Clinical comparison of semiconductor diode versus neodymium:YAG non-contact cyclo photocoagulation

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Abstract

Aims—The advent of diode lasers has allowed their use in transscleral cyclo photocoagulation for refractory glaucoma. A trial was performed to compare the ocular hypotensive and inflammatory effects of cyclo photocoagulation using a continuous wave diode (810 nm) and a free running neodymium:yttrium aluminium garnet (Nd:YAG) laser (1064 nm).

Methods—Forty patients with refractory glaucoma were randomised to receive either diode or Nd:YAG therapy. The intraocular pressure (IOP) and inflammatory response to treatment were monitored over 3 months.

Results—There was no significant laser related difference in the effect on IOP after one treatment. There was, however, a difference in effect in retreatments with the IOP lowering effect significantly less, but equally sustained in diode retreatment patients. Severe postoperative complications such as hyphaema or fibrinous anterior uveitis only occurred in the Nd:YAG group.

Conclusion—The degree and duration of the ocular hypotensive response to cyclo photocoagulation appears to be related to the available power output of the system used, and the extent of tissue damage.

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Cyclodestructive procedures have been established as a form of treatment for intractable glaucoma, arising from conditions such as iris neovascularisation. In recent years, non-contact laser transscleral cyclo photocoagulation has become a viable treatment alternative to cyclo cryocoagulation.[1][2] It is a requirement of the laser modality employed, that the wavelength of the treatment beam is in the near infrared region of the spectrum. In this waveband there is good transmission through the sclera, but significant absorption within the melanin of the ciliary body.[3] Non-contact cyclo photocoagulation using a Nd:YAG laser in the free running mode is widely used,[4][5] although contact treatment with a continuous wave Nd:YAG laser has been introduced more recently.[6][7] The non-contact semiconductor diode laser, which emits at 810 nm is of promising efficacy in such ocular conditions as diabetic retinopathy[8][9] and choroidal neovascularisation in age-related macular degeneration.[10] Histological studies[11-14] in rabbit eyes and human cadaver eyes have shown similar destructive lesions in the ciliary body after Nd:YAG and diode laser transscleral cyclo photocoagulation. A pilot study by Hennis[15] and a 1 year follow up[16] of the same patients reported that non-contact diode laser cyclo photocoagulation had a significant ocular hypotensive effect.

The aim of the present prospective study was to compare the effects of non-contact diode and Nd:YAG laser cyclo photocoagulation on intraocular pressure (IOP), and also to evaluate the incidence of severe non-therapeutic side effects.

Patients and methods

PATIENTS

The main inclusion criterion was glaucoma which had not been adequately controlled by topical drugs, or laser trabeculoplasty, and for which drainage surgery had not been thought appropriate. Patients had to provide informed consent before inclusion in the study. Forty patients with refractory glaucoma referred to the Glaucoma Unit or the Retinal Diagnostic Department of Moorfields Eye Hospital for a cyclo destructive procedure were recruited and randomised to receive either diode or Nd:YAG laser therapy. Twenty four patients were males and 16 females. Five patients were black Afro-Caribbean, two patients were Asian, and the remaining 33 patients were white. The mean age was 55 years (range 21–89 years). The most common diagnosis (13 patients) was iris neovascularisation due to central retinal vein occlusion or proliferative diabetic retinopathy. Other diagnoses are shown in Table 1.

METHODS

Pretreatment assessment included measurement of IOP using a Goldmann applanation tonometer mounted on a Haag Streit slit-lamp microscope (Berne, Switzerland) and best

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Table 1 Diagnosis

	No of cases	Treatment	
		Diode	Nd:YAG
Iris neovascularisation (CRVO, PDR)	13	7	6
Silicone oil	9	4	5
Closed angle (AC-IOL, PK)	7	4	3
Open angle glaucoma	5	2	3
Perforating injury (aniridia)	5	2	3
Eales disease	1	1	0
Total	40	20	20

CRVO=central retinal vein occlusion; PDR=proliferative diabetic retinopathy; PK=perforating keratoplasty; AC=anterior chamber; IOL=intraocular lens implant.

