Picosecond Neodymium:Yttrium Lithium Fluoride (Nd:YLF) Laser Peripheral Iridotomy

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• PURPOSE: We evaluated the picosecond neodymium:yttrium lithium fluoride (Nd:YLF) laser for performing peripheral iridectomies of predetermined size and shape in various types of irides.

• METHODS: In the first part of the study, we determined operating parameters from performing 60 iridotomies in human cadaver eyes. Subsequently, using the parameters obtained in cadaver eyes, iridectomies were created in eyes of patients with primary angle-closure glaucoma.

• RESULTS: In the cadaver eyes, the optimal parameters were a rectangular cutting pattern of 0.3 × 0.3 mm, 500-μm cutting depth, 50-μm spot separation, 200 to 400 μJ of energy per pulse, 200 to 400 pulses per second, and no focal offset distance. In 18 eyes of 11 patients, iridectomies with well-defined margins and size were created. Minimal hemorrhage occurred intraoperatively in ten of 18 eyes (55.6%), which did not affect the outcome of the procedure. Increases of postoperative intraocular pressure at one hour averaged 3.5 ± 5.1 mm Hg, with an increase of more than 10 mm Hg in three eyes (16.7%), and a maximum of 12 mm Hg. We observed no corneal or retinal damage.

• CONCLUSION: The picosecond Nd:YLF laser seems to be an effective instrument for reliably performing peripheral iridectomies of precise size and shape using low energy per pulse levels. This laser, unlike the argon laser, is successful independent of iris thickness or color and can easily make a larger iridotomy than is often possible with the Nd:YAG laser.

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LASER IRIDOTOMY IS THE INITIAL SURGICAL TREATMENT of choice in primary angle-closure glaucoma. Since the introduction of laser iridotomy in the 1970s, argon[1,2] and then later the Nd:YAG lasers[3,4] have been the preferred laser systems for peripheral iridotomy. Complications, including transient increases of intraocular pressure, hemorrhage, inflammation, iridotomy closure, cataract formation, and corneal or retinal damage have been reported to occur with both laser systems.[5-16] Currently, Nd:YAG lasers are often preferred because of the ease of performance, increased success rate, and increased long-term patency. However, there are concerns associated with performing an Nd:YAG iridotomy. Damage to the adjacent anterior segment structures induced by shock waves and cavitation bubbles from high power Nd:YAG laser pulses have been reported.[17,18] Another disadvantage of the Nd:YAG laser is the unpredictability of the iridotomy size and penetration depth. Iridotomies may be smaller than desirable, which has been reported to result in an acute angle-closure attack despite a patent iridotomy.[19]

The neodymium:yttrium lithium fluoride (Nd:YLF) laser can create tissue ablation with minimal thermal damage to surrounding tissue,[20] which is possible because of the low energy per pulse levels with short pulse duration time, in the picosecond range, and the high repetition rate. The computer-controlled laser settings allow for controlled tissue removal of a precise size and shape. Additionally, the low energy per pulse levels produce low-amplitude shock waves and smaller cavitation bubbles, possibly resulting in less damage to the adjacent structures.[21] We sought to determine the operating parameters and efficacy of the picosecond Nd:YLF laser for performing peripheral iridotomies.

MATERIAL AND METHODS

A TWO-PART STUDY WAS PERFORMED. THE FIRST PART involved adult human cadaver eyes, the second, patient eyes. All iridotomies were performed with an Nd:YLF laser, which operates at the near-infrared wavelength at 1,053 nm, emitting pulses of less than 60-picosecond duration with an energy per pulse level of up to 400 µJ and a repetition rate of up to 1,000 pulses per second. The spot size of the laser beam was 20 µm. A 66-diopter iridectomy laser lens (Ocular Instruments, Inc., Bellevue, Washington) was used with the Nd:YAG laser while performing iridotomies both in cadaver and patient eyes.

