Comparison of Long-term Outcomes of Selective Laser Trabeculoplasty versus Argon Laser Trabeculoplasty in Open-Angle Glaucoma

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Purpose: To compare the long-term success rate of selective laser trabeculoplasty (SLT) versus argon laser trabeculoplasty (ALT).

Design: Retrospective chart review.

Participants: One hundred ninety-five eyes of 195 patients with uncontrolled open-angle glaucoma (OAG), of which 154 eyes underwent ALT and 41 eyes underwent SLT and were followed up for a maximum of 5 years.

Intervention: The SLT patients were treated with the frequency-doubled q-switched neodymium:yytrium–aluminum–garnet laser (532 nm). Approximately 50 to 55 nonoverlapping spots were placed over 180° of the trabecular meshwork at energy levels ranging from 0.6 to 1.0 mJ per pulse. The ALT patients were treated with the argon blue–green laser with between 45 to 55 adjacent, nonoverlapping spots over 180° of the trabecular meshwork at 470 to 1150 mW of energy per pulse.

Main Outcome Measures: The success rates were defined by criterion I and criterion II. Success by criterion I was defined as a decrease in intraocular pressure (IOP) of 3 mmHg or more with no additional medications, laser, or glaucoma surgery. Criterion II had the same requirements as criterion I, except that a 20% or more IOP reduction was required for success.

Results: The mean follow-up time was 37.4±14.7 months for patients in the SLT group and 33.6±17.0 months for patients in the ALT group. The long-term success rate was not significantly different between the ALT and SLT groups by either criterion (Kaplan-Meier survival analysis log-rank $P = 0.20$ by criterion I and $P = 0.12$ by criterion II). When comparing patients with and without previous ALT, there was not a statistically significant difference in the patients treated with SLT by either criterion (log-rank $P = 0.37$ by criterion I and $P = 0.39$ by criterion II).

Conclusions: In eyes with primary OAG that are receiving maximally tolerated medical therapy, SLT was found to be as effective as ALT in lowering IOP over a 5-year period. However, long-term data reveal that many of the glaucoma patients treated with SLT and ALT required further medical or surgical intervention. Whether SLT has better long-term success than ALT in repeat laser trabeculoplasty treatments remains unclear. *Ophthalmology 2004;111:1853–1859 © 2004 by the American Academy of Ophthalmology.*

In 1979, when Wise and Witter[1] demonstrated that argon laser trabeculoplasty (ALT) lowered intraocular pressure (IOP), it added an additional therapeutic option to the treatment of open-angle glaucoma (OAG). It was hoped that ALT would postpone or eliminate the need for incisional or cyclodestructive surgical intervention. Other laser therapies, such as the krypton or diode lasers, have been used in trabeculoplasty with similar results to that of ALT.[2–4] However, histologic studies have shown that laser therapy causes coagulation damage and scarring of the trabecular meshwork (TM).[5–7] This theoretically can limit the success of future retreatment of the TM by ALT.

Selective laser trabeculoplasty (SLT) is a new and promising treatment that uses the 532-nm frequency-doubled q-switched neodymium:yytrium–aluminum–garnet laser and was developed to target selectively the pigmented TM cells without causing thermal or collateral damage to the nonpigmented cells or structures of the TM.[8,9] Selective laser trabeculoplasty treatment then may hold clinical ad-

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Table 1. Pretreatment Patient Characteristics

Characteristics	Selective Laser Trabeculoplasty (n = 41)	Argon Laser Trabeculoplasty (n = 154)	*P* Value
Age (mean ± SD), yrs	71.9 ± 8.8	69.7 ± 10.7	0.23*
Gender			
Male	19 (46.3%)	61 (39.6%)	0.54†
Female	22 (53.7%)	93 (60.4%)	
Race			
African American	25 (61.0%)	118 (76.6%)	0.10†
White	16 (39.0%)	36 (23.4%)	
Mean preoperative IOP (mmHg)	23.9 ± 2.6	24.3 ± 4.1	0.58*
Mean preoperative glaucoma medications	2.5 ± 1.3	2.5 ± 1.2	0.97‡
Follow-up (mos) (mean ± SD)	37.4 ± 14.7	33.6 ± 17.0	0.21*

IOP = intraocular pressure; SD = standard deviation.
*Two-tailed unpaired *t* test.
†Chi-square test.
‡Mann–Whitney *U* test.

vantages over ALT treatment. In several studies that compare ALT with SLT, the outcomes of IOP reduction, medical dependency, and short-term success have been equivalent.[9–11]

Although there are studies comparing SLT with ALT, no long-term data have been published that compare the efficacy of SLT versus ALT. The goal of the present study was to compare the long-term (5-year) success rates of patients who underwent ALT versus SLT.