Table 2 *Mean postoperative IOP (mm Hg)*

Time	Diode 360°					Nd:YAG 180°				
	n	IOP	SD	Min	Max	n	IOP	SD	Min	Max
Preop	20	32·1	9·7	12	55	20	39·2	12·7	19	67
Postop										
1 Hour	18	29·1	9·1	15	44	20	39·1	12·6	20	66
1 Day	16	23·5	6·6	8	34	17	25·9	9·9	8	45
1 Week	18	25·1	12·2	10	62	17	30·2	15·5	8	60
1 Month	16	24·4	7·7	12	41	16	31·6	16·7	10	63
3 Months	12	27·5	8·8	18	48	10	29·4	21·0	8	71

IOP=intraocular pressure; Min=minimum IOP in this group; Max=maximum IOP in this group; n=no of eyes.

corrected visual acuity tested with a Snellen chart at 6 metres. IOP and visual acuity were tested independently by a trained nurse. Five eyes were already blind before cyclo photocoagulation. In these cases the laser procedure was performed to prevent these eyes from becoming painful. Before laser cyclo photocoagulation all patients were on a standard medication regimen consisting of topical β adrenergic blocker and pilocarpine eyedrops and acetazolamide tablets (explaining why some patients had IOP below 20 mm Hg at entry level). This medication regimen was not altered during the review period. In patients with IOP below 20 mm Hg at entry level but inconvenient side effects from this medication, it was intended to discontinue acetazolamide tablets later on when cyclo photocoagulation had resulted in an additional hypotensive effect.

The two lasers used in this study were the 'Microlase' continuous wave semiconductor diode laser, emitting at 810 nm (Keeler, Windsor), and the 'Microruptor II' Nd:YAG laser, emitting at 1064 nm (Lasag, Thun, Switzerland). All laser burns were applied using a Shields transscleral cyclo photocoagulation contact lens (Ocular Instruments Inc, Bellevue, Washington, USA). Although the Shields lens does not have any focusing ability, it allows compression of the conjunctival and episcleral tissues thus increasing the transmission of laser radiation to the target area. Local and topical anaesthesia was provided by a combination of peribulbar or retrobulbar injection of 3 ml lignocaine 2% and benoxinate 0·4% eyedrops. The two laser modalities used had different output modes, continuous wave diode, and free running Nd:YAG. Additionally, the two laser wavelengths had different relative scleral transmission and melanin absorption properties. It was therefore difficult to choose exactly comparable laser settings when setting treatment variables. Treatment variables were therefore scheduled on the basis of maximum output powers available (4 J with the Nd:YAG and 1·2 W with the diode laser) and of previous pilot studies.[4][15]

All patients in the diode laser group, including the retreatment subgroup, were treated with a mean number of 98 exposures over a 360 degree pattern, aimed 1·5 mm posterior to the limbus, and focused on the sclera. Defocusing posteriorly with the slit-lamp delivery system seemed to be unnecessary because of the histopathological observation which had shown that the near infrared diode laser beam was transmitted through the sclera and got absorbed by the melanin pigment of the ciliary body.[12] The exposures were thus targeted over the pars plicata region of the ciliary body. The diode laser was always operated with its maximum power of 1·2 W, exposure time of 990 milliseconds (that is, an energy per pulse of approximately 1·2 J), and a spot size of 100 μm. The number of exposures with the diode laser was about fourfold that of the Nd:YAG laser to offset the overall difference in available energy between the two lasers. Patients in the Nd:YAG laser group were treated with a mean number of 22 exposures in a 180 degree pattern, 1·5 mm posterior to the limbus with the maximum defocus (switch position 9). The Nd:YAG laser was operated in the free running mode with a mean energy of 4 joules and 20 milliseconds of exposure time. This represented the standard treatment parameters used at this hospital. All patients were treated as day-case procedures.

Post treatment assessment included follow up at 1 hour, 1 day, 1 week, 1 month, and 3 months postoperatively. Post treatment examination consisted of visual acuity and IOP measurements and clinical assessment of anterior chamber inflammatory activity including the presence of cells, flare, hyphaema, and hypopyon. Visual acuity and IOP were again tested by a trained nurse. The anterior segment was photographed at each visit. Postoperatively, all patients were routinely treated with dexamethasone 0·1% eye drops, six times a day for 1 week. If necessary, this treatment was extended. If an inadequate response was obtained with either laser – that is, intraocular pressure was not reduced below 25 mm Hg after 1 month retreatment was carried out with that laser. Diode laser exposures were applied over 360 degrees in an identical fashion to the first treatment. With the Nd:YAG laser, it was decided to retreat over 360 degrees with 44 exposures, on the basis that ablation of a larger proportion of the secretory ciliary epithelium might have a more significant ocular hypotensive effect.