In the first part of the study, a cadaver eye model that closely simulated in vivo conditions was used before peripheral iridotomies were performed on human cadaver eyes.[22] This model consisted of a reusable container, an artificial cornea (infrared absorption rate, 0.6%) with refractive power and anterior radius of curvature similar to the human cornea, and a fresh cadaver eye (less than 48 hours from donation), which was prepared by removing the cornea and adjusting biometric parameters to normal values.[23] An artificial anterior chamber was formed with balanced saline solution. A total of 15 fresh human cadaver eyes were used in the study. Four iridotomies, 90 degrees apart, at the 11, 2, 5, and 8 o'clock meridians, were performed in each cadaver eye. The twin helium and neon aiming beams of the laser were sharply focused on a point in the peripheral one third of the iris through the Abraham iridotomy lens. A 0.3 × 0.3-mm rectangular cutting pattern with 500-µm cutting depth and no focal offset distance was used for all iridotomies. With 200-µJ energy and 200 pulses per second as a starting point, we determined the optimum energy per pulse and pulse repetition rate per second to create iridotomies in a controlled fashion. If a full-thickness perforation could not be produced, energy per pulse or pulse repetition rate was increased and the procedure was repeated at an adjacent site. Required number of pulses and total energy level for each iridotomy were recorded. Slit-lamp biomicroscopy was performed on each cadaver eye to confirm patency of the iridotomy and to examine the untreated crystalline lens for any capsular damage beneath the laser-treated areas.

After we received approval for human subjects from the institutional review board, picosecond Nd:YLF laser peripheral iridotomy was performed to 18 consecutive phakic eyes of 11 patients with primary angle-closure glaucoma. Before the laser procedure, each patient underwent a complete ophthalmic examination, including Snellen visual acuity measurement, applanation tonometry, slit-lamp biomicroscopy, and ophthalmoscopy. Central and peripheral anterior chamber depths were measured on the visual axis and 5 mm peripheral to the visual axis, respectively, on digitized Scheimpflug images with the EAS-1000 Anterior Eye Segment Analysis System (Nidek, Fremont, California). Pilocarpine 2% was instilled 15 minutes before the procedure in eyes of patients who were not already on miotic therapy.

After proper informed consent was obtained, under topical anesthesia (proparacaine HCl 1%), one iridotomy was performed in each eye in the peripheral supranasal or supratemporal quadrant through the Abraham contact lens. We used a rectangular cutting pattern of 0.3 × 0.3 mm, 500-µm cutting depth, 50-µm spot separation, 300- to 400-µJ energy per pulse, and a repetition rate of 300 to 400 pulses per second with no focus offset. Intraoperative evidence of successful penetration was manifested by the flow of aqueous humor and pigment from the posterior to the anterior chamber and patency was verified by direct slit-lamp visualization of the anterior lens capsule. The required total number of pulses, total energy level, and laser application time were recorded. A complete ophthalmic examination, including central and peripheral anterior chamber depth measurement of each eye, was done one hour after the procedure. Postoperatively, patients were treated with prednisolone acetate 1% four times a day for one week and were asked to return for a follow-up visit at one

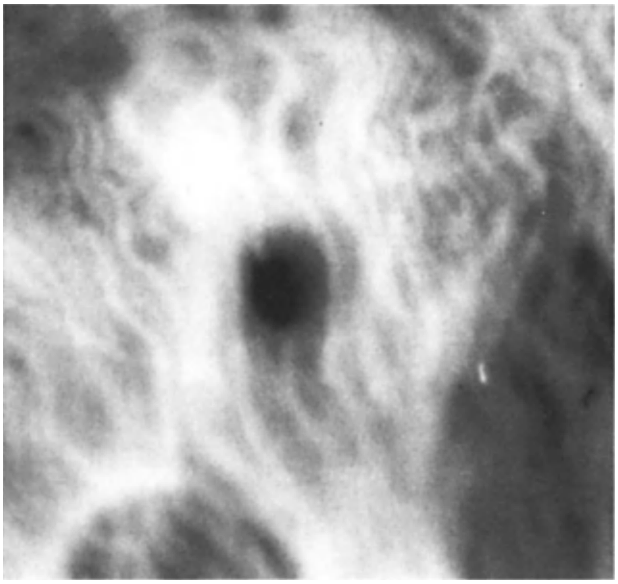

Fig. 1 (Oram and associates). Rectangular, approximately 0.3 × 0.3 mm in size, picosecond Nd:YLF laser peripheral iridotomy in a human cadaver eye viewed through the artificial cornea of the eye model.

day, one week, one month, three months, and six months after treatment. Postoperative examinations of patients were performed by an observer other than the surgeon. Statistical comparisons were performed with the Student's *t*-test.