Patients and Methods

This study is a retrospective chart review of patients who had undergone laser trabeculoplasty at the Kresge Eye Institute. The 154 ALT patients and 41 SLT patients were treated between January and June 1997. A total of 195 eyes of 195 patients with chronic OAG had a minimum follow-up of 3 months and a mean follow-up of 35.2±15.9 months. All of the patients had uncontrolled chronic OAG on maximally tolerated medication therapy. Patients who underwent SLT nonrandomly were asked to be included in a research experiment. All patients provided informed consent after the potential risks, benefits, and alternatives of the procedures were explained fully. Investigational review board approval was obtained for use of the Coherent Selecta 7000 laser (Coherent, Inc., Palo Alto, CA). Data on demos, past ocular history, medical dependency, and postoperative course were collected. Patients with evidence of glaucoma other than OAG and patients with prior glaucoma surgery other than ALT or peripheral iridectomy were excluded from the study.

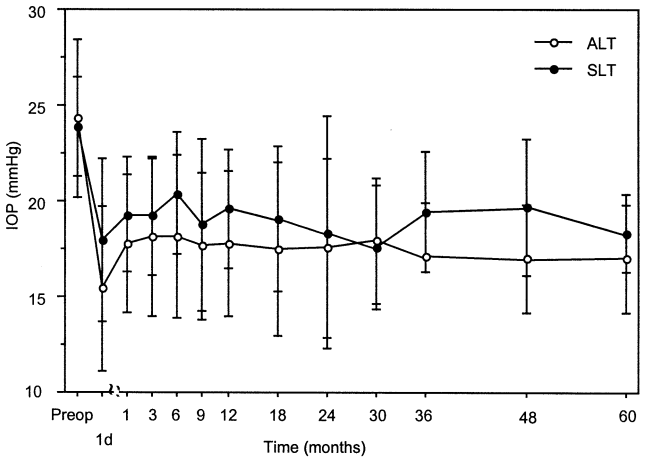


Figure 1. Mean intraocular pressure (IOP; ±1 standard deviation) in patients who underwent argon laser trabeculoplasty (ALT) or selective laser trabeculoplasty (SLT). d = day; preop = before surgery.

The operative techniques used in the SLT group were followed as described by Latina et al.[9] Topical tetracaine or proparacaine hydrochloride was used as anesthesia for the treatment, and eyes were pretreated with apraclonidine 1.0%. The Coherent Selecta 7000 laser, a frequency-doubled q-switched neodymium:yytrium–aluminum–garnet laser, was used to treat these patients. The laser was emitting at 532 nm with a pulse duration of 3 nanoseconds and a spot size of 400 μm. The pigmented TM was targeted, and between 50 to 55 adjacent, but nonoverlapping, laser spots were placed over 180° of the nasal TM. In SLT, the energy level for treatment was initially set at 0.8 mJ and ranged from 0.6 to 1.0 mJ. If the energy level was too high (demonstrated by cavitation bubbles or if disruption of the TM was visualized), the pulse energy was decreased by increments of 0.1 mJ until minimal bubble formation or disruption to the TM was visualized. The total number of pulses delivered at each energy level and the total amount of energy delivered, as indicated on the laser control panel, were recorded.

All SLT and ALT procedures were performed by the same surgeon (DHS). Patients undergoing ALT were pretreated with 1 drop of apraclonidine 1.0%. Patients were treated with a Coherent 900 laser, argon blue–green, with a 0.1-second pulse duration and a spot size of 50 μm. From 470 to 1150 mW of energy was delivered. Energy was titrated to achieve a blanching effect in the TM. The inferior 180° angle was used if the patient had no previous ALT or had previous 360° angle treatment. In patients who previously had been treated by 180° of ALT and underwent an additional 180° of ALT treatment, the untreated 180° was treated. Between 45 to 55 adjacent, nonoverlapping spots were applied to 180° of the TM.

