ORIGINAL ARTICLE

Outcomes of MicroPulse® Transscleral Laser Therapy Using the Revised MicroPulse P3® Delivery Device

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Abstract

Aims and background: To evaluate the safety and efficacy of MicroPulse® transscleral laser therapy (MP-TLT) using the revised MicroPulse P3® (MP3) probe compared to the original probe.

Materials and methods: A retrospective study of 122 consecutive eyes of 99 glaucoma patients who received MP-TLT with a minimum of 12 months follow-up. The primary outcome was success at 12 months, defined as final IOP <18 mm Hg and either IOP reduction of >20% or any medication reduction, without any adverse events or secondary surgical interventions (SSIs) within 12 months.

Results: Ninety-five eyes in 75 patients were treated with the original probe, and 27 eyes of 24 patients were treated with the revised probe. The mean total energy and fluence used were 113.6 joules (J) and 54.3 J/cm^2 for the original probe, and 79.9 J and 140.1 J/cm^2 for the revised probe. Subjects were mostly white with primary open-angle glaucoma and a mean age of 70.3 years. Significantly more eyes with advanced glaucoma were treated with the revised probe compared to the original probe ($p < 0.001$). At baseline, mean IOP was 23.0 ± 7.5 on 2.94 ± 1.19 medications for the original probe compared to 22.6 ± 6.9 ($p = 0.799$) on 3.15 ± 1.32 medications ($p = 0.429$) for the revised probe. At 12 months, mean IOP was 17.9 ± 5.9 mm Hg (21.4% reduction) on 2.55 ± 1.40 medications (13.0% reduction) for the original probe compared to 14.8 ± 5.7 mm Hg (29.7% reduction, $p = 0.063$) on 3.07 ± 1.49 medications (2.2% reduction, $p = 0.279$) for the revised probe. Thirty-one of 95 eyes (32.6%) and 11 of 27 eyes (40.7%) treated with original and revised MP-TLT, respectively, achieved success at 12 months ($p = 0.435$). The rate of SSIs was 12% and similar between groups ($p = 0.833$). Significantly more eyes treated with the original probe underwent repeat MP-TLT within 12 months (44.2 vs 22.2%, $p = 0.049$). No adverse events occurred in either group.

Conclusion and clinical significance: The revised probe for the MP3 device may result in an improved and longer-lasting IOP-lowering effect compared to the original probe, while maintaining an excellent safety profile.

Keywords: Glaucoma treatment, MicroPulse® transscleral laser therapy, Micropulse transscleral cyclophotocoagulation.

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Introduction

Traditional, continuous-wave diode transscleral cyclophotocoagulation (TS-CPC) lowers intraocular pressure (IOP) by irreversibly coagulating the ciliary body by delivering continuous thermal energy.[1–3] While extremely effective in lowering IOP, TS-CPC often results in several vision-threatening complications, including extended ocular inflammation, hypotony, cystoid macular edema, and even phthisis.[2,4,5]

MicroPulse® transscleral laser therapy (MP-TLT, Iridex, Mountain View, CA) is a distinct iteration of traditional TS-CPC. MP-TLT utilizes laser "pulses" to create cycles of "on" and "off" energy delivery. Throughout the "on" cycle, the pigmented epithelial layer of the ciliary body absorbs the laser's thermal energy, while the nonpigmented layer does not reach ablating thermal energy levels due to a lower photocoagulative threshold.[6–9] During the "off" cycle, the temperature of the pigmented epithelium drops below the thermal threshold, allowing this layer to cool and minimizing collateral tissue damage.[6–9]

Since 2015, MP-TLT has utilized the MicroPulse P3® (MP3) probe for treatment application, as visualized in Figure 1. The original MP3 probe was outfitted with an infrared diode laser with an 810 nm wavelength and a fiberoptic, hemispheric tip.[6,10,11] The original probe had a convex footplate, which caused the probe to slide anteriorly, resulting in inconsistent energy delivery.[12] Subconjunctival hemorrhages were common as the fiberoptic tip jutted out and disrupted the conjunctiva during treatment.[6,12]