RESULTS

SIXTY RECTANGULAR-SHAPED PATENT IRIDOTOMIES, APproximately 0.3 × 0.3 mm in size, were created in 15 human cadaver eyes (nine blue, four brown, and two hazel irides) with laser settings of 200- to 400-μJ energy per pulse and 200 to 400 pulses per second (Fig. 1). Direct visualization of the tissue ablation with control of the site of delivery was better with the lower repetition rates. Iris thickness influenced the required pulse energy and pulse repetition levels needed to create successful iridotomies. Thin, blue irides were easily penetrated with as little as 200 μJ of energy per pulse and 200 pulses per second. However, in dark, thicker irides these settings were unsuccessful and 300 to 400 μJ of energy per pulse with 300 to 400 pulses per second repetition rates were required.

Mean total energy levels needed to create successful iridotomies ranged between 131.8 and 987 mJ with a mean of 429.0 ± 190.1 mJ. Mean pulse number was 330.2 ± 358.0. No lens capsule damage was noted in any of the eyes.

Eighteen iridotomies were performed in 18 eyes of 11 consecutive patients with primary angle-closure glaucoma. Rectangular iridotomies approximately 0.3 × 0.3 mm in size were created in one session. Fourteen eyes were brown, two eyes were hazel, and two were blue. There were two men and nine women with a mean age of 65.2 years (range, 42 to 86 years). All eyes had previously had, or were judged to be at risk for, an acute primary angle-closure attack. Pre- and postoperative intraocular pressure measurements, anterior chamber dimensions, and required total energy levels are shown in the Table. The differences between the pre- and postoperative central anterior chamber depths ($P = .03$) and peripheral anterior chamber depths ($P < .0001$) were statistically signifi-

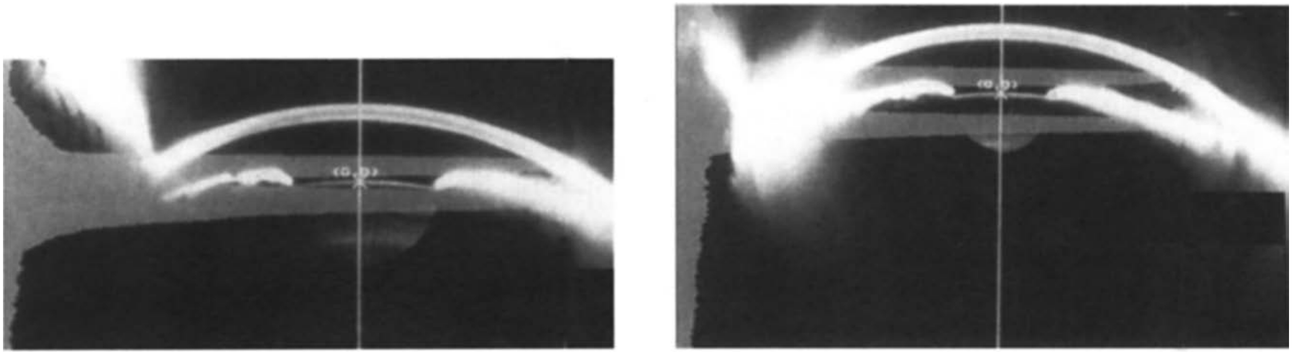

Fig. 2 (Oram and associates). Preoperative (left) and one-hour postoperative (right) Scheimpflug images of a patient eye show the increase in peripheral anterior chamber depth after Nd:YLF iridotomy. The line bisecting the pupil represents central anterior chamber depth on the visual axis. The other line is located 5 mm peripheral to the central line and was used for peripheral depth measurement.

cant (Student's t-test) (Fig. 2). The mean difference between preoperative and one-hour postoperative intraocular pressure was 3.5 ± 2.1 mm Hg (range, −5 to 12 mm Hg). A postoperative pressure increase greater than 5 mm Hg was measured in five of 18 eyes (27.8%). In three of 18 eyes (16.7%), an increase greater than 10 mm Hg was found. These eyes were treated with a single drop of apraclonidine hydrochloride 1% and returned to preoperative levels within two hours.

Required mean total energy level range was 528.5 ± 437.4 mJ (range, 165.2 to 1887.6 mJ) (Table) and mean total pulse number range was 1,357.4 ± 1,088.5 (range, 413 to 4,719). Laser application time ranged between 1.1 and 11.8 seconds with a mean of 4.1 ± 3.7 seconds. All eyes showed a trace of aqueous flare with scattered debris which resolved within the first 24 hours. Minimal hemorrhage was seen during the procedure in ten of 18 eyes (55.6%), but stopped spontaneously with slight pressure on the contact lens and cleared within the first 24 hours. No corneal or lens capsule damage was noted. The mean follow-up period was 3.8 months (range, one to six months). All the iridotomies remained patent through the follow-up period and no change in size was noted in any of the iridotomies over time (Fig. 3).

