

Efficacy and safety of the VISULAS green with option selective laser trabeculoplasty in pseudoexfoliative syndrome glaucoma and pseudoexfoliative syndrome ocular hypertension

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Received: 2025-05-21 Accepted: 2025-08-15

Abstract

• **AIM:** To assess the effectiveness and safety of VISULAS[®] green laser selective laser trabeculoplasty (SLT) in lowering intraocular pressure (IOP) in patients with pseudoexfoliative syndrome glaucoma (PEXG) and pseudoexfoliative syndrome ocular hypertension (PEXS-OHT).

• **METHODS:** This prospective, single-center, interventional study included 20 eyes from 20 patients diagnosed with PEXG or PEXS-OHT. Patients underwent 180° SLT using the VISULAS[®] green laser, a diode-pumped, frequency-doubled Nd:YVO4 laser with a 532 nm wavelength. IOP was measured at baseline and post-treatment at 1, 3, and 6mo. Medications regimen was stable through the study. Primary outcomes included mean IOP reduction, while secondary outcomes assessed visual and structural parameters, and safety.

• **RESULTS:** The mean age of participants was 72.2±6.6y, with 65% of the eyes being left eyes and 35% right eyes. At baseline, the mean IOP was 22.9±2.9 mm Hg. A significant reduction in IOP was observed at all follow-up intervals: 18.5±3.1 mm Hg at 1mo (18.8% reduction, $P=0.001$), 19.0±4.2 mm Hg at 3mo (16.7% reduction, $P=0.002$), and 18.2±4.5 mm Hg at 6mo (19.8% reduction, $P=0.001$). Subgroup analysis showed greater IOP reduction in patients with Shaffer grade 4 angles, phakic eyes, and those with PEXS-OHT compared to PEXG. No significant changes were detected in visual acuity, visual field index, mean deviation, or retinal nerve fiber layer thickness. At 1h post-procedure, 20% of eyes showed an IOP spike >5 mm Hg that resolved without intervention except for one patient.

• **CONCLUSION:** SLT with the VISULAS[®] green laser is an effective and safe treatment for PEXG and PEXS-OHT, achieving significant IOP reduction without increasing medication burden or causing severe complications. These findings suggest its potential as an alternative or adjunct therapy in managing pseudoexfoliative glaucoma.

• **KEYWORDS:** laser trabeculoplasty; glaucoma; exfoliative; ocular hypertension; laser therapy; intraocular pressure

DOI:10.18240/ijo.2026.04.09

Citation: Casas-Llera P, García-Gil R, del Valle-Najarro Y, Lauzirika G, Fernández-Buenaga R. Efficacy and safety of the VISULAS green with option selective laser trabeculoplasty in pseudoexfoliative syndrome glaucoma and pseudoexfoliative syndrome ocular hypertension. *Int J Ophthalmol* 2026;19(4):701-708

INTRODUCTION

Glaucoma is a chronic, progressive optic neuropathy that, if not effectively managed, can lead to peripheral and, eventually, central vision loss. It is the leading cause of irreversible blindness worldwide. Currently, an estimated 76 million people live with glaucoma, and this number is projected to rise to 112 million by 2040^[1].

Among the various types of glaucoma, pseudoexfoliation syndrome glaucoma (PEXG) is the most common identifiable cause of secondary open angle glaucoma. It occurs due to the accumulation of abnormal extracellular matrix material in the trabecular meshwork (TM), leading to increased intraocular pressure (IOP)^[2]. Pseudoexfoliation syndrome (PEX) is a prevalent condition, affecting about 10% to 20% of individuals over the age of 60 across diverse global populations^[3].

Patients with PEXG typically experience elevated IOP, greater fluctuations in IOP levels, and more severe glaucomatous damage compared to those with primary open angle glaucoma (POAG). Additionally, PEX has been recognized as an independent risk factor for the development of glaucoma

in individuals with ocular hypertension, highlighting the importance of medical treatment in these cases^[4]. A study of patients with unilateral PEX found that 32% of the affected eyes and 38% of the contralateral eyes developed bilateral PEXG within seven years^[5].

Upon diagnosis of PEXG, treatment typically involves a combination of therapies, along with regular monitoring of IOP and frequent eye exams. Managing IOP in PEXG can be more challenging than in POAG, with patients often requiring combination therapy to achieve effective IOP control. Surgical intervention is more commonly necessary in advanced PEXG cases, as patients tend to have a poorer response to medical treatment. Achieving target IOP with monotherapy is often difficult, and medication adherence issues are frequent, which can result in significant vision loss if not addressed properly^[2,6]. In cases where medical therapy is insufficient, trabeculectomy with mitomycin-C has shown better IOP control than maximal medical therapy in advanced disease. However, PEXG patients are more prone to postoperative complications, such as inflammation, fibrinous reactions, and posterior synechiae^[2].