Post-treatment management of both groups was similar. Topical steroid was prescribed 4 times daily for 1 week. The IOP was checked at 1 hour after both ALT and SLT. Additionally in the SLT group, the IOP was checked after 2 hours in all cases. If a ≥5-mmHg rise in the IOP occurred in either treatment group, that eye was treated with the appropriate antiglau-

Table 2. Intraocular Pressure Percent Reduction in Selective Laser Trabeculoplasty and Argon Laser Trabeculoplasty Groups

Time	Selective Laser Trabeculoplasty		Argon Laser Trabeculoplasty		*P* Value†
	*% Decrease**	*n*	*% Decrease**	*n*	
1 mo	19.4 ± 11.5	41	19.4 ± 16.3	154	0.99
3 mos	19.4 ± 13.1	39	17.8 ± 19.5	130	0.63
6 mos	14.3 ± 14.4	37	17.1 ± 20.2	116	0.43
1 yr	18.1 ± 10.2	32	18.1 ± 18.9	110	0.99
2 yrs	23.4 ± 24.3	29	19.2 ± 23.4	88	0.40
3 yrs	23.4 ± 13.2	25	20.8 ± 15.6	70	0.56
4 yrs	21.2 ± 18.7	21	19.1 ± 15.9	45	0.67
5 yrs	27.1 ± 21.4	20	23.5 ± 25.2	40	0.75

*Mean ± standard deviation.
†Two tailed unpaired t-test.

coma medications. Patients subsequently were evaluated at 1 day, 1 week, and 1 month, and at 4- to 6-month intervals thereafter in both groups. At each follow-up visit, the IOP, visual acuity, and number of medications prescribed were recorded, and any complications were treated appropriately. The final IOP used for calculation was the last measured pressure before failure of surgery or loss to follow-up.

Two criteria were used to define a successful response to ALT or SLT treatment. Criterion I was defined as an IOP reduction of 3 mmHg or more without additional medications or additional glaucoma surgery (including 5-fluorouracil needling revision or the need for additional laser trabeculoplasty). Criterion II had the same requirements as criterion I, except the IOP reduction was 20% or more of the pretreatment IOP.

Data were analyzed statistically using a 2-tailed unpaired *t* test, chi-square test, Mann–Whitney *U* test, repeated-measures analysis of variance, and a Kaplan-Meier survival analysis with Mantel-Cox log-rank test to compare outcomes between groups. The level of significance was considered to be 0.05 unless otherwise noted.

Results

The pretreatment demographic characteristics of the 2 groups are listed in Table 1. The ALT and SLT groups were similar in age, race, gender, preoperative IOP, and number of glaucoma medications. The mean follow-up time was 37.4±14.7 months for patients in the SLT group and 33.6±17.0 months for patients in the ALT group ($P = 0.21$), with a range of 3 to 60 months. Twenty-eight of the 41 patients (68.3%) in the SLT group and 128 of the 154 patients (83.1%) in the ALT group had no previous glaucoma surgery or laser trabeculoplasty to the treated trabecular meshwork. Six patients (14.6%) in the SLT group and 16 patients (10.4%) in the ALT group were treated previously by 180° ALT before the study and were included in the no previous ALT group because the trabecular meshwork being treated was considered to be primary treatment.

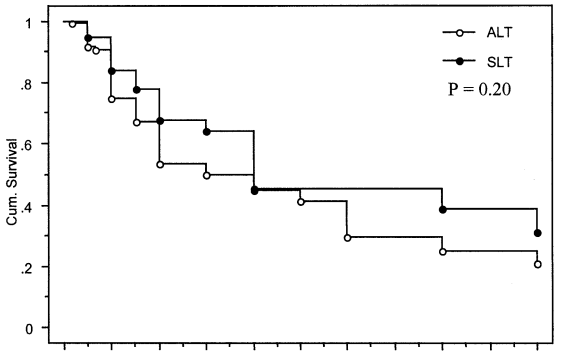
We defined pretreatment IOP as the average IOP of the 2 visits before the date when laser trabeculoplasty was performed. When comparing pretreatment IOP with all follow-up times, there was a significant reduction in IOP (Fig 1). The last follow-up IOP defined as the last IOP before failure or the last IOP recorded for the patient was similar between the ALT and SLT groups (ALT, 17.0±3.9 mmHg vs. SLT, 18.0±3.7 mmHg; $P = 0.15$). The mean IOP percent reduction at each follow-up visit was similar between ALT and SLT treatment groups (Table 2). There was no significant difference in the number of medications in the ALT and SLT groups at all time points (Table 3).