STATISTICAL ANALYSIS

All data were entered onto standard proformas. The data were subjected to statistical analysis using the paired *t* test (within treatment group) and unpaired *t* test (between treatment group testing). Analysis was performed on a personal computer using the SPSS (SPSS Inc) software package.
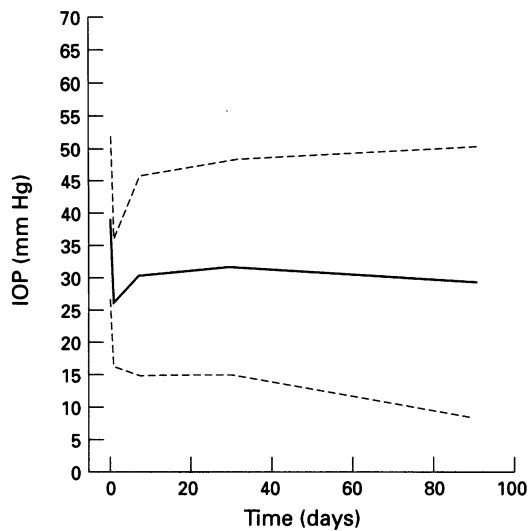
Figure 1   Hypotensive effect of Nd:YAG 180 degree cyclo photocoagulation over 3 months. (- - - - - 1 SD)

Figure 3   Mean decrease in intraocular pressure (IOP) of diode 360 degree compared with Nd:YAG 180 degree treatment. (- - - - - 95% confidence interval)

Results

The mean preoperative IOP was lower in the diode laser group (32·1 (range 12–55) mm Hg) compared with the Nd:YAG laser group (39·2 (range 19–67) mm Hg). This apparent, though not significant difference (unpaired t test, $p<0.05$), in the initial IOPs is a reflection of the relatively small sample size rather than because of any systematic selection bias. The mean postoperative changes in IOP are listed in Table 2.

The IOP fall between pretreatment and each follow up measurement (pretreatment minus post-treatment IOP) was calculated within both treatment groups. In the Nd:YAG (180 degrees) treated group, there was a statistically significant IOP fall between pretreatment and 1 day after treatment (paired t test: $p<0.001$) and this IOP reduction still reached significance at 1 week ($p=0.004$). The hypotensive effect was still present at 1 and 3 months, although it did not attain statistical significance in this group (1 month $p=0.08$, 3 months $p=0.82$) (Fig 1).

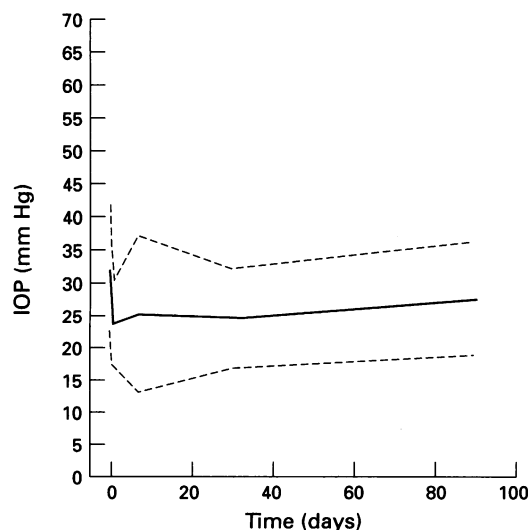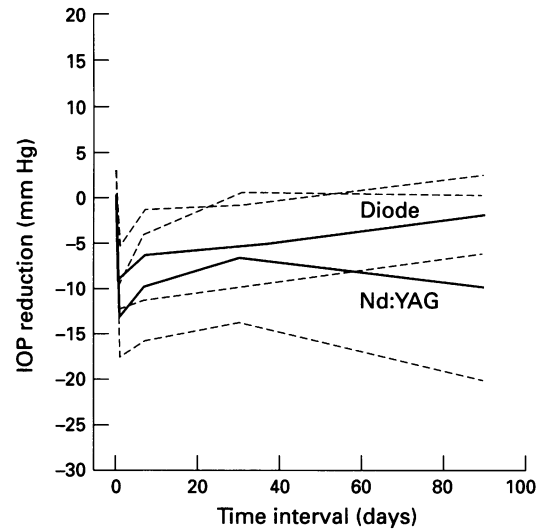In the diode (360 degrees) treated group there was a significant IOP reduction between

pretreatment level and 1 day through to 1 month follow up (paired t test: 1 day $p<0.001$, 1 week $p=0.022$, 1 month $p=0.032$). The hypotensive effect was not statistically significant ($p=0.397$) in this group at 3 months (Fig 2).