Selective laser trabeculoplasty (SLT), first introduced by Park *et al*^[7] in 1995, provides an alternative treatment for open-angle glaucoma. This technique uses a Q-switched, frequency-doubled laser with a 532 nm wavelength and a pulse duration of 3ns, which selectively targets pigmented cells in the TM while sparing non-pigmented cells^[8]. Over the years, SLT has become a widely accepted therapy, often used early in the management of glaucoma^[9]. Research shows that SLT can reduce IOP by 11% to 40% across various types of glaucoma, with effects ranging from short to intermediate-term^[10]. Numerous studies have highlighted the effectiveness of SLT as an additional treatment option for lowering IOP and reducing the reliance on medication in open angle glaucoma. There is also strong evidence suggesting that SLT can serve as an effective first-line treatment for both open angle glaucoma and ocular hypertension (OHT)^[11-15]. While the exact mechanisms behind SLT's ability to lower IOP are still not fully understood, it is believed that cytokine secretion, matrix metalloproteinase induction, enhanced cell division, and macrophage recruitment may improve trabecular outflow and contribute to lowering IOP.

The VISULAS[®] green laser (Carl Zeiss Meditec AG, Jena, Germany) represents a recent introduction in SLT technology, utilizing a frequency-doubled diode-pumped 532 nm Nd:YVO4 laser. This laser combines both retinal and glaucoma laser functions, allowing for selective treatment of glaucoma. Unlike traditional SLT lasers, the VISULAS[®] green laser usually does not produce visible cavitation bubbles during treatment and removes the need for the titration process, reducing treatment time and minimizing unnecessary energy

exposure to the eye. Additionally, this laser employs a 400 µm laser spot, achieved by sequentially applying 52 square spots, each measuring 50 µm along the edge. This ensures a uniform distribution of energy. The fluence delivered by the VISULAS[®] green laser is comparable to that of traditional SLT lasers, maintaining effective treatment while sparing non-pigmented structures^[16].

The aim of the current study was to assess the efficacy and safety of the VISULAS[®] green laser with SLT in patients with PEXG and pseudoexfoliative syndrome ocular hypertension (PEXS-OHT).

PARTICIPANTS AND METHODS

Ethical Approval This prospective, single-center, interventional study aims to evaluate the efficacy and safety of the VISULAS[®] green laser with SLT in patients with PEXG and PEXS-OHT. The study was approved (PXG-SLT FCO; 2023.063) by the Ethical Committee of Cantabria (Comité de ética de la investigación con medicamentos de Cantabria; Spain). Written informed consent was obtained from all study participants, and the study was carried out in accordance with the principles of Declaration of Helsinki. The study was conducted from June 2023 to July 2024.

A total of 20 eyes from 20 consecutive patients aged 22y or older, diagnosed with either PEXG or PEXS-OHT, were enrolled. These patients had not reached their target IOP or had experienced repeated IOP fluctuations.

The inclusion criteria were: adults (22y or older) with PEXG and PEXS-OHT and IOP \geq 17 mm Hg, with or without medication and anterior chamber angle Shaffer grades 3 or 4. Exclusion criteria were: significant corneal disease or pathology that interferes with laser light transmission or corneal stability; severe cataracts, vitreous hemorrhage, or other conditions affecting ocular media transparency; narrow palpebral fissures or deep orbits; prior or planned ocular surgeries within 3mo (except for cataract surgery performed at least 3mo prior); a history of uveitis, congenital glaucoma, significant diabetic retinopathy, or neurological disorders preventing compliance; pregnant or lactating women or those not using medically approved contraception.

Patients were to continue their preoperative glaucoma medications regimen until end of the clinical investigation. The change in glaucoma medications due to intolerance or insufficient IOP control is reported as well as repetition of the SLT procedure, which was permitted starting from 3mo after the initial procedure. Additional glaucoma surgery is categorized as failure and results are excluded after the additional glaucoma surgery.

Preoperative Evaluation Eligible patients underwent a thorough preoperative examination, which involved medical history including number and classes of IOP-lowering

medications, baseline ocular examination, and the assessment of best corrected visual acuity (VA) using a Snellen chart. IOP was measured using a calibrated Goldmann applanation tonometer (GAT). IOP measurements were taken for each patient within a consistent two-hour time window during each study visit, while the patient was seated. A complete baseline ocular exam also included measurements of pachymetry, slit-lamp examination, and dilated fundus examination. Gonioscopy was conducted using a gonioscope on an undilated pupil, with the anterior chamber angle graded from 0 to 4 based on the Shaffer classification^[17]. Automated Humphrey perimetry was performed using the Swedish Interactive Threshold Algorithm (SITA) standard 24-2 program (Humphrey Field Analyzer; Carl Zeiss Meditec Inc., Jena, Germany). This baseline examination occurred within 60d before treatment, and informed consent was obtained at least 24h before the procedure.

Treatment Procedure SLT was performed with topical anesthesia. Laser treatment was performed using the VISULAS[®] green. The VISULAS[®] green is a dual-purpose retinal and glaucoma laser system, utilizing a diode-pumped, frequency-doubled Nd:YVO₄ laser with a 532 nm wavelength. It can be used in photocoagulation mode for various retinal conditions or in SLT mode for glaucoma treatment. Approximately 50 non-overlapping 400 μm laser spots were applied to 180° of the temporal TM under direct visualization using a Latina SLT gonioscope (Ocular Instruments, Inc., USA) placed on the eye with methylcellulose 1%. The laser energy level was adjusted based on the pigmentation of the TM, starting at 30-40 μJ for minimal pigmentation, 20-30 μJ for mild to moderate pigmentation, and 10-20 μJ for marked to intense pigmentation. PEXS and PEXG is a non-cleared indication from ZEISS.