The long-term success rate was not significantly different between the ALT and SLT groups by either criterion ($P = 0.20$, log-rank by criterion I, Fig 2; $P = 0.12$, log-rank by criterion II, Fig 3). Success rates at 1, 3, and 5 years after SLT were 68%, 46%, and 32% by criterion I and were 58%, 38%, and 31% by criterion II. Success rates at 1, 3, and 5 years after ALT were 54%, 30%, and 31% by criterion I and were 46%, 23%, and 13% by criterion II. The long-term success rate of ALT versus SLT patients in the subgroup of patients without previous ALT did not demonstrate a significant difference ($P = 0.38$, log-rank by criterion I, Fig 4; *P*

Table 3. Mean Number of Medications in Selective Laser Trabeculoplasty and Argon Laser Trabeculoplasty Groups at Time Periods

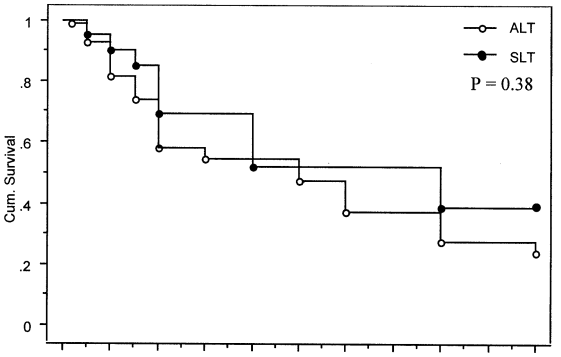
Time	Selective Laser Trabeculoplasty		Argon Laser Trabeculoplasty		*P* Value*
	Mean ± Standard Deviation	*n*	*Mean ± Standard Deviation*	*n*	
Pretreatment	2.5 ± 1.3	41	2.5 ± 1.2	154	0.79
3 mos	2.6 ± 1.4	39	2.7 ± 1.3	130	0.63
6 mos	2.6 ± 1.6	37	2.6 ± 1.3	116	0.71
1 yr	2.1 ± 1.4	32	2.6 ± 1.3	110	0.11
2 yrs	2.3 ± 1.4	29	2.4 ± 1.4	88	0.78
3 yrs	2.5 ± 1.5	25	2.4 ± 1.4	70	0.70
4 yrs	2.5 ± 1.5	21	2.4 ± 1.6	45	0.57
5 yrs	2.5 ± 1.6	20	2.4 ± 1.5	40	0.62
P value†	0.34		0.63		

*Mann–Whitney *U* test.
†Repeated measures analysis of variance.



Time (months)	0	6	12	18	24	30	36	42	48	54	60
SLT (n)	41	37	32	31	29	27	25	23	21	21	20
ALT (n)	154	116	110	101	88	79	70	59	45	43	40

Figure 2. Survival curve using criterion I (defined as a decrease in intraocular pressure of 3 mmHg or more and no additional medications and no additional laser or glaucoma surgery) of *all patients* in the argon laser trabeculoplasty (ALT) and selective laser trabeculoplasty (SLT) groups. Cum. = cumulative; n = number of all eyes examined in each group at each time point.



Time (months)	0	6	12	18	24	30	36	42	48	54	60
SLT (n)	28	25	22	21	20	18	17	15	14	14	14
ALT (n)	128	96	91	84	73	65	58	49	37	36	33

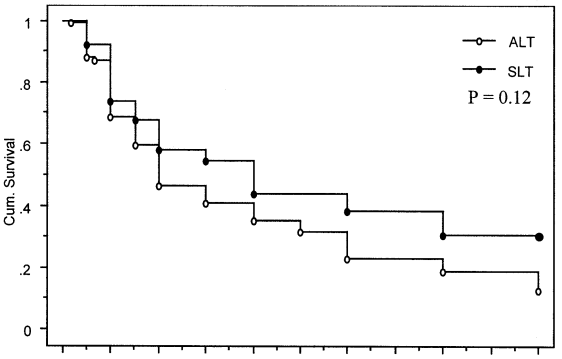
Figure 4. Survival curve using criterion I (defined as a decrease in intraocular pressure of 3 mmHg or more and no additional medications and no additional laser or glaucoma surgery) of patients with *no prior* argon laser trabeculoplasty (ALT) in the ALT and selective laser trabeculoplasty (SLT) groups. Cum. = cumulative; n = number of all eyes with no prior ALT examined in each group at each time point.