Comparison of IOP change using unpaired t testing showed no significant ($p<0.05$) difference in the magnitude of IOP fall at any follow up visit, between 360 degree diode and 180 degree Nd:YAG treatment (Fig 3).

An initial rise in IOP 1 hour after operation occurred in six patients in the diode laser group and in eight patients in the Nd:YAG laser group. The mean rise was 6 (range 1–10) mm Hg in the diode, and 5 (range 1–18) mm Hg in the Nd:YAG laser group.

Five eyes in the diode laser group and seven eyes in the Nd:YAG laser group were retreated after 1 month. The albeit small retreatment groups (diode 360 degrees, n=5, and Nd:YAG 360 degrees, n=7) were examined using the same analysis. There was no significant IOP fall within the diode retreatment group at any point until the 3 month follow up when the IOP reduction
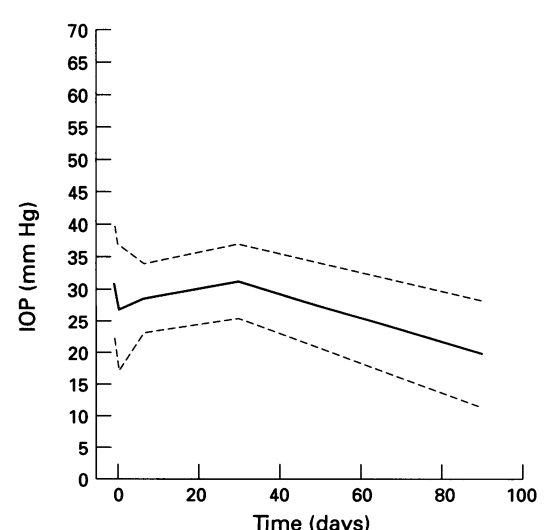

Figure 2   Hypotensive effect of diode 360 degree cyclo photocoagulation over 3 months. (- - - - - 1 SD)

Figure 4   Hypotensive effect of diode 360 degree retreatments over 3 months. (- - - - - 1 SD)
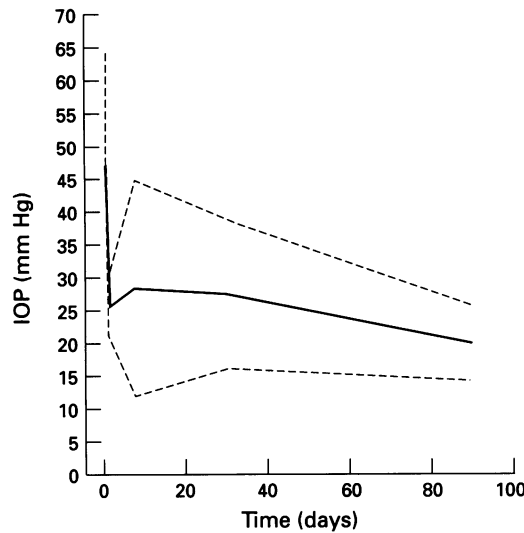
Figure 5   Hypotensive effect of Nd:YAG 360 degree retreatments over 3 months. (- - - - - 1 SD)
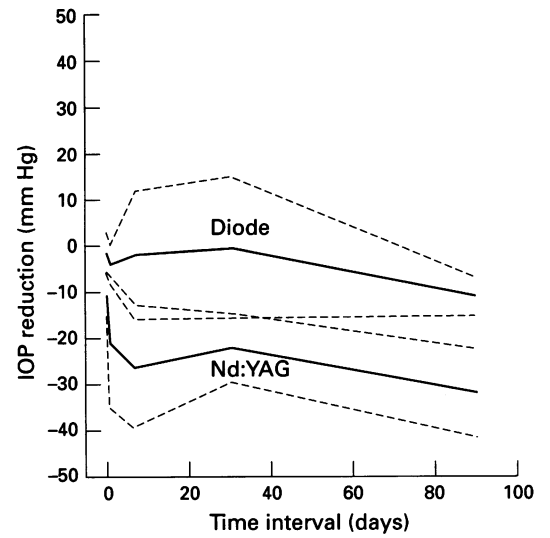

Figure 6   Mean decrease in intraocular pressure (IOP) of diode 360 degree retreatments compared with Nd:YAG 360 degree retreatments. (- - - - 95% confidence intervals)

reached significance (paired t test: p=0·006) (Fig 4).