DISCUSSION

LASER IRIDOTOMY IS CURRENTLY THE METHOD OF choice for peripheral iris ablation in the treatment of pupillary block. Argon laser iridotomies may be difficult to perform in dark, thick irides, and can close because of proliferation of iris pigment epithelium.[11] In one study, the picosecond Nd:YLF laser effectively performed laser iridotomies in all cadaver and patient eyes irrespective of iris color or thickness. Total energy required to perform an iridotomy varied with the thickness of the iris. Relatively high total pulse numbers and energy levels were required in patient eyes with thick, dark brown irides, while iridotomies

TABLE

ND:YLF IRIDOTOMY IN PATIENT EYES

PATIENT NO., EYE	IRIS	INTRAOCULAR PRESSURE (MM HG)		CENTRAL ANTERIOR CHAMBER DEPTH (MM)		PERIPHERAL ANTERIOR CHAMBER DEPTH (MM)		INTRAOPERATIVE HEMORRHAGE*	TOTAL ENERGY (MJ)
		PREOPERATIVE	POSTOPERATIVE	PREOPERATIVE	POSTOPERATIVE	PREOPERATIVE	POSTOPERATIVE		
1 R.E.	Brown	13	8	1.84	1.85	0.16	0.68	−	484.4
L.E.	Brown	21	29	2.00	2.03	0.29	0.46	+	1,023.2
2 R.E.	Hazel	18	20	2.06	2.08	0.18	0.45	+	198.0
L.E.	Hazel	20	20	2.02	2.06	0.16	0.29	−	219.2
3 R.E.	Brown	22	33	1.88	1.88	0.21	0.44	+	992.0
L.E.	Brown	25	25	1.83	1.94	0.28	0.52	−	403.2
4 R.E.	Brown	16	20	1.97	1.98	0.13	0.42	−	165.2
L.E.	Brown	16	18	2.03	2.07	0.24	0.47	+	263.6
5 R.E.	Brown	18	30	2.54	2.50	0.63	0.63	+	1,887.6
L.E.	Brown	20	20	2.36	2.54	0.39	0.40	+	306.8
6 R.E.	Blue	17	29	1.98	1.98	0.42	0.76	−	475.8
L.E.	Blue	17	21	2.02	2.13	0.36	0.76	+	302.4
7 R.E.	Brown	24	29	1.77	1.78	0.34	0.52	−	570.0
L.E.	Brown	23	28	1.76	1.82	0.31	0.52	+	527.6
8 L.E.	Brown	30	38	2.11	2.07	0.26	0.37	+	176.0
9 R.E.	Brown	19	15	1.99	2.11	0.36	0.60	+	360.0
10 L.E.	Brown	21	20	2.24	2.30	0.39	0.54	+	219.2
11 L.E.	Brown	14	14	1.73	1.76	0.37	0.52	−	939.2
Mean		19.7	23.2	2.01	2.05	0.30	0.52		528.5

*A plus (+) sign indicates iris hemorrhage during the iridotomy procedure; a minus sign (−), no hemorrhage.

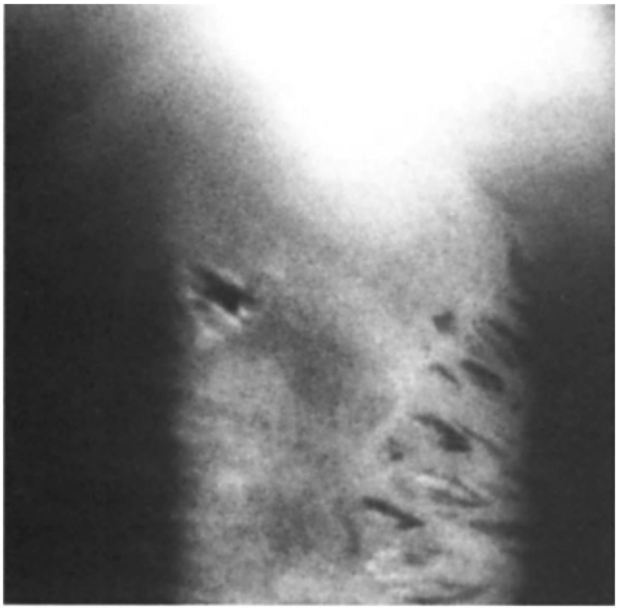

Fig. 3 (Cheon and associates). Nd:YLF laser iridotomy in a patient eye six months after the procedure.

could be performed in thin, blue or normal-thickness, brown irides using total energy levels as low as 165.2 mJ.

