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Internal ablative sinostomy using a fiber delivered Q-switched CTE: YAG laser (2.69 μm)

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Abstract

Current trends of laser technology towards low-thermal photoablative pulsed mid-infrared lasers open new, more adequate approaches to experimental surgical procedures which have already been evaluated in the past.

Transcorneal laser ablation of the trabecular meshwork (internal sinostomy) in human autopsy eyes was performed with a Q-switched CTE:YAG laser (wavelength: 2.69 μm, pulse width: 1 μs). Beam delivery was achieved with conventional optical quartz fibers (Low-hydroxy-fused-silica: 0,3 ppm, 50 cm length, 200 μm diameter). Light- and scanning-electron-microscopy were used for histological examination and micromorphological analysis.

By applying two laser pulses (6 J/cm^2) to the functional trabecular meshwork, a round sinostomy with a diameter corresponding to the diameter of the fiber-tip was achieved. It was possible to set several internal sinostomies into the chamber angle opposite to the entering paracentesis of the laser fiber-tip. Collateral thermal tissue alteration reached up to 50 μm, and since fiber-tip contact was maintained during laser application, thermal tissue alteration was also found around the opposite wall of Schlemm's canal. At higher energy fluences mechanical (disruptive vaporization) effects were significantly enhanced.

It can be concluded, that low-thermal pulsed mid-infrared lasers are adequate instruments to perform transcorneal trabecular ablation (abinterno sinostomy). The laser used in this study (CTE:YAG) bears the advantage that its radiation can easily be delivered in conventional optical quartz fibers.

Introduction

To date only few surgical approaches deal directly and exclusively with the pathoanatomical site of maximum outflow resistance, the trabecular meshwork. It has been shown in enucleated human eyes, that the largest portion of resistance to outflow can be eliminated by incising the trabecular meshwork and entering the canal of Schlemm [1]. The outer layers of the trabecular meshwork are believed to play a key role in the pathology of open-angle glaucoma [2–4].

Attempts, to develop surgical approaches are found both in conventional- and laser-surgery. Microsurgical dissection of the trabecular meshwork (trabeculotomy, goniotomy) has been employed for both congenital and open-angle glaucoma [5–7].

First attempts in laser surgery were performed with photodisruptive pulsed Nd:YAG lasers [8, 9]. An approach to non-invasive laser trabecular puncture was feasable. The wavelenght of the Nd:YAG

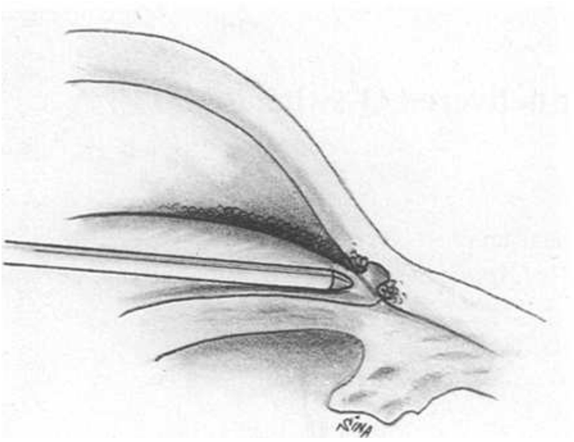

Fig. 1. Transcorneal, ab-interno sinostomy using optical fiber delivered pulsed mid-infrared laser energy. Several filtration canals with a diameter corresponding to the diameter of the fiber-tip (200 µm) can be placed into the chamber angle opposite to the entering paracentesis.

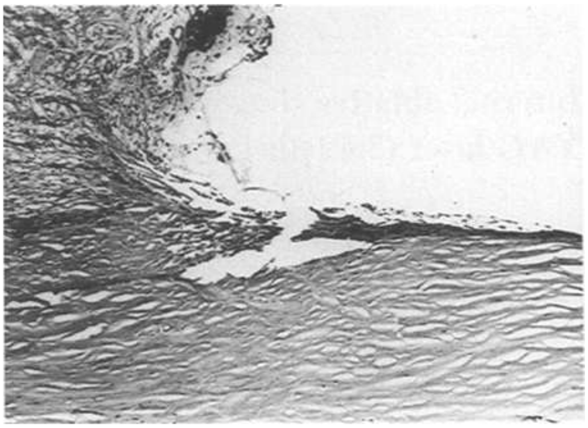

Fig. 2. Histological section (HE) showing a side portion of a filtration canal through the trabecular meshwork (internal sinostomy) that has been created with a CTE:YAG laser. Laser energy (2 pulses of 6 J/cm^2 fluence) was delivered via a conventional (quartz) optical fiber of 50 cm length.

laser (1064 nm) allows high transmission through the cornea and aqueous humor. The method failed, because the induction of photodisruptive effects (optical breakdown) within the trabecular meshwork required very high pulse energies. The mechanical stress involved lead to a severe damage of chamber angle structures [10, 11].