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A revised MP3 probe was released in late 2019 with multiple design alterations to address these issues (Fig. 2).[6,13] Notable changes involved the fiberoptic cable and the plastic contact tip. The "bunny ear" shaped plastic tip helps align the probe to the limbus. The length between the probe and the fiberoptic laser was extended to 3 mm. This locates the area of treatment more posterior to the limbus, which helps decrease ocular surface complications that can result from treating too close to the edge.[12] Recessing the fiberoptic cable allows for an added fluid channel,

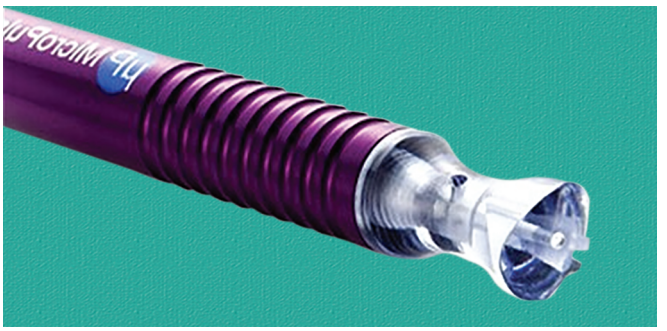

Fig. 1: Original MP3 delivery device. The original MP3 delivery device, released in 2015, is a handheld fiber-optic probe equipped with a large, convex footplate

Fig. 2: Revised MP3 delivery device. Released in 2019, the revised MP3 delivery device has a smaller, concave footplate to match the curvature of the sclera and includes a fluid channel that retains the viscous coupling agent

enabling constant immersion in viscous fluid to enhance light coupling to the pigmented layer. Additionally, the concave footplate matches the curvature of the sclera, and the elongated stem of the plastic contact tip allows for improved visualization and ergonomics, particularly in patients with tighter lid spaces or small, sunken eyes.[12]

To our knowledge, there are limited long-term studies evaluating the safety and efficacy of the revised MP3 probe compared to the original probe.[14,15] Our primary goal was to investigate any potential differences in safety and treatment efficacy following the revision of the MP-TLT probe.

Materials and Methods

Study Design, Patient Selection, and Data Collection

Following IRB approval from the University of Missouri, a retrospective chart review was conducted on patients who had undergone MP-TLT in one or both eyes at the University of Missouri Mason Eye Institute from October 2016 to August 2020. The original probe was used from October 2016 until May 2019, while the revised probe was used from June 2019 until August 2020. Our study respected the principles of the Declaration of Helsinki, and data collection and storage were maintained confidentially.

About 122 consecutive eyes in 99 patients undergoing MP-TLT were followed for 12 months, with 27 eyes in 24 patients treated with the revised delivery probe. Glaucoma was diagnosed by clinical assessment of the optic nerve and retinal nerve fiber layer using optical coherence tomography (OCT) and Humphrey visual field (HVF) testing. All patients had at least 12 months of follow-up. Patients who required an additional IOP-lowering procedure, including repeat MP-TLT, within 12 months of MP-TLT treatment, were included and reported separately.

Baseline characteristics included age, gender, ethnicity, glaucoma type and severity, preoperative best corrected visual acuity (BCVA), IOP, and glaucoma medications. Glaucoma severity was defined based on HVF defects according to the current ICD-10 guidelines.[16] MP-TLT energy and delivery settings were collected, and total energy and fluence were calculated based on formulas outlined by Grippo et al.[17] (see Appendix A, Table A1 for calculations). The primary outcome was success at 12 months, which was defined as final IOP <18 mm Hg and either IOP reduction of >20% or any medication reduction, without any adverse events or secondary surgical interventions (SSIs) within 12 months. Secondary outcomes included mean and % reduction of IOP and number of medications at 1 month, 3, 6, and 12 months postoperatively. In addition, any adverse events and additional glaucoma procedures were collected. Repeat MP-TLT and laser trabeculoplasty were analyzed separately.