Postoperative Care and Follow-Up Patients continued their preoperative glaucoma medications throughout the study unless intolerable, in which case the investigator would adjust the medication. IOP was measured 1-hour post-laser to record any IOP spikes. Neither prophylactic IOP lowering medications nor steroid or non-steroidal anti-inflammatory drugs (NSAID) therapy was administered. In cases where an IOP spike of more than 5 mm Hg occurred, a single drop of brimonidine was applied. Patients were assessed at 1d, 1, 3, and 6mo postoperatively. During each follow-up visit, corrected distance VA (CDVA) and IOP were measured, and a slit-lamp examination was conducted to assess conjunctival injection, anterior chamber cell and flare, as well as the condition of the cornea, lens, and iris. Adverse events related to the device or procedure were monitored throughout the study and beyond until resolved or stabilized.

Endpoints Primary efficacy endpoint: The mean absolute

change in IOP from baseline to 1, 3, and 6mo. Secondary efficacy endpoints: The rate of patients achieving IOP reductions of >0 to <10%, 10% to <20%, and ≥20% from baseline at 1 and 3mo. Safety parameters were: postoperative IOP at 1h and 1d; rate of intraoperative adverse device effects; rate of adverse device effects and device deficiencies during the entire study.

For patients with PEXG, failure was defined as the need for additional glaucoma surgery. This definition was not applied to PEXS-OHT patients, in whom SLT was performed as a prophylactic intervention.

Statistical Analysis Statistical analysis was performed using SPSS version 28 (IBM, Armonk, NY, USA). Descriptive statistics, including mean±standard deviation (SD), were used to summarize changes in IOP from the preoperative visit to 6mo post-treatment. To compare baseline values with follow-up measurements, the Wilcoxon signed-rank test was applied. A *P*-value of <0.05 was considered indicative of statistical significance.

RESULTS

A total of 20 eyes from 20 participants were included in the study. The mean age of participants was 72.2±6.6y, with 65% of the eyes being left eyes and 35% right eyes. Baseline IOP was 22.9±2.9 mm Hg on 1.1±1.0 glaucoma medications (one eye required the addition of 1 medication). At baseline, 10 eyes had PEXS-OHT (7 eyes were medications naïve and 3 on medications preoperatively; total mean of 0.4 medications), and the other 10 eyes had PEXG (all 10 eyes were already on medications preoperatively; total mean of 1.8 medications). Eyes with Shaffer grade 3 were 45% and eyes with Shaffer grade 4 were 55%. Demographics, baseline characteristics and glaucoma preoperative assessments were summarized in Table 1.

IOP Outcomes A significant reduction in IOP was observed at all follow-up time points as shown in Table 2 and Figure 1. At 1-month post-treatment, the mean IOP decreased to 18.5±3.1 mm Hg, representing an 18.8% reduction from baseline (*P*=0.001). At 3 and 6mo, the mean IOP was 19.0±4.2 mm Hg representing a 16.7% reduction from baseline (*P*=0.002) and 18.2±4.5 mm Hg representing a 19.8% reduction from baseline (*P*=0.001), respectively, maintaining a significant reduction compared to baseline.

Table 3 showed the percentages of participants who achieved a ≥20%, 10%-20%, 0-10% reduction in IOP, at 1-, 3-, and 6-month.

At 1mo, 15% of patients had an IOP≤15 mm Hg, and 55% had an IOP≤18 mm Hg. At 3 and 6mo, 10% and 20% of eyes, respectively, had an IOP≤15 mm Hg. Meanwhile, 55% of eyes had an IOP≤18 mm Hg at 3mo, which increased to 75% at 6mo.

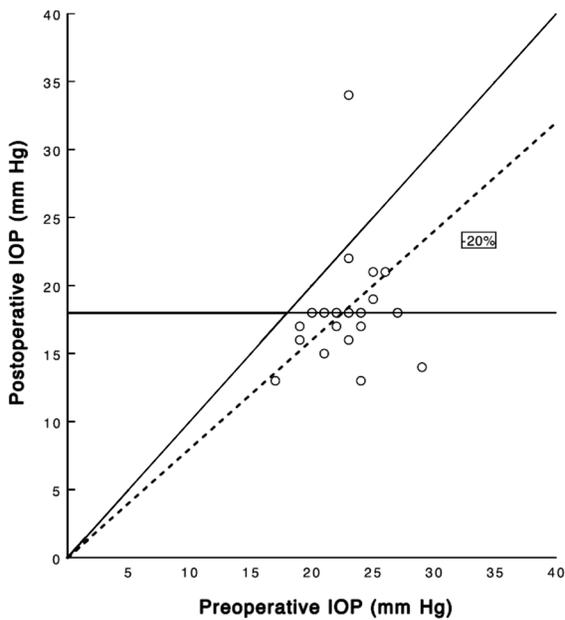


Figure 1 IOP scatterplot: each point (eye) demonstrates pre- and postoperative IOP outcomes. Points on or below the dashed line indicate eyes with $\geq 20\%$ reduction in IOP from baseline. Horizontal line represents 18 mm Hg. IOP: Intraocular pressure.

