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ORIGINAL PAPER

Selective laser trabeculoplasty (SLT): 1-year results in early and advanced open angle glaucoma

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Abstract The purpose of this study was to examine the efficacy of selective laser trabeculoplasty (SLT) in eyes with early and more advanced stages of open angle glaucoma within 1 year of follow-up. Retrospective chart review in a consecutive series of patients treated by SLT to reduce intraocular pressure (IOP) or decrease number of topical medications in cases of discomfort and allergy. The cup-to-disc ratio of the optic nerve and the GSS 2 (glaucoma staging system 2) was used to differentiate between early (group 1) and more advanced (group 2) stages of glaucoma. At the time of SLT treatment, no new signs of glaucoma progression were seen. Only the first treated eye of every patient was included in the analysis. In group 1 (early glaucoma), 27 eyes were included. IOP reduction <21 mmHg/>20 % of the preoperative IOP-value and reduction of medication were achieved in 17 eyes (62.96 %). Successful re-treatment was necessary in 2 eyes (7.4 %). In group 2 (advanced glaucoma), 44 eyes underwent SLT. In eight eyes (18.18 %), filtrating surgery was necessary after initial SLT. In the remaining 36 eyes, IOP reduction <21 mmHg/>20 % of the baseline IOP was achieved in 26 eyes (59.09 % of 44 eyes) and IOP reduction <18 mmHg/>30 % of the baseline IOP in 22 eyes (50 % of 44 eyes). SLT was safe and effective in nearly 2/3 of early glaucoma patients and also in 50 % of advanced glaucoma patients using stronger criteria of success. Failure of SLT in advanced glaucoma should lead to immediate filtrating surgery, which seems not to be associated with higher risk of fibrosis.

Keywords Selective laser trabeculoplasty · Trabeculoplasty · Glaucoma · Intraocular pressure

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Introduction

Laser surgery of the trabecular meshwork is a part of glaucoma treatment for more than 35 years and started with the use of argon laser trabeculoplasty (ALT) by Wise and Witter in 1979 [1]. Although the procedure was generally very safe, some limitations have been described over years (e.g., ineffective re-treatments, peripheral anterior synechiae) [2]. Especially, ALT was suggested to increase the role of bleb encapsulation after filtration surgery, and therefore ALT was avoided by some clinicians [3, 4]. The mechanisms of action have never been fully understood but were thought to be a combination of photothermal effects resulting in scarring and subsequent widening of adjacent intertrabecular spaces, finally resulting in an increased outflow facility and possible biological and cellular effects [1].

Selective laser trabeculoplasty (SLT) has been developed by Latina in 1998 and is based on a continuous-wave, frequency-doubled Nd:YAG laser (532 nm) [5]. Laser energy is delivered to the trabecular meshwork using parameters resulting in selective absorption of energy by pigmented endothelial trabecular cells, sparing adjacent cells, and tissues from thermal damage [6]. Damage of pigment-containing trabecular cells due to the cracking of pigment probably leads to a subclinical inflammatory response including the invasion of macrophages and the rebuilding of the trabecular endothelial cell layer (cellular hypothesis). After SLT, cultured human trabecular meshwork cells showed changes in their expression of genes involving cell motility, extracellular matrix production, and others, but without damage either at molecular or phenotypic levels [7]. Direct laser treatment of cultured Schlemm canal cells increases the permeability of Schlemm canal cells comparable to the effects of prostaglandin application, supporting the hypothesis of common mechanisms leading to their IOP lowering effects [8].

Clinical studies showed comparable effects on the intraocular pressure (IOP) with ALT and SLT [9–11]. However, some of the difficulties associated with ALT have possibly been remedied by the introduction of SLT, which was approved by the FDA in 2002. SLT appears to be more effective than ALT as a retreatment option in patients with prior ALT [12, 13]. Complications after SLT treatment are rare and include IOP spikes, macular edema, iritis, or corneal haze [14–16].

Whereas laser trabecular surgery is traditionally indicated in early stages of open angle glaucoma, trabeculectomy remains the "gold standard" in advanced open angle glaucoma. The risks of filtering surgery are well recognized including the possible functional deterioration in patients with advanced glaucoma (wipe-out syndrome) [17]. There are a range of new surgical procedures (e.g., canaloplasty, trabectome, trabecular bypass stent), but it is still unclear, if these procedures are comparable in efficacy to trabeculectomy [18].