Laser Technique

MP-TLT was performed at the University of Missouri under intravenous sedation and monitored anesthesia care. In all original probe cases, peribulbar blocks of 2% lidocaine with epinephrine mixed with 0.5% bupivacaine were used. No blocks were used in the revised probe cases. As a coupling agent, lidocaine topical gel was used. MP-TLT was conducted with either the original or revised MP3 delivery device connected to an 810 nm diode laser console. Procedure settings for the original probe were a power range of 2–2.25 Watts (W) (mean 2.07 W, SD 0.11 W), a total duration of 160–180 seconds (mean 175 seconds, SD 13.1 seconds), with 10 seconds per hemisphere sweep and a mean fluence of 54.3 Joules (J)/cm^2 (range 52.4–59.0 J/cm^2). For the revised probe, a power range of 2–2.5 W (mean 2.3 W, SD 0.22 W), a duration of 100–180 seconds (mean 111 seconds, SD 23.6 seconds), with 20 seconds per hemisphere sweep were used and a mean fluence of 140.1 J/cm^2 (range 121.9–152.4 J/cm^2). All cases utilized a 31.3% duty cycle (0.5 milliseconds "on" then 1.1 milliseconds "off"), and 360° of treatment, omitting the 3 and 9 o'clock positions. At the conclusion of the procedure, all patients received 0.4 mL of dexamethasone in the inferior subconjunctiva. Patients were instructed to use topical 1% prednisolone acetate ophthalmic suspension four times a day in the postoperative eye for 1 week. Medications were introduced and removed based on target IOP per the treating physician's clinical decision at each visit.

Outcome Measures

The primary outcome measure included success at 12 months, which was defined as achieving a target IOP <18 mm Hg with either IOP reduction >20% or any medication reduction. Any additional SSIs were considered failure, including incisional glaucoma surgeries and continuous wave cyclophotocoagulation. Laser trabeculoplasty and repeat micropulse transscleral laser therapy were not considered failure but were separately reported.

Secondary outcomes included average IOP and medications, and % reduction of IOP and medications at the 1-, 3-, 6-, and 12-month postoperative timepoints. Any adverse events or SSIs within 12 months were also compared.

Statistical Analysis

Data analysis was conducted using the R Statistical Software (version 4.0.5; R Foundation for Statistical Computing, Vienna, Austria). Unpaired *t*-tests were used to analyze IOP, IOP reduction, and number of additional glaucoma procedures between the original and revised probes. Paired *t*-tests were used to analyze preoperative and postoperative IOP and IOP reduction for

the same probe. Wilcoxon signed-rank tests were utilized to analyze preoperative and postoperative medications. Chi-square was employed to analyze success rates of the original MP-TLT probe compared to the revised probe. All tests were two-sided with an α set at 0.05. All values are reported as mean ± SD unless otherwise specified. The Kaplan–Meier survival curve was used to analyze time to additional glaucoma procedures (excluding additional laser procedures such as trabeculoplasty and repeat MP-TLT). In the survival analysis, missing data were represented as censored cases.

Results

Most patients included in this study were white (83.6%), with an age range of 24–96 years and a mean age of 70.3 years (Table 1). Of the 122 eyes, most were categorized as mild (69.7%), primary open-angle glaucoma (POAG, 81.1%) with a mean baseline IOP of 23.0 ± 7.4 on 3.0 ± 1.22 medications. With regard to age, gender, ethnicity, glaucoma type, preoperative visual acuity, baseline IOP, and medications, there were no significant differences between the groups (Table 1). However, the severity of disease was significantly different; the majority of eyes treated with the original probe were mild (86.3%), and the majority treated with the revised probe were advanced (77.8%) ($p < 0.001$). Total energy was significantly higher for the original probe compared to the revised probe (113.6 vs 79.9 J, $p < 0.0001$). The average fluence was significantly lower for the original probe compared to the revised probe (54.3 J/cm^2 vs 140.1 J/cm^2, $p < 0.0001$) (Appendix A).