Table 1 Demographics mean \pm SD or n (%)

	mean \pm SD or n (%)
Participants	n=20
Age (y)	72.2 \pm 6.6
Gender	
Male	7 (35)
Female	13 (65)
Eyes	n=20
Laterality	
Left	13 (65)
Right	7 (35)
Lens	
Phakic	13 (65)
Pseudophakic	7 (35)
Shaffer grade	
0, 1, 2	0
3	9 (45)
4	11 (55)
Glaucoma type	
PEXS-OHT	10 (50)
PEXG	10 (50)
Glaucoma severity	
Mild	7 (35)
Moderate	3 (15)
Severe	0
Missing	10 (50)
Baseline measurements	
Central corneal thickness (μ m)	538.2 \pm 35.1
Intraocular pressure (mm Hg)	22.9 \pm 2.9
Medications (n)	1.1 \pm 1.0

SD: Standard deviation; PEXS-OHT: Pseudoexfoliative syndrome ocular hypertension; PEXG: Pseudoexfoliative syndrome glaucoma.

Protocol Deviations No change in the number of medications was noted throughout the study period except 2 PEXS-OHT eyes that had a raise of 1 medication (from 0 medication at baseline to 1 at month 6).

Two eyes in the PEXG group repeated the SLT procedure; one at 3rd month and the other at 5th month, as IOP was above the target and further reduction was required.

Visual and Structural Outcomes There were no significant changes in VA, visual field index (VFI), mean deviation (MD), or retinal nerve fiber layer (RNFL) thickness throughout the study period. Similarly, endothelial cell density (ECD) and coefficient of variation (CV) of cell size showed no significant changes at 3mo ($P=0.097$ and $P=0.618$, respectively).

Subgroup Analysis Significant reductions were observed in specific subgroups over time. Subgroup analyses based on Shaffer grade, lens status, glaucoma type, and other factors were shown in Table 4. Significant reductions were observed in patients with Shaffer grade 4 ($P=0.004$ at 3 and 6mo), phakic and pseudophakic patients ($P\leq 0.025$), and PEXS-OHT ($P=0.006$). Patients receiving >1543 mJ/cm² SLT energy units ($P=0.006$), those with MD >-6 ($P\leq 0.011$), and ECD ≤ 2130 ($P=0.006$) also showed significant decreases.

Safety Outcomes No significant adverse events occurred in the study group. At 1-hour post-procedure, 20% of eyes showed an IOP spike >5 mm Hg that resolved within the first 24h in all cases.

Failure Analysis One eye in the PEXG group (10%) was classified as failure, defined by the need for additional minimally invasive glaucoma surgery (MIGS) at month 5. This patient had the following IOP measurements: 23 mm Hg preoperatively, 29 mm Hg at 1h postoperatively, 18 mm Hg at 1d, 25 mm Hg at 1mo, 20 mm Hg at 2mo, and 34 mm Hg at 3mo. The IOP elevation became sustained, necessitating additional MIGS at month 4. This situation falls within what is considered normal in PEXG, a type of glaucoma known for its high IOP variability and slow progression. We do not believe this IOP dysregulation is related to the SLT treatment administered.

DISCUSSION

While the effectiveness of SLT in POAG is well established, limited research has explored its efficacy in other glaucoma subtypes, such as pigmentary and pseudoexfoliative glaucoma. This prospective study demonstrates that 180°-SLT using the VISULAS[®] green laser is an effective and safe intervention for reducing IOP in patients with PEXG and PEXS-OHT.

Our results demonstrated a significant reduction in IOP at all follow-up intervals, with decreases of 18.8% at 1mo, 16.7% at 3mo, and 19.8% at 6mo. These findings are consistent with previous studies confirming the efficacy of SLT in PEXG. Shazly *et al*^[18] reported greater IOP reductions, with a 26.3%

Table 2 Outcomes at available timepoints

mean±SD

Outcomes	Baseline	Month 1	Month 3	Month 6
IOP (mm Hg)	22.9±2.9	18.5±3.1 (<i>P</i> <0.001)	19.0±4.2 (<i>P</i> =0.002)	18.2±4.5 (<i>P</i> =0.001)
Medications (<i>n</i>)	1.1±1.0	NA	1.1±1.0	1.2±0.9 (<i>P</i> =0.346)
VA (logMAR)	0.03±0.05	0.03±0.04 (<i>P</i> =0.363)	0.02±0.05 (<i>P</i> =0.363)	0.02±0.04 (<i>P</i> =0.289)
VFI	92.9±10.0	NA	91.6±11.3 (<i>P</i> =0.133)	91.9±11.4 (<i>P</i> =0.106)
MD	-3.38±4.55	NA	-3.73±4.80 (<i>P</i> =0.430)	-3.62±4.84 (<i>P</i> =0.409)
PSD	3.47±3.30	NA	3.86±3.55 (<i>P</i> =0.312)	3.59±3.31 (<i>P</i> =0.852)
RNFL	77.1±10.8	NA	78.4±12.8 (<i>P</i> =0.140)	76.5±10.6 (<i>P</i> =0.470)
ECD	2196.2±363.2	NA	2160.8±342.7 (<i>P</i> =0.097)	NA
CV	35.8±6.4	NA	35.3±7.4 (<i>P</i> =0.618)	NA
HEX	51.7±8.4	NA	54.7±8.1 (<i>P</i> =0.094)	NA

P values calculated using Wilcoxon signed-rank test. SD: Standard deviation; IOP: Intraocular pressure; VA: Visual acuity; VFI: Visual field index; MD: Mean deviation; PSD: Pattern standard deviation; RNFL: Retinal nerve fiber layer; ECD: Endothelial cell density; CV: Coefficient of variation of cell size; HEX: Hexagonality; NA: Not available.