In clinical practice, the individual situation of patients is more heterogeneous than clinical studies normally can reflect. There is an increasing number of older glaucoma patients with a range of systemic diseases and medications, sometimes cognitive limitations or complicated life circumstances, which can delay the indication and performance of filtering surgery (or other invasive surgery). The aim of this retrospective study was to investigate the results of SLT in patients with early and more advanced open angle glaucoma. Indications for SLT treatment were insufficient medical treatment (elevated IOP, discomfort with mediation, or incompliance) without actual signs of functional or morphological glaucoma progression.

Materials and methods

Study design

We performed a retrospective chart review of patients who had undergone laser trabeculoplasty at the Department of Ophthalmology, Clinic Pallas (Olten, Switzerland) within 1 year and showed a follow-up time of 1 year or more. All SLT procedures were performed by two surgeons (TS, MK), all trabeculectomies after failure of SLT by the same surgeon (TS).

Only the first treated eye of any patient with a follow-up of at least 12 months after initial SLT was included into the analysis to avoid a shift to more positive results, because more patients may receive bilateral treatment with a successfully treated first eye than an unsuccessful treated first eye. Patients with previous treatment of the trabecular meshwork by argon laser or other surgical procedures were not included in the study.

Indications for SLT

SLT was performed in patients with primary open angle glaucoma (POAG), pseudoexfoliation glaucoma (PEXG), pigment dispersion glaucoma (PDG), and (primary) ocular hypertension. Patients with normal tension glaucoma were not included. Indications for SLT treatment were insufficient IOP control, allergy or discomfort to topical antiglaucoma medication, or non-compliance to topical treatment. In cases of advanced glaucoma, no actual signs of visual field defect progression or increasing optic disc excavation were present at the time of SLT treatment.

Glaucoma staging

We used the most established parameter to describe the morphologic damage in a glaucoma patient: the vertical

cup–disc ratio (vCDR) of the optic nerve. To include the degree of functional damage, we used the enhanced glaucoma staging system (GSS2) [19]. The GSS2 is based on the main perimetric global indices (mean deviation and pattern standard deviation, or loss variance) and can be used both with the Humphrey and Octopus threshold tests. This standardized classification system of functional damage includes 6 stages ranging from stage 0 to stage 5 to describe the severity of the functional damage. Using both the GSS2 and the vCDR, it was possible to classify all eyes concerning the stage of glaucoma as early or more advanced glaucoma.

An early stage of glaucoma was assumed in patients with vCDR < 0.8 and normal or low degree perimetric changes (GSS 0–1).

A more advanced stage of glaucoma was assumed in all patients with clinically subtotal papilla excavation (vCDR ≥ 0.9), all patients with GSS2 $\geq$ stage 3 (advanced stages of functional damage) and the remaining patients with vCDR 0.6–0.8 and GSS2 ≥ 2.

Laser technique and treatment parameter

The operative techniques were followed as described by Latina et al. in 1998 [5]. The standard procedure included topical anesthesia with tetracaine eye drops, and eyes were pretreated with apraclonidine 1.0 %. The Ellex Solo Laser is a Q-switched, frequency-doubled Nd:YAG laser (532 nm) with a spot size of 400 microns and a pulse duration of 3 ns. The pigmented trabecular meshwork was targeted, and between 50 and 70 adjacent, non-overlapping, laser spots were placed over 180° of the inferior trabecular meshwork. The energy level for treatment was initially set at 0.7 mJ and ranged from 0.6 to 1.0 mJ. If the energy level was too high (cavitation bubbles at following spot applications), the pulse energy was decreased by increments of 0.1 mJ until minimal bubble formation at nearly 50 % of all spots was visible. Post-treatment management consisted of topical non-steroidal anti-inflammatory eye drops 4 times a day during 1 week.

IOP measurements, visits, and retreatment

Intraocular pressure was measured preoperatively, first postoperative day, and at 1, 3, 6, and 12 months after laser treatment. All IOP measurements were performed with Goldmann applanation tonometry. Under daily conditions, retreatment was normally performed, if IOP increased again after initial, successful SLT treatment $\geq$21 mmHg in early and $\geq$18 mmHg in more advanced glaucoma.