The Nd:YAG 360 degrees retreatment group showed significant IOP reduction at 1 week (p=0·016; n=5), 1 month (p=0·004; n=5), and at 3 months (p=0·007; n=4), but note the very small sample size (Table 3, Fig 5).

Comparison of IOP decrease using the unpaired t test showed no significant difference between diode 360 degree and Nd:YAG 360 degree retreatment until 1 week after treatment. At this stage, there was a significantly greater IOP reduction in the Nd:YAG group (p=0·031, mean IOP fall Nd:YAG: 26·4 mm Hg; n=5). This effect was still present at 1 month (p=0·053, mean IOP fall Nd:YAG: 22·0 mm Hg; n=5) and 3 months (p=0·016, mean IOP fall Nd:YAG: 32·0 mm Hg: n=4) (Fig 6).

Severe postoperative ocular complications only occurred in the Nd:YAG laser groups. Subconjunctival haemorrhages or other minor problems related to the peribulbar or retrobulbar injection are not mentioned here. By the first day after treatment, three patients had developed a hypopyon, one patient had a hyphaema, and another patient showed a subconjunctival haemorrhage that occurred immediately after a Nd:YAG laser exposure. All these complications resolved within 2 weeks. In contrast, the eyes treated with the diode laser only showed a very mild anterior segment inflammatory response. Conjunctival

burns with the diode laser only occurred in one black patient with a heavily pigmented conjunctiva (Fig 7).

Evaluation of visual acuity measurements before and after treatment was inconclusive owing to the very poor visual function in the majority of treated eyes at entry level, reflecting the advanced stages of the underlying disease processes. However, there was no significant change in vision and no significant difference in the course of visual acuity as a result of the laser modality employed.

Discussion

In the present study there was no significant difference between the ocular hypotensive effect after one treatment session using 360 degree diode or 180 degree Nd:YAG cyclo photocoagulation. There was a gradual diminution of the ocular hypotensive effect of both the diode and the Nd:YAG cyclo photocoagulation over a 3 month period which was more marked at 3 months in the diode laser group. In the small subgroups of retreatments there was a significantly greater hypotensive effect in 360 degree Nd:YAG treated eyes, although there was also a significant hypotensive effect at 3 months in the 360 degree diode retreated eyes.

The overall rate of retreatments in this study was rather low because preoperative visual function in the majority of eyes was already very poor and the primary aim of cyclo

Table 3   Mean postoperative IOP (mm Hg) in the retreatment groups

Time	Nd:YAG 360°					Diode 360°				
	n	IOP	SD	Min	Max	n	IOP	SD	Min	Max
Preop	7	49·9	10·3	37	63	5	30·8	8·8	16	38
Postop										
1 Hour	5	37·4	9·4	25	47	5	29·6	9·1	19	42
1 Day	3	25·7	4·5	21	30	4	26·8	10·0	13	37
1 Week	5	28·4	16·5	12	55	3	28·3	5·5	22	32
1 Month	5	27·4	11·3	12	40	4	31·0	5·8	24	38
3 Months	4	20·0	5·7	12	25	5	19·6	8·4	8	29