= 0.34, log-rank by criterion II, Fig 5). The long-term success rates of ALT versus SLT patients in the subgroup of patients with previous ALT did not demonstrate a significant difference (P = 0.35, log-rank by criterion I, Fig 6; P = 0.21, log-rank by criterion II, Fig 7). Before completing the study, we estimated that the power to detect a 20% difference in survival rates between the ALT and SLT groups was 82%. Using the actual difference in success rates of the 2 groups, the power of our study was 72%.

Discussion

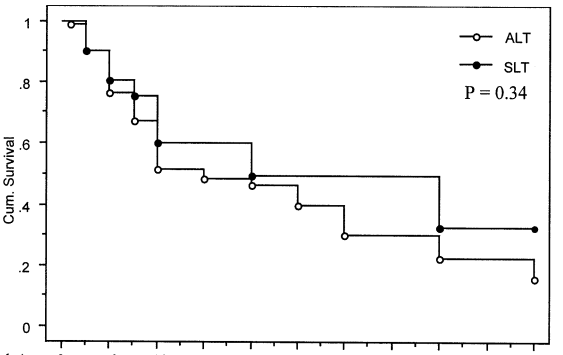
For many years, ophthalmologists have been using various laser therapies to reduce IOP in patients with glaucoma. Argon laser trabeculoplasty has been shown to control IOP for various lengths of time and with different success rates.[1,12–22] Initial ALT treatment has been shown to be as efficacious as initial treatment with topical medication.[13] Argon laser trabeculoplasty treatment also has been used as a substitute for surgery and controlled IOP in one third of cases for 5 years.[12] Although there is a theory that ALT reduces the trabecular ring circumference and therefore the diameter with contractile laser microscars, ALT causes coagulation damage and scarring to the trabecular meshwork.[23–25] Repeat treatment of the angle using ALT may lead to excess damage and scarring, which can lead to increased IOP, and this may limit its efficacy in repeat trabeculoplasty procedures.[26–28]

Because SLT delivers less than 1% of the energy of ALT



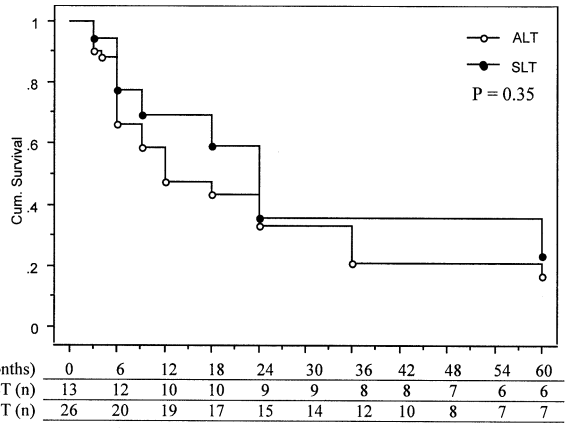
Time (months)	0	6	12	18	24	30	36	42	48	54	60
SLT (n)	41	37	32	31	29	27	25	23	21	21	20
ALT (n)	154	116	110	101	88	79	70	59	45	43	40

Figure 3. Survival curve using criterion II (defined as an intraocular pressure reduction of 20% or more of the pretreatment intraocular pressure and no additional medications and no additional laser or glaucoma surgery) of *all patients* in the argon laser trabeculoplasty (ALT) and selective laser trabeculoplasty (SLT) groups. Cum. = cumulative; n = number of all eyes examined in each group at each time point.



Time (months)	0	6	12	18	24	30	36	42	48	54	60
SLT (n)	28	25	22	21	20	18	17	15	14	14	14
ALT (n)	128	96	91	84	73	65	58	49	37	36	33

Figure 5. Survival curve using criterion II (defined as an intraocular pressure reduction of 20% or more of the pretreatment intraocular pressure and no additional medications and no additional laser or glaucoma surgery) of patients with *no prior* argon laser trabeculoplasty (ALT) in the ALT and selective laser trabeculoplasty (SLT) groups. Cum. = cumulative; n = number of all eyes with no prior ALT examined in each group at each time point.