Success criteria for the early stage glaucoma group

- Eyes with elevated IOP prior to SLT should have a reduction of IOP < 21 mmHg and >20 % of the initial IOP, and eyes with discomfort to antiglaucoma medication but controlled IOP should have a reduction in the number of medication ≥ 1 and an IOP < 21 mmHg;
- number of eyes with additional glaucoma surgery;
- number of re-treatments with SLT.

Success criteria for the more advanced stage glaucoma group

- Reduction of IOP < 21 mmHg and >20 % of the baseline IOP (success criterion of the early glaucoma group);
- IOP reduction <18 mmHg (Advanced Glaucoma Intervention Study, AGIS criteria) and no additional glaucoma medication at all time points after SLT;
- IOP reduction <18 mmHg and >30 % of the baseline IOP;
- number of eyes with additional glaucoma surgery within the follow-up time after failure of SLT.

Data analysis

Statistical analysis was performed using Medcalc® Version 9.3 (MedCalc Software, Mariakerke, Belgium). Normal data distribution was checked using the Kolmogorov–Smirnov test. Wilcoxon-test, paired *t* test, and ANOVA analysis were applied for statistical analysis as appropriate. $P \leq 0.05$ was considered statistically significant. Continuous variables data are expressed as the mean $\pm$ SD unless otherwise specified.

Results

Early glaucoma stage group

27 eyes of 27 patients with a follow-up of 12 months were available for statistical analysis (demographic data and glaucoma characteristics Table 1). The reasons for SLT were an elevated IOP in 19 eyes, discomfort with topical medication in 7 eyes, and a mixed situation with both aspects in 1 eye. SLT was well tolerated in all treated eyes, and no side effects were described in the charts.

Overall, a significant mean IOP reduction was achieved (ANOVA <0.001, Table 2). Using the defined criteria, the following results were obtained:

- IOP reduction <21 mmHg/>20 % of the preoperative IOP and reduction of medication: 17 eyes (63 %);
- no eyes with additional glaucoma surgery;
- successful re-treatment in 2 eyes (7.4 %) 6 months after initial, effective SLT treatment. In both eyes, IOP increased >21 mmHg but responded again to a level <21 mmHg/20 % of the initial IOP.

More advanced glaucoma stage group

Initially, 44 eyes of 44 patients with more advanced glaucoma underwent SLT (demographic data and glaucoma characteristics Table 1). SLT was well tolerated in all eyes, and no severe side effects/complications were recorded.

Success rate with regard to different success criteria revealed the following results (trabeculectomy was regarded as failure):

- IOP reduction <21 mmHg and >20 % of the baseline IOP: 26 eyes (59.1 %);
- IOP reduction <18 mmHg and unchanged topical medication: 29 eyes (65.9 %);
- IOP reduction <18 mmHg and >30 % of the baseline IOP: 22 eyes (50 %);
- number of eyes with additional glaucoma surgery: 8 eyes (18.2 %).

In 36 eyes without additional surgery, effects on IOP and medication after initial SLT were further evaluated with a follow-up of 12 months (Tables 1, 3). In comparison to the early glaucoma group, there was no difference concerning the baseline IOP between both groups (*t* test, $P = 0.42$). Whereas a significant IOP reduction (ANOVA <0.001) was documented, mean number of medication remained unchanged (Table 3).

Filtering surgery after SLT

8 eyes (18.18 %) of the advanced glaucoma group underwent filtering surgery (trabeculectomy) because of insufficient IOP reduction after initial SLT. All 8 eyes were treated to lower the elevated IOP. 4 out of 31

Table 1 Demographic data and glaucoma characteristics before SLT

	Early glaucoma stage group	Late glaucoma stage group
Number of eyes/patients	27/27	44/44
Mean age of patients ± standard deviation (range)	64.5 ± 11.2 (47–86) median = 65	73.8 ± 9.7 (50–91) median = 74
Male:female	10:17	16:28
OD:OS	10:17	22:22
Diagnosis	POAG $n = 15$	POAG $n = 31$
	OHT $n = 7$	PEXG $n = 11$
	PEXG $n = 3$	PDG $n = 2$
	PDG $n = 2$	
Mean GSS2 ± standard deviation (range)	0.55 ± 0.6	2.69 ± 1.6
Mean vCDR ± standard deviation (range)	0.45 ± 0.2 [0.1, 0.7] median = 0.5	0.87 ± 0.1 [0.6, 1.0] median = 0.9