Table 3 Percentage outcomes at available timepoints

Parameters	Baseline	Month 1	Month 3	Month 6
Mean IOP reduction from baseline	-	-18.8%	-16.7%	-19.8%
Patients with >0-10% IOP reduction	-	3 (15)	2 (10)	2 (10)
Patients with >10%-20% IOP reduction	-	6 (30)	8 (40)	6 (30)
Patients with ≥20% IOP reduction	-	10 (50)	9 (45)	11 (55)
Eyes with IOP≤15 mm Hg	0	3 (15)	2 (10)	4 (20)
Eyes with IOP≤18 mm Hg	1 (5)	11 (55)	11 (55)	15 (75)

IOP: Intraocular pressure.

decrease at 3mo in PEXG eyes; similarly, Ayala and Chen^[19] found a 25% reduction in baseline IOP at 1mo in PEXG eyes; Goldenfeld *et al*^[20] study in uncontrolled PEXG showed SLT brought a 31.5% reduction in baseline IOP (*P*<0.001); Miraftebi *et al*^[21] found a 30% IOP reduction in PEX eyes. While our study showed slightly lower IOP reductions, the overall trend aligns with these previous reports, further reinforcing SLT as an effective intervention for IOP control in both PEXG and PEXS-OHT. Interestingly, the 4 studies cited above where SLT was performed in PEX eyes had a preoperative IOP slightly higher than in our study, but showed that final postoperative IOP was about within the same 18 mm Hg range at the 3- to 6-month follow up (18.8 mm Hg in Shazly *et al*^[18] after 3mo; 18.6 mm Hg in Ayala and Chen^[19] at 1mo; 17.8 mm Hg in Goldenfeld *et al*^[20] after 12mo; 17.9 mm Hg in Miraftebi *et al*^[21] after 6mo), in line with the final IOP in our study at 18.2 mm Hg at the 6-month visit. This suggests that the higher baseline IOP leads to higher IOP reductions; however, SLT performed in uncontrolled PEX eyes may lead to similar postoperative IOP values around 18 mm Hg. This observation must be validated with a larger cohort and a more comprehensive literature Meta-analysis. Table 5^[18-19,22-23] provided a comparison of our results with those of previous studies that utilized 180° SLT.

Argon laser trabeculoplasty (ALT) has been established as

an effective method for lowering IOP in various types of glaucoma. However, ALT induces significant thermal damage to the TM by causing coagulative tissue shrinkage at the treatment site, which in turn opens adjacent spaces to enhance aqueous outflow. In contrast, SLT offers a safer alternative with comparable IOP-lowering efficacy. Unlike ALT, SLT delivers laser pulses shorter than the thermal relaxation time of the target structures, confining heat energy within pigmented TM cells without causing collateral thermal damage to surroundings^[24-26].

A clinical study comparing SLT and ALT in 76 eyes from 60 PEX patients further supports SLT's comparable efficacy. Of these, 45 eyes received SLT, while 31 eyes underwent ALT. After 6mo of follow-up in 63 eyes, both treatments achieved similar IOP reductions, with a mean IOP of 18.2±4.77 mm Hg in the ALT group and 16.2±4.77 mm Hg in the SLT group (*P*=0.12). Additionally, no significant differences were observed in medication use or adverse events^[27].

In our study, the higher baseline IOP observed in the PEXS-OHT group (24.2±1.9 mm Hg) compared to the PEXG group (21.5±3.1 mm Hg) can be attributed to the fact that many PEXG eyes were already under medical treatment prior to SLT, which may have contributed to their lower starting IOP. In contrast, PEXS-OHT eyes were largely treatment-naïve. However, SLT lowered IOP effectively in both groups.