At 12 months, the success rate was 32.6% for the original probe and 40.7% for the revised probe, and the difference was not significant ($p = 0.435$) (Table 2 and Fig. 3).

Both probes resulted in a significant IOP reduction, with an average IOP reduction of 5.8 ± 7.6 (25.2%) ($p < 0.001$). The 12-month mean IOP was significantly lower with the revised probe (17.9 ± 6.0 mm Hg original vs 14.8 ± 5.7 mm Hg revised, $p = 0.017$), even though the percentage reduction of IOP was not significant between probes (21.4% reduction in original vs 29.7% in revised, $p = 0.14$) (Table 2 and Fig. 4). Both probes resulted in a nonsignificant reduction in medications at 12 months, and the difference between groups was not significant (Table 2 and Fig. 5).

About 31 (32.6%) and 8 (29.6%) eyes treated with original and revised MP-TLT, respectively, required an SSI at 12 months ($p = 0.764$) (Table 3). Kaplan–Meier analysis demonstrated no significant difference in time to SSI (Fig. 6). Significantly more eyes treated with the original probe underwent repeat MP-TLT (42/95 eyes, 44.2%) compared to the revised probe (6/27 eyes, 22.2%) at 12 months

Table 1: Baseline demographic, glaucoma status, and procedure data

	Total (n = 122)	*Original (n = 95)*	*Revised (n = 27)*	*p-value*
Demographic data				
Age (years), mean ± SD	70.3 ± 13.7	71.3 ± 10.6	65.7 ± 20.3	0.2031
Gender, % (*n*)				0.5417
Female	54.9% (67)	57.9% (55)	44.4% (12)	
Male	45.1% (55)	42.1% (40)	55.6% (15)	
Ethnicity, % (*n*)				0.1903
Caucasian	83.6% (102)	86.3% (82)	74.1% (20)	
Black	12.3% (15)	10.5% (10)	18.5% (5)	
Asian	2.9% (3)	2.1% (2)	3.7% (1)	
Hispanic	1.6% (2)	1.1% (1)	3.7% (1)	
Glaucoma status data				
Glaucoma severity, % (*n*)				<0.001
Mild	69.7% (85)	86.3% (82)	11.1% (3)	
Moderate	13.1% (16)	13.7% (13)	11.1% (3)	
Advanced	17.2% (21)	0.0% (0)	77.8% (21)	
Glaucoma type, % (*n*)				0.8533
POAG/NTG	81.1% (99)	84.2% (80)	63.4% (19)	
SG	18.9% (23)	15.8% (15)	29.6% (8)	
Congenital (aphakic)	7.4% (9)	6.3% (6)	11.1% (3)	
Steroid response; uveitic	4.9% (6)	6.3% (6)	0.0% (0)	
Pseudoexfoliative	1.6% (2)	1.1% (1)	3.7% (1)	
Combined mechanism	3.3% (4)	1.1% (1)	11.1% (3)	
Secondary OHT	0.8% (1)	0.0% (0)	3.7% (1)	
Iatrogenic	0.8% (1)	1.1% (1)	0.0% (0)	
Baseline data				
LogMAR visual acuity ± SD	0.41 ± 0.59	0.44 ± 0.63	0.34 ± 0.42	0.43
IOP (mm Hg), mean ± SD	23.0 ± 7.4	23.0 ± 7.5	22.6 ± 6.9	0.79
Medications, mean ± SD	3.0 ± 1.22	2.94 ± 1.19	3.15 ± 1.32	0.43

ACG, angle closure glaucoma; IOP, intraocular pressure; MP-TLT, MicroPulse® transscleral laser therapy; NTG, normal tension glaucoma; POAG, primary open angle glaucoma; SD, standard deviation; SG, secondary glaucoma

($p = 0.049$) (Table 4). No adverse events occurred in either group within 12 months.