OD Right eye, *OS* left eye, *GSS2* glaucoma stage system 2, *vCDR* vertical cup–disc ratio, *POAG* primary open angle glaucoma, *OHT* ocular hypertension, *PEX* pseudoexfoliation glaucoma, *PDG* pigment dispersion glaucoma

Table 2 Effects of SLT on intraocular pressure and medication in the early glaucoma stage group (27 eyes)

	Mean IOP ± SD [range], median	*t* test	Mean no. of topical medication ± SD [range]	Wilcoxon-test
Baseline	22.9 ± 4.4 [16, 34] median = 22		1.6 ± 0.8 [0, 3] median = 2	
1 month	19.3 ± 3.4 [14, 32] median = 18	$P = 0.0004$	1.3 ± 1.0 [0, 3] median = 1	$P = 0.062$
3 months	18.7 ± 2.9 [15, 26] median = 18	$P < 0.0001$	1.3 ± 1.1 [0, 3] median = 1	$P = 0.027$
6 months	18.7 ± 2.1 [15, 23] median = 18	$P < 0.0001$	1.3 ± 1.1 [0, 3] median = 1	$P = 0.027$
12 months	18.2 ± 2.9 [14, 25] median = 18	$P < 0.0001$	1.3 ± 1.1 [0, 3] median = 1	$P = 0.027$

IOP showed a normal data distribution but not the number of topical medications (Kolmogorov–Smirnov test)

SD Standard deviation, *no.* number

Table 3 Effects of SLT on intraocular pressure and medication in 36 eyes of the more advanced glaucoma stage group (patients with trabeculectomy excluded)

	Mean IOP ± SD [range], median	*t* test	Mean no. of medications ± SD [range]	*t* test
Baseline	22.1 ± 4.1 [16, 35] median = 22		1.9 ± 1.0 [0, 4] median = 2	
1 month	16.7 ± 3.1 [11, 24] median = 16	$P < 0.0001$	1.9 ± 1.0 [0, 4] median = 2	$P = 0.66$
3 months	16.1 ± 3.5 [7, 24] median = 16	$P < 0.0001$	1.9 ± 1.1 [0, 4] median = 2	$P = 0.71$
6 months	16.3 ± 2.8 [10, 22] median = 16	$P < 0.0001$	1.9 ± 1.0 [0, 4] median = 2	$P = 0.79$
12 months	14.8 ± 2.4 [8, 21] median = 15	$P < 0.0001$	1.9 ± 1.0 [0, 4] median = 2	$P = 1$

All data (IOP, number of medication) showed a normal distribution (Kolmogorov–Smirnov test)

SD Standard deviation, *no.* number)

eyes with primary open angle glaucoma (13 %) and 4 out of 11 eyes with pseudoexfoliation glaucoma (36.4 %) underwent filtering surgery. Mean IOP prior to trabeculectomy was 28 ± 7.65 mmHg (range 20–45 mmHg) and decreased postoperatively after 1 month to 16.75 ± 4.2 mmHg (range 10–23 mmHg, $P < 0.001$), after 3 months to 16.29 ± 1.37 mmHg (range 14–18 mmHg, $P = 0.004$), and after 6 months (6 eyes) to 17 ± 0.89 mmHg (range 16–18 mmHg, $P = 0.01$). No abnormal wound healing/bleb encapsulation was described in these eyes. Except in one eye with monotherapy, no topical medication was used after filtrating surgery.

Discussion

SLT has been described as a successful IOP lowering technique in primary and secondary open angle glaucoma and ocular hypertension. Success rates after 1 year ranged from 59 to 96 % with an average reduction in IOP from 7 to 40 % [2, 11]. Recent studies documented that SLT may be used as initial therapy in open angle glaucoma and ocular hypertension with the same safety and efficacy in comparison to a pharmacological monotherapy [20]. SLT efficacy seems to be positively associated with the degree of IOP elevation before SLT, the age of patients, and SLT dose [21, 22]. Other factors may (e.g., corneal thickness, iridocorneal angle pigmentation, pretreatment with prostaglandin analog therapy) or may not (e.g., sex, pseudophakia) influence the efficacy of SLT [23–27].