Table 4 IOP outcomes at baseline and at 3, 6mo, split by groups

Parameters	n	Baseline	Month 3	Month 6
mean±SD, mm Hg				
CA (Shaffer)				
Grade 3	9	24.3±2.7	20.1±5.5 (P=0.123) ^b	19.0±6.1 (P=0.086) ^b
Grade 4	11	21.6±2.5	18.0±2.8 (P=0.004) ^{b,c}	17.5±2.6 (P=0.004) ^{b,c}
<i>P</i> ^a		0.036 ^c	0.319	0.494
Lens				
Phakic	13	24.2±2.3	19.9±4.7 (P=0.025) ^{b,c}	18.9±5.1 (P=0.019) ^{b,c}
Pseudophakic	7	20.4±2.2	17.1±2.7 (P=0.021) ^{b,c}	16.7±2.8 (P=0.022) ^{b,c}
<i>P</i> ^a		0.004 ^c	0.111	0.226
Glaucoma type				
PEXS-OHT	10	24.2±1.9	19.0±2.4 (P=0.006) ^{b,c}	17.6±2.8 (P=0.006) ^{b,c}
PEXG	10	21.5±3.1	18.9±5.7 (P=0.082) ^b	18.7±5.8 (P=0.083) ^b
<i>P</i> ^a		0.035 ^c	0.960	0.597
Medications preop. (0 vs 1+)				
No medications	7	24.4±2.1	19.6±1.5 (P=0.021) ^{b,c}	17.7±2.5 (P=0.022) ^{b,c}
1+medications	13	22.0±2.9	18.6±5.2 (P=0.025) ^{b,c}	18.4±5.3 (P=0.023) ^{b,c}
<i>P</i> ^a		0.051	0.547	0.706
SLT energy				
≤1543	10	23.7±2.3	20.0±5.5 (P=0.082) ^b	19.6±5.5 (P=0.074) ^b
>1543	10	22.0±3.3	17.9±2.4 (P=0.006) ^{b,c}	16.7±2.5 (P=0.006) ^{b,c}
<i>P</i> ^a		0.198	0.287	0.157
MD preop.				
≤-6	5	20.2±1.3	17.0±1.0 (P=0.054) ^b	17.2±0.8 (P=0.057) ^b
>-6	15	23.7±2.7	19.6±4.7 (P=0.011) ^{b,c}	18.5±5.1 (P=0.009) ^{b,c}
<i>P</i> ^a		0.002 ^c	0.062	0.371
ECD preop.				
≤2130	10	22.3±2.9	17.8±3.0 (P=0.006) ^{b,c}	17.1±3.0 (P=0.006) ^{b,c}
>2130	10	23.4±2.9	20.1±5.1 (P=0.079) ^b	19.2±5.5 (P=0.065) ^b
<i>P</i> ^a		0.409	0.240	0.308

^a*P* values between groups calculated by Welch test; ^b*P* values between baseline and postop. timepoint calculated by Wilcoxon signed-rank test; ^cStatistical significance (P<0.05). IOP: Intraocular pressure; CA: Chamber angle; PEXS-OHT: Pseudoexfoliative syndrome ocular hypertension; PEXG: Pseudoexfoliative syndrome glaucoma; SLT: Selective laser trabeculoplasty; MD: Mean deviation; ECD: Endothelial cell density.

Table 5 Comparison of our results with those of previous studies that utilized 180° SLT

Study/references	SLT type	Patient details	Basal IOP	1mo IOP	3mo IOP	6-9mo IOP
Current study	180° SLT	20 patients, PEX, IOP>target	22.9±2.9	18.5±3.1	18.95±4.25	17.05±2.70
Shazly <i>et al</i> ^[18]	180° SLT	13 patients (18 eyes), PEXG naïve	25.5±3.4	NR	18.8±3.0	18.1±3.3
Ayala and Chen ^[19]	90° SLT	30 PEXG patients, SLT adjuvant	24.80±3.03	18.61±3.03	NR	NR
Gracner ^[22]	180° SLT	10 PEXG, SLT adjuvant	23.60±5.70	18.40±6.36	18.30±5.48	17.35±4.33
Kara <i>et al</i> ^[23]	180° SLT	37 PEXG patients, SLT adjuvant	22.4±2.9	16.1±2.2	16.2±2.4	16.7±2.3

SLT: Selective laser trabeculoplasty; IOP: Intraocular pressure; PEX: Pseudoexfoliation syndrome; PEXG: Pseudoexfoliative syndrome glaucoma; NR: Not reported.

Despite the significant IOP reduction, no significant changes were observed in medication use throughout the study period except in 2 eyes (1 more medication in each). The impact of SLT on reducing medication use varies across studies. While some research indicates no significant change in the number of medications after SLT, others have reported a notable reduction in medication use following the procedure^[23,28-30].

While the crystalline lens is considered a major source of pseudoexfoliative material, recent evidence suggests that pseudoexfoliation is a systemic process affecting multiple ocular structures beyond the lens, such as the TM, iris, and ciliary body. Studies have shown that pseudoexfoliative material may continue to be produced and deposited even after cataract surgery, with documented accumulation on

intraocular lenses years postoperatively^[31-32]. As such, the pseudoexfoliative process remains active in pseudophakic eyes and can still contribute to IOP elevation and disease progression. Therefore, including both phakic and pseudophakic eyes in our study population, whether diagnosed with PEXS-OHT or PEXG, ensures a more representative assessment of SLT outcomes across the clinical spectrum of pseudoexfoliative disease.

Patients with Shaffer grade 4 angles, phakic eyes, and OHT experienced greater IOP reductions, indicating that anatomical and physiological factors play a role in treatment response. Additionally, higher SLT energy levels were linked to greater IOP reduction, reinforcing the importance of customizing treatment parameters based on individual patient characteristics.

Lee *et al*^[33] investigated predictors of SLT success and failure in 111 eyes with normal-tension glaucoma (NTG) and POAG. Their analysis found that higher baseline IOP, use of carbonic anhydrase inhibitors, thinner retinal nerve fiber layer, and lower IOP on day 1 post-SLT were strong indicators of treatment success. Martow *et al*^[34] reported that pre-treatment IOP was the only significant predictor of SLT success, emphasizing that higher baseline IOP is associated with better treatment outcomes as noted in this discussion above when reporting the results of SLT studies in PEX eyes in the scientific literature.