Discussion

This study aimed to evaluate the safety and efficacy of MP-TLT using the revised MP3 probe compared to the original probe. Our study demonstrated that the revised probe resulted in a significantly lower postoperative IOP and rates of repeat MP-TLT compared to the original probe, with no adverse events within 12 months.

While the majority of eyes treated with the original probe were considered mild glaucoma, the majority of eyes in the revised probe group were considered advanced glaucoma. Several studies have demonstrated that MP-TLT, especially with the revised probe, provides significant IOP reduction in advanced glaucoma cases that would otherwise require more invasive procedures.[18–23] In a multicentric, retrospective study of 55 eyes with an average preoperative IOP of 24.1 ± 0.96 mm Hg, Laruelle et al. found that >50% of eyes attained >20% IOP reduction at 12 months when treated with the revised probe.[20] Also using the revised probe, Zaarour et al. found that 75 eyes with moderate to severe glaucoma and a preoperative IOP of 26.0 ± 7.91 mm Hg achieved an average IOP reduction of 35.4% at 15 months ($p < 0.001$).

These studies may reflect the evolving use of MP-TLT as a later stage in management after patients have reached maximal medications.[18–22,24] To this point, in our study, the average number of preoperative glaucoma medications for the revised

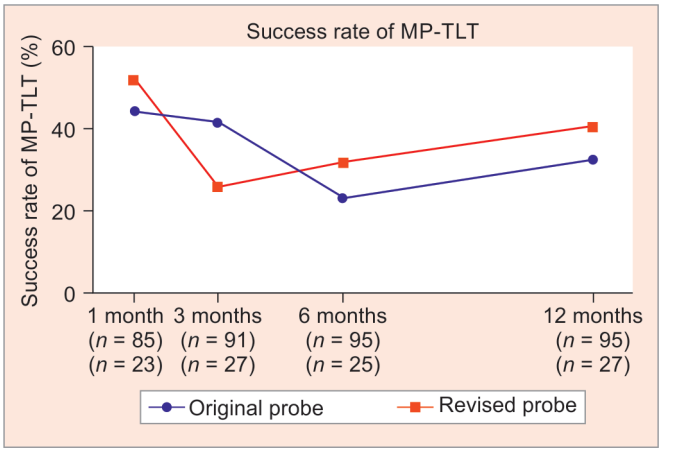

Fig. 3: Success rate of MP-TLT. Success of eyes undergoing MP-TLT with the original and revised devices at 1, 3, 6, and 12-months postoperatively

Table 2: Comparison of postoperative outcomes of MP-TLT based on delivery device

		Original (n = 95)	*Revised (n = 27)*	*p-value*
Mean IOP mm Hg + SD	Preoperative	23.0 ± 7.5	22.6 ± 6.9	0.799
	1 month	20.1 ± 7.3	19.6 ± 6.6	0.756
	3 months	18.6 ± 7.0	20.8 ± 9.4	0.187
	6 months	19.0 ± 5.9	19.0 ± 8.6	0.994
	12 months	17.9 ± 6.0	14.8 ± 5.7	0.017
p-value at 12 months		6.192e-06	1.839e-07	
Mean number of medications Mean ± SD	Preoperative	2.93 ± 1.19	3.14 ± 1.32	0.429
	1 month	2.83 ± 1.22	3.27 ± 1.15	0.103
	3 months	2.76 ± 1.35	3.22 ± 1.34	0.117
	6 months	2.67 ± 1.29	3.28 ± 1.34	0.040
	12 months	2.55 ± 1.40	3.07 ± 1.49	0.110
p-value at 12 months		0.120	0.910	
IOP reduction Mean ± SD (%)	1 month	2.9 ± 7.4 (10.3%)	3.0 ± 6.8 (10.9%)	0.949
	3 months	4.4 ± 7.2 (13.0%)	1.8 ± 8.3 (6.1%)	0.112
	6 months	4.1 ± 6.7 (13.6%)	3.6 ± 7.8 (9.8%)	0.742
	12 months	5.1 ± 6.8 (21.4%)	7.85 ± 6.4 (29.7%)	0.063
p-value at 12 months		0.034	0.009	
Medication reduction Mean ± SD (%)	1 month	–0.11 ± 0.53 (–3.8%)	0.00 ± 1.07 (–7.1%)	0.485
	3 months	–0.18 ± 0.83 (–6.1%)	0.08 ± 0.87 (2.5%)	0.173
	6 months	–0.26 ± 0.92 (–8.9%)	0.14 ± 0.97 (4.4%)	0.458
	12 months	–0.38 ± 1.27 (–13.0%)	–0.07 ± 1.30 (–2.2%)	0.279
p-value at 12 months		0.003	0.626	
Success rate % (*n*)	1 month	44.7% (38/85)	47.8% (11/23)	0.787
	3 months	41.8% (38/91)	25.9% (7/27)	0.136
	6 months	23.2% (22/95)	32.0% (8/25)	0.363
	12 months	32.6% (31/95)	40.7% (11/27)	0.435
SSIs *n* (%)	1 month	4 (4.2%)	0 (0%)	0.280
	3 months	4 (4.2%)	1 (3.7%)	0.904
	6 months	11 (11.6%)	4 (14.8%)	0.653
	12 months	12 (12.6%)	3 (11.1%)	0.833