In 2007, a Cochrane Data analysis under evidence-based criteria described laser trabeculoplasty as less effective than trabeculectomy in controlling IOP at 2-year follow-up [28]. The authors noted that further studies are needed in different directions, including the evaluation of SLT efficacy with regard to the different stages of open angle glaucoma. This question addressed to our study reporting the results of SLT depending on the stage of glaucoma under daily clinical conditions. This question may be important because of an increasing global prevalence of

glaucoma including an increasing part of older and very old (>90 years of age) glaucoma patients [29]. Difficult life circumstances, multimorbidity, polypharmacy, and other factors are of increasing influence on our daily work with patients. In our experience, SLT is of increasing value to treat a wide range of glaucoma patients: SLT is quick, effective, very safe, and cost- and time-saving.

One year after treatment, we found an IOP reduction <21mmH and >20 % of the preoperative IOP or a reduction of medication in nearly 2/3 of eyes of the early glaucoma group. This is in accordance with the results of many other publications. Additionally, we also found quite good results in the advanced glaucoma group using stronger criteria of success: 2/3 of treated eyes showed an IOP < 18 mmHg after SLT without additional surgery at all visits after SLT (AGIS criterion, recommendation of the European Glaucoma Society) [30]. Furthermore, even a more stronger criterion with IOP < 18 mmHg/IOP reduction >30 % was fulfilled in 50 % of eyes. It is clear that no additional reduction of medication can be achieved in this situation. Nearly, 20 % of eyes underwent subsequent filtering surgery within the first year after initial SLT. In our small group of patients with trabeculectomy after SLT, no fibrosis of the filtering bed was observed, and all eyes achieved a satisfying IOP lowering effect. Filtering surgery was performed in 13 % of eyes with advanced POAG and 36.4 % of advanced PEX glaucoma. This difference may reflect a tendency of lower SLT efficacy in PEX glaucoma.

Because IOP reduction with SLT will not achieve the lower teen's values in most patients, it seems not appropriate for advanced glaucoma with signs of progression. In these cases, filtering surgery remains the "gold standard" of treatment. On the other hand, discussion of the risk–benefit–cost ratio may be allowed in comparison to standard procedures (like trabeculectomy) and other, newer surgical procedure (like canaloplasty). Recently published results 4 years after trabeculectomy of 797 eyes included a total success rate of 60 % (IOP ≤ 15 mmHg and ≥25 reduction), worsening of lens opacity in 55 %, loss of 3 or more Snellen lines in 21 %, and subsequent glaucoma surgery in 13 % [31]. Concerning canaloplasty, 3 years results of the multicenter European study group showed a mean IOP of 15.1 ± 3.1 mmHg combined with further glaucoma medical therapy (mean 0.9 ± 0.9) [32]. Late complications included cataract development in 20 %. These results and risks should be weighed in every individual patients, and SLT may have a place as a part inside the spectrum of indications for the treatment of more advanced open angle glaucoma patients.

In conclusion, SLT is very safe, easy to perform, little stressful for patients and can be regarded as an established and effective part of glaucoma treatment in early and moderate stages of primary and secondary open angle glaucoma. With regard to an increasing glaucoma prevalence and a more older population in western countries, SLT will achieve more importance in future. Furthermore, SLT may be helpful in patients with advanced glaucoma and moderate IOP elevation, maximal topical medication, and co-existing systemic diseases or medication (e.g., warfarin, phenprocoumon), which makes filtering surgery difficult and potentially dangerous. Patients should be closely monitored, and filtering surgery can be performed immediately in cases of SLT failure. SLT is not indicated in advanced glaucoma with actual signs of functional or morphological glaucoma progression. Further investigation is needed to determine the full value of SLT in patients with different stages of glaucoma and different glaucoma diagnosis (e.g., pseudoexfoliation).

Conflict of interest The authors have declare no financial or conflicting interest.

Ethical standards This retrospective study adhered to the tenets of the Declaration of Helsinki.

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