The VISULAS[®] green laser demonstrated a favorable safety profile, with no severe adverse events including uveitis, choroidal effusion, anterior synechiae, corneal edema, or cystoid macular edema, observed in our cohort. These complications, though infrequent, have been reported in association with SLT^[30]. Transient IOP spikes (>5 mm Hg), a commonly observed side effect following SLT, occurred in 20% of our cases at 1h post-procedure. Interestingly, none of the patients experienced an IOP spike greater than 10 mm Hg. Reports on IOP spike incidence vary across studies, ranging from 0 to 62%^[30]. Significant IOP spikes requiring surgery after SLT are extremely rare with only few cases in the literature reporting high IOP that persisted for weeks after the procedure^[35-36].

This study has several limitations that should be considered when interpreting the findings. The relatively short follow-up period of 6mo is a key limitation, as previous studies have suggested that the IOP-lowering effect of SLT may diminish over time, particularly in PEXG patients^[21,37]. As a result, long-term efficacy, durability of IOP control, and potential late complications could not be assessed. Additionally, the small sample size limits the generalizability of the findings, as larger studies may provide more robust conclusions regarding predictors of success and treatment durability. Another limitation is the lack of a control group, preventing direct

comparisons between SLT and other treatment modalities. Future research should focus on longer follow-up periods, larger patient cohorts, and comparative studies to further establish the long-term efficacy, safety, and optimal patient selection criteria for SLT in PEXG and PEXS-OHT. Additionally, there is a need for further studies applying the 360° SLT treatment.

In conclusion, this study demonstrates that 180° SLT using the VISULAS[®] green laser is a safe and effective treatment for PEXG and PEXS-OHT, achieving significant IOP reduction without increasing medication burden or causing severe complications. The findings suggest that SLT can serve as a viable treatment option, particularly in patients with higher baseline IOP, wider anterior chamber angles, and ocular hypertension due to pseudoexfoliation.

ACKNOWLEDGEMENTS

Foundation: Editorial support was provided by Carl Zeiss Meditec AG.

Conflicts of Interest: Casas-Llera P is consultant to Carl Zeiss Meditec AG; García-Gil R, None; del Valle-Najarro Y, None; Lauzirika G, None; Fernández-Buenaga R, None.

REFERENCES

- 1 Stein JD, Khawaja AP, Weizer JS. Glaucoma in adults—screening, diagnosis, and management: a review. *JAMA* 2021;325(2):164.
- 2 Gillmann K, Meduri E, Niegowski LJ, *et al*. Surgical management of pseudoexfoliative glaucoma: a review of current clinical considerations and surgical outcomes. *J Glaucoma* 2021;30(3):e32-e39.
- 3 Mayro EL, Ritch R, Pasquale LR. Early-onset exfoliation syndrome: a literature synthesis. *J Glaucoma* 2021;30(4):e164-e168.
- 4 Tomczyk-Socha M, Tomczak W, Winkler-Lach W, *et al*. Pseudoexfoliation syndrome—clinical characteristics of most common cause of secondary glaucoma. *J Clin Med* 2023;12(10):3580.
- 5 Puska PM. Unilateral exfoliation syndrome: conversion to bilateral exfoliation and to glaucoma: a prospective 10-year follow-up study. *J Glaucoma* 2002;11(6):517-524.
- 6 Pose-Bazarrá S, López-Valladares MJ, López-de-Ullibarri I, *et al*. Surgical and laser interventions for pseudoexfoliation glaucoma systematic review of randomized controlled trials. *Eye (Lond)* 2021;35(6):1551-1561.
- 7 Park CH, Latina MA, Schuman JS. Developments in laser trabeculoplasty. *Ophthalmic Surg Lasers Imaging* 2000;31(4):315-322.
- 8 Chen YF. Mechanism of selective laser trabeculoplasty: a systemic review. *Int J Ophthalmol* 2024;17(5):963-968.
- 9 Sarenac T, Bečić Turkanović A, Ferme P, *et al*. A review of selective laser trabeculoplasty: “the hype is real”. *J Clin Med* 2022;11(13):3879.
- 10 Narayanaswamy A, Sood SR, Thakur S. Selective laser trabeculoplasty: an updated narrative review. *Indian J Ophthalmol* 2024;72(3):312-319.
- 11 Abe RY, Maestrini HA, Guedes GB, *et al*. Real-world data from selective laser trabeculoplasty in Brazil. *Sci Rep* 2022;12:1923.

