other complications. This was true during the operation and in the extended follow-up period after the surgery. The absence of any complications in our patients is probably related to the choice of optimal irradiation conditions, which were selected on the basis of our previous investigations in vivo and in vitro.[10,12,13]

The main difficulties associated with our microsurgical system are of a technical nature. The articulated arm is rather cumbersome—heavy and not flexible enough. The energy stability on the exit of the arm should be improved. An additional disadvantage is the need for a sclerotomy diameter of ~1.5 mm, larger than the standard. Among the limitations of the method is the minimal safe distance at which the laser can be applied. Future developments may permit on-line control of tip-to-surface distances.

The 193-nm excimer laser-based ultramicrosurgical system for vitreoretinal applications, developed at the Hadassah University Hospital Laser Center, has several attractive features and advantages when compared with other methods: Membranes are removed without any traction (this feature is characteristic of all laser-based approaches and is one of the main advantages of such techniques when compared with mechanical peeling); cutting occurs only when the tip touches the tissue, a feature that makes it much safer than lasers that are absorbed in water (er:YAG, CO_2) or those that penetrate deeply in biologic fluids (XeCl excimer, Nd:YAG); and a variety of techniques allows the surgeon the flexibility to choose the best way for total membrane removal with minimal damage to the surrounding tissue.

From our experience in the three patients described, it appears that the 193-nm excimer laser-based ultramicrosurgical system could become an important technical auxiliary in patients with severe vitreoretinal proliferative disease that require surgical intervention.

Key Words

193-nm excimer laser, epiretinal membrane, laser ablation, subretinal membrane, vitreoretinal surgery

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