Pulsed mid-infrared lasers (Er:YAG, Er:YSGG, Ho:YAG) have recently been proposed for laser trabecular ablation (LTA). The interaction with the tissues using these lasers, is known to be of relatively low-thermal character and involves less mechanical stress. Due to a high absorption peak around 3 microns, tissue water functions as a chromophore when irradiated by Er:YAG (2.9 µm) or Er:YSGG (2.79 µm) laser radiation [13, 14].

Beam transmission in conventional optical quartz fibers, however, is very poor for these two laser types. Adequate beam delivery, therefore, remains a key problem in mid-infrared laser surgery.

The Ho:YAG laser has been propagated as an alternative tool for glaucoma filtering procedures. With a wavelength of 2.1 µm the Holmium laser shows very good transmission in conventional optical quartz fibers [15]. For trabecular surgery, however, the Holmium laser has been proved inadequate [12]. Due to a relatively low absorption of 2.1 µm radiation in water tissue interaction with the Holmium laser is mainly characterized by coagulation and vaporisation [16].

The CTE:YAG laser is a new mid-infrared laser emitting at 2,69 µm. It has been demonstrated that its quality of tissue ablation is comparable with the Er:YAG- and Er:YSGG laser [17–19]. However, unlike these two laser types, the CTE:YAG laser shows very good optical fiber transmission. Trabecular ablation, therefore, is within the scope of potential applications for the CTE:YAG-laser.

Materials and methods

The laser used in this study is a solid state Cr^{3+}, Tm^{3+}, Er^{3+} (CTE):YAG laser, that emits radiation at a wavelength of 2.69 µm. A rotating prism is used as a Q-switch. The pulse duration is 1 µs. The maximum energy in the prototype used is 50 mJ/pulse (appr. 10^5 W). At a focus diameter (∅) of 200 µm the maximal fluence reaches up to 150 J/cm^2. Repetition rates are 1–10 Hz. A flexible optical quartz fiber (Low Hydroxy Fused Silica-Ceram Optec™) of 200 microns diameter and 50 cm lengths was used for radiation delivery.

The experimental procedure performed on 10 human eye-bank globes, unsuitable for keratoplasty, was an invasive ab interno, transcorneal tra-

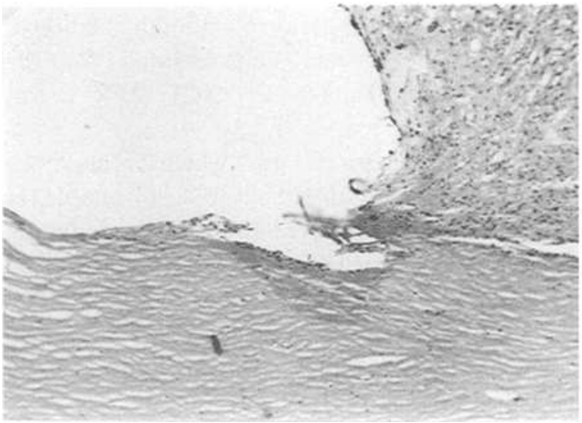

Fig. 3. Histological section (HE) showing the interaction area at the trabecular meshwork when high (> 10 J/cm^2) laser fluences were applied. The mechanical, disruptive effects are enhanced, the tissue is torn apart and the canal architechture is not preserved.

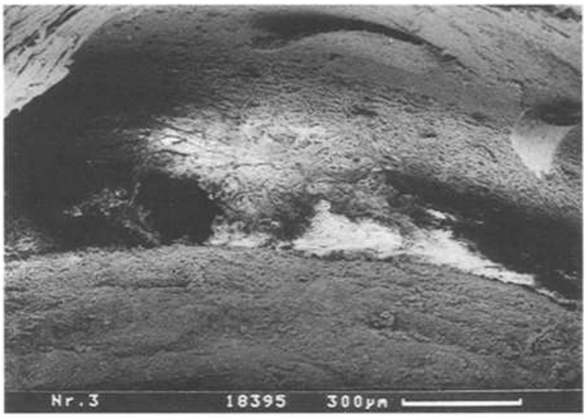

Fig. 4. Scanning electron microscopy showing a chamber angle with an internal sinostomy that has been created with a CTE:YAG laser (2 pulses of 6 J/cm^2 fluence). Signs of mechanical damage are not visible, the iris plane is unaffected. Endothelial defects are due to artefacts of histological preparation.

becular ablation (Fig. 1). The aim was to create several internal filtering sinostomies.

First, a paracentesis was set opposite to the chamber angle to be treated. Prior to laser application, the chamber angle was deepened with viscoelastics (Healon™). The laser fiber-tip was inserted into the anterior chamber through the paracentesis and directed to the opposite chamber angle. A gonio-lens was then placed on the cornea, therefore allowing control of the fiber-tip through the co-axial microscope. Once the fiber-tip contacted the functional trabecular meshwork, two laser pulses were applied. On each eye four internal sinostomies were created. Applied fluences ranged from 4 to 12 J/cm^2. After laser application, viscoelastics were rinsed out of the anterior chamber.