The Nd:YAG laser has the ability to create iridotomies reliably with single or multiple bursts with high energy per pulse levels (5 to 15 mJ).[8] However, despite reported successful results with relatively low complication rates, there are several disadvantages of the nanosecond Nd:YAG laser for this procedure. The high-pulse energy causes production of large cavitation bubbles and high amplitude shock waves that can damage adjacent intraocular structures.[16] A lack of exact control of size and depth during the procedure can result in difficulty in enlarging a small iridotomy, which may require multiple applications.

Picosecond Nd:YLF laser offers several potential advantages for performing iridotomy. This laser system has the ability to ablate tissue in a predetermined shape, size, and depth with the computer-controlled settings. Short pulses in the picosecond range produce high irradiance and power density capable of creating optical breakdown of the target tissue with low energy per pulse levels.[21] With moderate to high repetition rates each low-energy pulse produces a cumulative cutting of the tissue while confining collateral damage.[21] The low-energy pulses produce lower-amplitude shock waves and cavitation bubbles and are expected to cause less damage to the adjacent intraocular structures.[21,22,23] A current study suggests that the picosecond Nd:YLF laser pulse results in an approximately sevenfold reduction in the diameter of the shock wave radius, resulting in a reduction in the volume of the shock wave by approximately 350 times less than a nanosecond Nd:YAG laser. Additionally, cavitation bubble diameter is reduced from 1 to 4 mm with nanosecond lasers to 0.08 to 0.7 mm with picosecond Nd:YLF.[17] Frangie, Park, and Aquavella[19] successfully performed three iridotomies in patient eyes using a 2-mm-long line pattern of the Nd:YLF laser with no complication. However, required total energy levels were relatively high with a mean of 1,925.5 mJ.

This laser allows preadjustment of the cutting depth to mean iris thickness (500 μm). Because recurrence of angle closure has been reported[18] despite a patent 75-μm iridotomy, we performed a rectangular-shaped iridotomy of approximately 300 × 300-μm size with a minimum diameter of 150 to 200 μm in all eyes to prevent further attacks of angle-closure glaucoma. The rectangular pattern allowed effective clearance of microbubbles that resided in the defect.

The effectiveness of Nd:YLF iridotomy in patient eyes was confirmed with a significant increase in peripheral anterior chamber depths. Although this study's conclusions are limited by the relatively short follow-up and limited number of patients, no change in iridotomy size was observed through the follow-up period.

In general, required total energy to achieve iridotomies (165.2 to 1,887.6 mJ) in patient eyes with the picosecond Nd:YLF laser was higher than reported energy levels for Nd:YAG laser iridotomies (7 to 200 mJ).[8] However, energy per pulse levels were remarkably lower with the Nd:YLF laser (300 to 400 μJ) than Nd:YAG laser. Despite the possible clinical relation between the transient increase in intraocular pressure and total energy level,[20] postoperative intraocular pressure increase percentages were similar to those seen with Nd:YAG laser.

The other kinds of complications seen in patients were similar to those found with the Nd:YAG laser. Intraoperative hemorrhage occurred in one of 18 eyes

(55.6%) possibly because of direct vessel incision within the relatively large iridotomy area. However, bleeding was easily stopped with slight pressure on the contact lens and did not prevent the successful completion of the procedure. There was no evidence of damage to the lens capsule, which is consistent with the results of Guenrsdand, Rodrigues, and Thomas[11] that suggest an energy per pulse threshold of 6 mJ with bursts of more than two pulses for lens damage. The major disadvantage of this laser compared to the Nd:YAG laser was the relatively long laser application time in the range of a few seconds rather than milliseconds. This did not cause any difficulties in our patients; however, patient movement not controlled with the contact lens could potentially be a problem. Should this be a concern, the duration of application could be reduced to less than one second and repeated applications could be performed to minimize the potential for movement.

In conclusion, using low energy per pulse levels, picosecond Nd:YLF laser seems to be an effective instrument for reliably performing controlled iridotomies of predetermined size and shape. The importance of its characteristics compared to the Nd:YAG and other lasers will need to be assessed in further clinical studies with long-term follow-up.

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