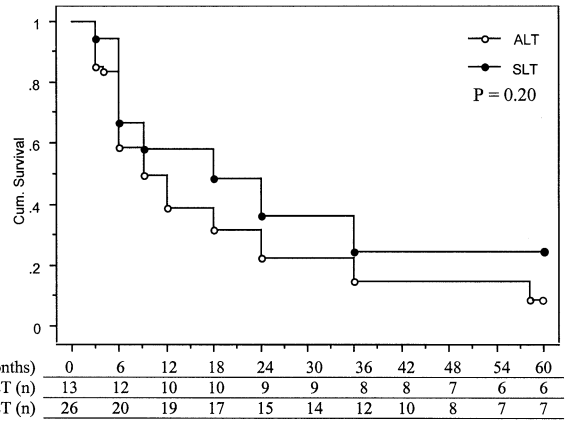


Time (months)	0	6	12	18	24	30	36	42	48	54	60
SLT (n)	13	12	10	10	9	9	8	8	7	6	6
ALT (n)	26	20	19	17	15	14	12	10	8	7	7

Figure 6. Survival curve using criterion I (defined as a decrease in intraocular pressure of 3 mmHg or more and no additional medications and no additional laser or glaucoma surgery) of patients *with prior* argon laser trabeculoplasty (ALT) in the ALT and selective laser trabeculoplasty (SLT) groups. Cum. = cumulative; n = number of all eyes with prior ALT examined in each group at each time point.

by using a nanosecond pulse duration and selectively targets pigmented TM cells, it minimizes coagulation and collateral damage to the nonpigmented cells or adjacent structures.[25] This difference has led the proponents of SLT to postulate that SLT may have an increased long-term success rate as compared with ALT. Therefore, we compared the long-term success rate, reduction of IOP, and medical dependency of OAG patients who underwent SLT versus ALT.

Other authors have studied the efficacy of SLT and have shown it to reduce the IOP at total follow-up times between 6 weeks and 12 months (Table 4; Klin Monatsbl Augenheilkd 213:12, 1998).[9–11,29] Only 1 study compared SLT with ALT and found similar IOP reductions. Although our study has a similar number of eyes treated by SLT as other studies, our study has a much longer total follow-up period. The results of our study demonstrate that ALT and SLT were similarly effective in decreasing the IOP at each follow-up time compared with the pretreatment IOP. These reductions are comparable with the results of other studies at their respective follow-up times.



Time (months)	0	6	12	18	24	30	36	42	48	54	60
SLT (n)	13	12	10	10	9	9	8	8	7	6	6
ALT (n)	26	20	19	17	15	14	12	10	8	7	7

Figure 7. Survival curve using criterion II (defined as an intraocular pressure reduction of 20% or more of the pretreatment intraocular pressure and no additional medications and no additional laser or glaucoma surgery) of patients *with prior* argon laser trabeculoplasty (ALT) in the ALT and selective laser trabeculoplasty (SLT) groups. Cum. = cumulative; n = number of all eyes with prior ALT examined in each group at each time point.

Damji et al[11] compared 18 cases of ALT with 18 cases of SLT for a follow-up period of 6 months. In their study, no difference in IOP was observed between the 2 groups before surgery or at any follow-up period. The study concluded that SLT was equivalent to ALT in lowering IOP. When our success criteria of a 3-mmHg or more reduction in IOP and no additional medication is applied to their patients, we calculated SLT patients to have a 50% success rate at 6 months after surgery and ALT patients to have a 39% success rate at 6 months after surgery. Latina et al[9] studied 101 patients (45 patients on maximum antiglaucoma medication and 56 patients who had a previous failed ALT) treated by SLT. They found a 70% success rate in those patients according to the criteria of a 3-mmHg or more reduction in IOP and no additional medication at 6 months after treatment. Our study, using the same criteria, confirms these results but with more patients and longer follow-up time.

Table 2 shows that the percent IOP reduction improves slightly with time. We postulate that this is because patients dropped out as failures and only successes remain in the calculation. Our study found similar success rates as defined by criterion I and criterion II. The results demonstrate that 32% of patients treated by SLT and 21% of patients treated by ALT were considered successes according to criterion I at the end of the 5-year follow-up. Using criteria II, 31% of the SLT patients and 13% of the ALT patients were successes at 5 years. Although there was a trend of SLT having a better success rate than ALT, it was not statistically significant. Therefore, in eyes with POAG on maximally tolerated medical therapy, SLT was found to be as effective as ALT in lowering IOP over a 5-year period. However, long-term data also reveal that many of the patients treated with SLT and ALT required further glaucoma medical or surgical intervention.