IOP=intraocular pressure; SD=standard deviation; Min=minimum IOP in this group; Max=maximum IOP in this group; n=no of eyes.
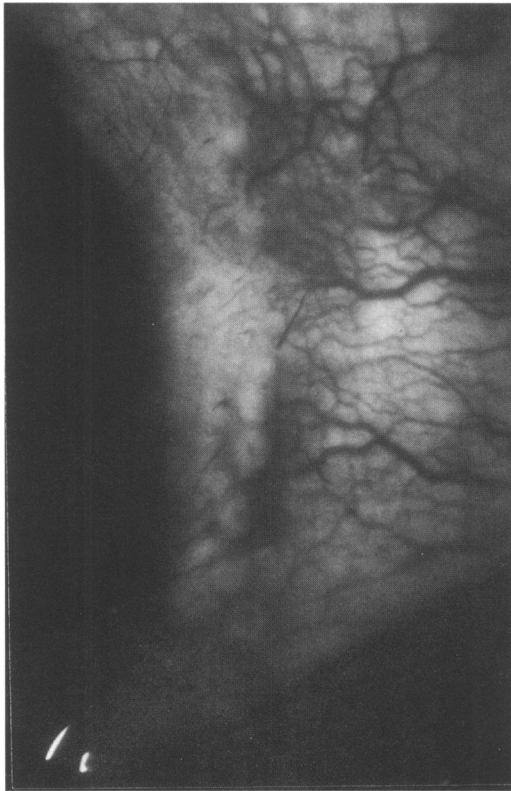
Figure 7 Conjunctival burns following diode laser cyclo photocoagulation in a black patient with a heavily pigmented conjunctiva.

photocoagulation in most cases was to prevent these eyes from becoming painful.

Free running Nd:YAG laser cyclo photocoagulation over 180 degrees is currently the standard cyclo destructive procedure performed for refractory glaucoma at Moorfields Eye Hospital. Compared with a 360 degree treatment pattern,[6 7] there seems to be limited inflammatory response, and thus therapy can be performed as a day-case procedure. However, to lower intraocular pressure below the level of 22 mm Hg using the 180 degree pattern technique may need multiple treatment sessions. By contrast, Heidenkummer and Hampton[6 7] have shown a more marked response to one session of a 360 degree pattern of treatment. This is in agreement with our findings. Compared with the present study, Hawkins,[16] with regard to non-contact diode laser cyclo photocoagulation, achieved a more prolonged hypotensive effect with the same technique. This may be related to the fact that Hawkins and coworkers had excluded the more unpredictable cases with neovascular glaucoma from their study.

The essential aim of cyclo photocoagulation is to induce damage or destruction of the secretory ciliary epithelium, in order to reduce aqueous production and thus lower the intraocular pressure.[4–7] The biophysical processes by which this is achieved may provide an explanation for the differential effect on intraocular pressure observed between the two laser modalities. The essential components implicit in tissue photocoagulation consist of transmission and scatter of the radiation through the ocular media, its absorption within a chromophore, the conversion of incident radiation to heat, and finally the induced tissue

reaction.[3] For both diode (810 nm) and Nd:YAG (1064 nm) irradiation, scleral transmission is high with scleral compression. The principal absorbing chromophore in the ciliary body is melanin within the pigmented ciliary epithelium, adjacent to the non-pigmented secretory epithelium.[7] Although absorption within melanin is higher at 810 nm than at 1064 nm, clearly the extent of the tissue reaction will also be related to the radiant energy. The Nd:YAG laser used in the study had a higher maximum energy than the diode laser. The pulse duration of exposures (20 milliseconds) also tended to confer a more explosive and less purely thermal effect on the ciliary body than the diode laser, which would also tend to result in more extensive tissue destruction. If the extent of ciliary body destruction can be related to the effect on intraocular pressure, then free running Nd:YAG laser irradiation will tend to have a more marked ocular hypotensive effect than the diode laser system employed, with its maximum output of 1·2 joules. However, contact diode laser systems are now available with maximum power outputs of up to 3 W. Pilot studies using this system have demonstrated significant and sustained reductions in intraocular pressure using energies of the order of 3 joules.[17 18]

In the present study a much less marked inflammatory response was seen following diode laser treatment compared with Nd:YAG therapy. This may be explained by the relatively explosive effect on the ciliary body of the short pulse duration of the Nd:YAG laser exposures in the free running mode (20 ms).[19] This is less likely to occur following irradiation with the continuous wave diode laser, which induces a more thermal tissue effect. The conjunctival burns which are commonly induced by the free running Nd:YAG laser may also exacerbate the inflammatory response.[4] In the diode laser group conjunctival burns, similar to those shown by Hennis in his pilot study,[15] only occurred in one black patient with a heavily pigmented conjunctiva (Fig 7).

In conclusion, the degree and duration of the ocular hypotensive response to cyclo photocoagulation appears to be related to the available power output of the system used, and the extent of tissue damage. The delivery of greater total energies also seems to increase the amount of inflammatory response.