- 12 Konstantakopoulou E, Gazzard G, Garway-Heath D, *et al.* Selective laser trabeculoplasty after medical treatment for glaucoma or ocular hypertension. *JAMA Ophthalmol* 2025;143(4):295.
- 13 Khawaja AP, Campbell JH, Kirby N, *et al.* Real-world outcomes of selective laser trabeculoplasty in the United Kingdom. *Ophthalmology* 2020;127(6):748-757.
- 14 Swain DL, Eliassi-Rad B. Five-year outcomes of selective laser trabeculoplasty: a retrospective study. *Front Med* 2023;9:1039195.
- 15 Gazzard G, Konstantakopoulou E, Garway-Heath D, *et al.* Laser in glaucoma and ocular hypertension (LiGHT) trial: six-year results of primary selective laser trabeculoplasty versus eye drops for the treatment of glaucoma and ocular hypertension. *Ophthalmology* 2023;130(2):139-151. Erratum in: *Ophthalmology* 2025;132(11):1323-1325.
- 16 Richter CU, Sauer TC. Laser trabeculoplasty for open-angle glaucoma. *Albert and Jakobiec's Principles and Practice of Ophthalmology* 2022:2529-2539.
- 17 Kanski JJ. *Clinical Ophthalmology: A Systematic Approach*. Butterworth-Heinemann, 2007.
- 18 Shazly TA, Smith J, Latina MA. Long-term safety and efficacy of selective laser trabeculoplasty as primary therapy for the treatment of pseudoexfoliation glaucoma compared with primary open-angle glaucoma. *Clin Ophthalmol* 2010;5:5-10.
- 19 Ayala M, Chen E. Comparison of selective laser trabeculoplasty (SLT) in primary open angle glaucoma and pseudoexfoliation glaucoma. *Clin Ophthalmol* 2011;5:1469-1473.
- 20 Goldenfeld M, Geyer O, Segev E, *et al.* Selective laser trabeculoplasty in uncontrolled pseudoexfoliation glaucoma. *Ophthalmic Surg Lasers Imaging* 2011;42(5):390-393.
- 21 Miraftabi A, Nilforushan N, Nassiri N, *et al.* Selective laser trabeculoplasty in patients with pseudoexfoliative glaucoma vs primary open angle glaucoma: a one-year comparative study. *Int J Ophthalmol* 2016;9(3):406-410.
- 22 Gracner T. Intraocular pressure response of capsular glaucoma and primary open-angle glaucoma to selective Nd:YAH laser trabeculoplasty: a prospective, comparative clinical trial. *Eur J Ophthalmol* 2002;12(4):287-292.
- 23 Kara N, Altan C, Yuksel K, *et al.* Comparison of the efficacy and safety of selective laser trabeculoplasty in cases with primary open-angle glaucoma and pseudoexfoliative glaucoma. *Kaohsiung J Med Scie* 2013;29(9):500-504.
- 24 Francis BA, Loewen N, Hong B, *et al.* Repeatability of selective laser trabeculoplasty for open-angle glaucoma. *BMC Ophthalmol* 2016;16(1):128.
- 25 Landers J. Selective laser trabeculoplasty: a review. *Clin Exp Ophthalmol* 2021;49(9):1102-1110.
- 26 Zhou RX, Sun Y, Chen HY, *et al.* Laser trabeculoplasty for open-angle glaucoma: a systematic review and network meta-analysis. *Am J Ophthalmol* 2021;229:301-313.
- 27 Kent SS, Hutnik CML, Birt CM, *et al.* A randomized clinical trial of selective laser trabeculoplasty versus argon laser trabeculoplasty in patients with pseudoexfoliation. *J Glaucoma* 2015;24(5):344-347.
- 28 Katz LJ, Steinmann WC, Kabir A, *et al.* Selective laser trabeculoplasty versus medical therapy as initial treatment of glaucoma: a prospective, randomized trial. *J Glaucoma* 2012;21(7):460-468.
- 29 Church B, Wassermann P. Real-world results of the Zeiss selective laser trabeculoplasty in adult South African primary open-angle glaucoma patients. *Ther Adv Ophthalmol* 2024;16:25158414241302891.
- 30 Wong MOM, Lee JWY, Choy BNK, *et al.* Systematic review and meta-analysis on the efficacy of selective laser trabeculoplasty in open-angle glaucoma. *Surv Ophthalmol* 2015;60(1):36-50.
- 31 Shouchane-Blum K, Zahavi A, Geffen N, *et al.* Long-term evaluation of pseudoexfoliation syndrome post-cataract extraction. *J Pers Med* 2023;13(5):818.
- 32 da Rocha Bastos RA, Falcao-Reis F, Melo A, *et al.* Pseudoexfoliation material on posterior chamber intraocular lenses. *Clin Ophthalmol* 2014:1475.
- 33 Lee JWY, Liu CCL, Chan JCH, *et al.* Predictors of success in selective laser trabeculoplasty for Chinese open-angle glaucoma. *J Glaucoma* 2014;23(5):321-325.
- 34 Martow E, Hutnik CML, Mao A. SLT and adjunctive medical therapy: a prediction rule analysis. *J Glaucoma* 2011;20(4):266-270.
- 35 Bettis DI, Whitehead JJ, Farhi P, *et al.* Intraocular pressure spike and corneal decompensation following selective laser trabeculoplasty in patients with exfoliation glaucoma. *J Glaucoma* 2016;25(4):e433-e437.
- 36 Harasymowycz PJ, Papamatheakis DG, Latina M, *et al.* Selective laser trabeculoplasty (SLT) complicated by intraocular pressure elevation in eyes with heavily pigmented trabecular meshworks. *Am J Ophthalmol* 2005;139(6):1110-1113.
- 37 Bovell AM, Damji KF, Hodge WG, *et al.* Long term effects on the lowering of intraocular pressure: selective laser or argon laser trabeculoplasty. *Can J Ophthalmol* 2011;46(5):408-413.