There were other similarities between ALT and SLT as we compared the success rates (using criterion I and criterion II) between African American and white persons after either ALT or SLT treatment. No statistically significant difference was found between races when analyzing the long-term success rate ($P = 0.42$ by criterion I, $P = 0.21$ by criterion II).

Several authors have demonstrated decreased efficacy with repeat ALT treatment.[26–28] Our study included primary ALT and SLT treatments as well as ALT and SLT after having previous ALT treatment. Our study did not include any patients who had more than 1 SLT treatment. Our comparisons of repeat ALT treatment and SLT after ALT demonstrate that there is no difference in long-term success between these 2 sets. Although there was a trend for SLT to have better long-term success, the groups of previous and no previous ALT treatment subgroups had statistically similar success rates.

This study was limited by the small number of patients in

Table 4. Comparison of Other Selective Laser Trabeculoplasty Studies

Study	Selective Laser Trabeculoplasty	Argon Laser Trabeculoplasty	Total Follow-up	Percent Success at Time Periods
Latina et al, 1998*	53 eyes		6 months	No prior ALT: 4.6-mmHg (18.7%) IOP reduction @ 6 mos Prior ALT: 2.1-mmHg (9.7%) IOP reduction @ 6 mos
Kaulen et al, 1998†	224 eyes		10 months	6.0-mmHg (23%) IOP reduction @ 10 mos
Lanzetta et al, 1999‡	8 eyes		6 weeks	5.2-mmHg (39.9%) IOP reduction @ 6 mos
Damji et al, 1999§	18 eyes	18 eyes	6 months	SLT: 4.8-mmHg (21%) IOP reduction @ 6 mos ALT: 4.7-mmHg (21%) IOP reduction @ 6 mos
Gracner, 2001‖	50 eyes		12 months	No prior ALT: 4.6-mmHg (18.7%) IOP reduction @ 6 mos 92% @ 3 mos, 88% @ 6 mos, 86% @ 12 mos
Melamed et al, 2003¶	45 eyes		18 months	7.7-mmHg (30%) IOP reduction @ 18 mos

ALT = argon laser trabeculoplasty; IOP = intraocular pressure; SLT = selective laser trabeculoplasty.
*Latina MA, Sibayan SA, Shin DH, et al. Q-switched 532-nm Nd:YAG laser trabeculoplasty (selective laser trabeculoplasty): a multicenter, pilot, clinical study. Ophthalmology 1998;105:2082–8; discussion 2089–90.
†Kaulen P, Richter A, Wiemer C. Druckverlauf in den ersten 20 Monaten nach selektiver Lasertrabekuloplastik. Klin Monatsbl Augenheilkd 1998;213:12.
‡Lanzetta P, Menchini U, Virgili G. Immediate intraocular pressure response to selective laser trabeculoplasty. Br J Ophthalmol 1999;83:29–32.
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‖Gracner T. Intraocular pressure reduction after selective laser trabeculoplasty in primary open angle glaucoma. Coll Antropol 2001;25(suppl):111–5.
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the SLT treatment group and by its retrospective study design. One issue to consider is selection bias. Patients underwent either SLT or ALT based on the availability of the lasers. There was no selection for laser treatment based on severity of glaucoma. This is supported by the statistically similar pretreatment IOP and medications. Because SLT does not cause coagulative damage, it is proposed that SLT is effective in repeat treatments on the same eye.[25] Further studies involving more than 1 SLT treatment on the same eye are needed to determine this. Another limitation of our study is the result of our methodology. We treated the nasal 180° of the TM by SLT and the inferior or previously untreated 180° of the TM by ALT. Other long-term ALT studies compared 360° treatment to 360° treatment. Perhaps comparing 360° ALT treatment with 360° SLT treatment would have demonstrated different results.

In summary, SLT seems to be as effective as ALT in patients with OAG on maximally tolerated medical therapy in long-term success rates. However, long-term data reveal that many of the glaucoma patients treated with SLT or ALT required further medical or surgical intervention. We look forward to a long-term prospective, randomized clinical trial directly comparing ALT and SLT, with a larger SLT sample size. Additionally, whether SLT has better long-term success than ALT in repeat laser trabeculoplasty treatments remains unclear.

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