Each experimental series was performed on two eyes. One sample was determined for light microscopy (LM: standard HE-staining) and the other for scanning electron microscopy (SEM).

Results

Two laser pulses of low fluence (4–6 J/cm^2) were required to create a filtration hole into the canal of Schlemm, creating an internal sinostomy. Histological analysis showed that findings of thermal tissue deterioration were present in surounding meshwork structures and beyond the posterior wall of Schlemm's canal within the scleral tissue (Fig. 2). The integrity of the canal architechture, however, was preserved and collateral mechanical damage was minimal as provided by SEM documentation (Fig. 3).

The diameter of processed sinostomies corresponded to the diameter of the optical fiber (200 µm). Mechanical, disruptive effects, which could be due to the expulsive forces of the ablative process, were only seen in those samples where fluences higher than 6 J/cm^2 were applied (Fig. 4). The entire functional trabecular meshwork in an area of over 500 µm around the interaction zone was torn apart.

Discussion

Although Scheie's concept of goniopuncture is derived from the 1950s its clinical value has not yet been established, possibly due to the lack of adequate surgical instrumentation [5].

There were numerous reasons for scepticism in the past years and the arguments were of a functional and technical character.

It is commonly understood that the outer trabecular meshwork functions like a valve preventing backflow of blood in situations of hypotony or increased episcleral venous pressure. Filtration holes within the trabecular meshwork would outpass such a security system and endanger the ocular integrity. As a result, outflow resistance could be reduced so dramatically that hypotony and backflow of blood into the eye could occur. Furthermore, it is conceivable that a persistant collapse of the sinus could result from such treatment.

Until recently, there was no adequate laser instrument available to perform internal sinostomies.

Conventional surgical instruments (trabeculotomy) rather dissect the tissue, leaving large wound surfaces that are likely to facilitate fibroproliferation and scarring [6, 7].

Photodisruptive lasers (pulsed Nd:YAG) turned out to be inadequate for the procedure as well [20–22]. Although laser energy could be directed to the meshwork by means of gonio-lenses, preventing a surgical opening of the eye, the experimental effort in the field ceased in the mid-eighties. It was clear that the character of tissue interaction was dominated too strongly by the mechanical effects of optical breakdown. The subsequent disruptions were so strong that large areas beyond the target site were effected. Each following laser pulse was more difficult to be placed since aqueous humor was opacified by tissue debris and pigment dispersion. Excessive endothelial damage as well as cyclodialysis were described [8, 9].

As the classical photoablative laser, the excimer laser also has been evaluated for goniophotoablation [23]. Only the XeCl-excimer-laser, however, emitting at 308 nm, is transmittable through optical fibers and is therefore, useful for an experimental approach to the procedure. High primary and secondary costs of gas laser systems, as well as the potential hazard of intraocular application of ultraviolett radiation, decreased the possibility of acceptance of the 308 nm excimer laser.

Hill and Berns revived the idea of treating the trabecular meshwork directly [12]. This time, the laser instruments used were much more promising, and reflected the current development in laser technology towards low-thermal photoablative pulsed mid-infrared-lasers [24–27]. The authors compared different mid-infrared lasers for a procedure which they called laser trabecular ablation (LTA). The general possibility to perform a smooth ablation of trabecular tissue, was demonstrated for the Er:YAG (2.94 μm) and the Er:YSGG (2.79 –BDm) laser.

The Ho:YAG laser (2.1 μm), which has also been under investigation turned out to be unsuitable for the procedure. Although Holmium Laser radiation is very easy to be delivered in conventional optical quartz fibers its tissue interaction is mainly characterized by coagulation and vaporisation.

The results of this study, using a new mid-infrared laser that emits at 2.60 μm correspond to the work of Hill and Berns (1992). The general feasability of the CTE:YAG laser to perform smooth trabecular ablations could be demonstrated.

The development in laser technology has advanced so far that the technical problems regarding trabecular ablation appear to be solved so far that an adequate experimental approach is possible. Whether the procedure is performed with an Er:YAG, an Er:YSGG or a CTE:YAG laser might not influence the result. The CTE:YAG laser has advantages regarding its beam delivery, since conventional optical quartz fibers can be used for beam delivery. Thermal side effects are not significantly different from Er:YAG or Er:YSGG laser radiation, since CTE:YAG laser pulses can be applied in the Q-switch mode [17, 18].

The key questions remain: Now that there are adequate laser instruments to perform trabecular ablation, what will the response be of treated eyes? Early closure of filtration canals due to fibroproliferation can still occur no matter how smooth the sinostomies have been employed. And if the filtration canals will remain patent, will the stability of the canal of Schlemm be preserved or will it collapse? Also, it is not clear whether a backflow of episcleral venous blood and hypotony will occur when the trabecular valve mechanism is outruled.

It is worthwhile to investigate these questions. Laser trabecular ablation, if feasable, would be a very valuable contribution to glaucoma surgery avoiding complications due to failure of the conjunctival filtering bleb in conventional trabeculectomy [28, 29]. Furthermore, a more controlled and gradual improvement of outflow facility could be achieved.

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