1 Assia EI, Hennis HL, Stewart WC, Legler UFC, Carlson AN, Apple DJ. Comparison of Nd:YAG and diode transscleral cyclophotocoagulation and cyclocryotherapy. *Invest Ophthalmol Vis Sci* 1991; **32**: 2774–8.

2 Fankhauser F, van der Zypen E, Kwasniewska S, Rol P, England C. Transscleral cyclo photocoagulation using a neodymium:YAG laser. *Ophthalmic Surg* 1986; **17**: 94–100.

3 Vogel A, Dlugos C, Nuffer R, Birngruber R. Optical properties of human sclera, and their consequences for transscleral laser applications. *Lasers Surg Med* 1991; **11**: 331–40.

4 Heidenkummer HP, Mangouritsas G, Kampik A. Clinical application and results of Nd:YAG cyclocoagulation in

refractory glaucoma. *Klin Monatsbl Augenheilkd* 1991; **98:** 174–80.

5 Hampton C, Shields MB, Miller KN, Blasini M. Evaluation of a protocol for transscleral neodymium:YAG cyclo photocoagulation in one hundred patients. *Ophthalmology* 1990; **97:** 910–7.

6 Kwasniewska S, Fankhauser F, van der Zypen E, Rol P, Henchoz PD, England C. Acute effects following transscleral contact irradiation of the ciliary body and the retina/choroid with the cw Nd:YAG laser. *Lasers Light Ophthalmol* 1988; **2:** 25–34.

7 Ando F, Miyake K, Federman JL. Nd:YAG laser transscleral contact cyclophotocoagulation in refractory glaucoma. *Lasers Light Ophthalmol* 1990; **3:** 119–22.

8 Ulbig MRW, Arden GB, Hamilton AMP. Color contrast sensitivity and pattern electroretinographic findings after diode and argon laser photocoagulation in diabetic retinopathy. *Am J Ophthalmol* 1994; **117:** 583–8.

9 Bandello F, Brancato R, Trabucchi G, Lattanzio R, Malegori A. Diode versus argon-green laser panretinal photocoagulation in proliferative diabetic retinopathy: a randomized study in 44 eyes with a long follow-up time. *Graefes Arch Clin Exp Ophthalmol* 1993; **231:** 491–4.

10 Ulbig MRW, McHugh JDA, Hamilton AMP. Photocoagulation of choroidal neovascular lesions with a diode laser. *Br J Ophthalmol* 1993; **77:** 218–21.

11 Blasini M, Simmons R, Shields MB. Early tissue response to transscleral neodymium:YAG cyclophotocoagulation. *Invest Ophthalmol Vis Sci* 1990; **31:** 1114–8.

12 Hennis HL, Ehud A, Stewart WC. Transscleral photocoagulation using a semiconductor diode laser in cadaver eyes. *Ophthalmic Surg* 1991; **22:** 274–8.

13 Hampton C, Shields MB. Transscleral neodymium:YAG cyclophotocoagulation. A histologic study of human autopsy eyes. *Arch Ophthalmol* 1988; **106:** 1121–3.

14 Schuman JS, Jacobson JJ, Puliafito CA. Experimental use of semiconductor diode laser in contact transscleral cyclophotocoagulation in rabbits. *Arch Ophthalmol* 1990; **108:** 1152–7.

15 Hennis HL, Stewart WC. Semiconductor diode laser transscleral cyclophotocoagulation in patients with glaucoma. *Am J Ophthalmol* 1992; **113:** 81–5.

16 Hawkins TA, Stewart WC. One-year results of semiconductor transscleral cyclophotocoagulation in patients with glaucoma. *Arch Ophthalmol* 1993; **111:** 488–91.

17 Gaasterland DE, Abrams DA, Belcher CD, Liebmann JN, Pollack IP, Ritch R, *et al.* A multicenter study of contact diode laser transscleral cyclophotocoagulation in glaucoma patients. *Invest Ophthalmol Vis Sci (ARVO Suppl)* 1992; **33:** 1019.

18 Ulbig MW, McHugh JDA, McNaught AI, Hamilton AMP. Contact cyclo photocoagulation for refractory glaucoma with a diode laser. A pilot study. *German J Ophthalmol* 1994; **3:** 212–5.

19 Okisaka S, Kiu G, Mizukawa A. Comparative histopathological study of free-running mode and continuous wave Nd:YAG laser photocoagulation of monkey retina and choroid. *Jpn J Ophthalmol* 1991; **35:** 233–58.