SD, standard deviation

probe (3.14 ± 1.32) was also found to be higher compared to the original (2.93 ± 1.19), although this was not significant statistically (p = 0.429). These differences in baseline characteristics may have blunted the IOP and medication lowering outcomes in the revised probe group. Despite this, the revised probe was found to be noninferior in success at all time points when compared to the original probe. Compared to the original probe, the revised probe was found to have a significantly lower postoperative IOP at 12 months.

We used a lower total energy and higher average fluence by means of slower sweep velocity in the revised probe group due to the modified recommendation by the expert panel.[12] Recently, Checo et al. performed a cohort study in uncontrolled glaucoma patients receiving MP-TLT divided into six groups of 10–11 patients with durations of 50 and 60 seconds and 3, 4, or 5 sweeps.[23] The groups with 60 seconds exposure durations and a total energy of 47 J achieved the greatest IOP reductions, although this was not statistically significant.[23] Balendiran et al. performed a randomized control trial of 19 patients comparing MP-TLT treatment durations of 100–120 seconds, and found greater success with a longer treatment duration with higher fluence (131 vs 109.2 J/cm^2) and higher total energy (78.25 vs 93.9 J).[25] Compared to Balendiran et al., we used a higher fluence (mean 140.2 J/cm^2) and a lower total energy (79.9 J) for the revised probe to achieve a slightly greater IOP lowering effect (–7.85 ± 6.4 mm Hg, 29.7% reduction vs –5.5 ± 3.9 mm Hg, –26.6% reduction) without any adverse events. This may indicate that there is room for higher energy delivery in order to improve IOP lowering outcomes.

As per literature on the original probe and the most recent consensus guidelines, a total energy of 150 to 200 J (applied through 10 seconds sweeps per hemisphere) seems to safely reduce IOP without adverse events.[17,26,27] In a prospective study of 52 eyes from mostly white patients with a higher mean baseline IOP (32.6 mm Hg), Marchand et al. showed that a total energy delivery of 150–200 J using the original probe led to a significant IOP reduction and long-lasting effect (35.6% reduction at 18 months).[28] A 2018 review by Sanchez et al. described a dose-response association between the total energy applied and IOP reduction in both experimental and clinical MP-TLT studies with the original probe.[26] Studies that used between 112 and 150 J of total energy obtained a decrease in IOP of 30% with few complications.[26] Studies that used lower energy levels delivered similar results in the short term, but required repeat treatments to maintain the effect.[24] Total energy above 200 J showed a greater IOP reduction of 40–60% from baseline, but the risk of moderate to severe complications increased significantly, similar to CPC.[26]

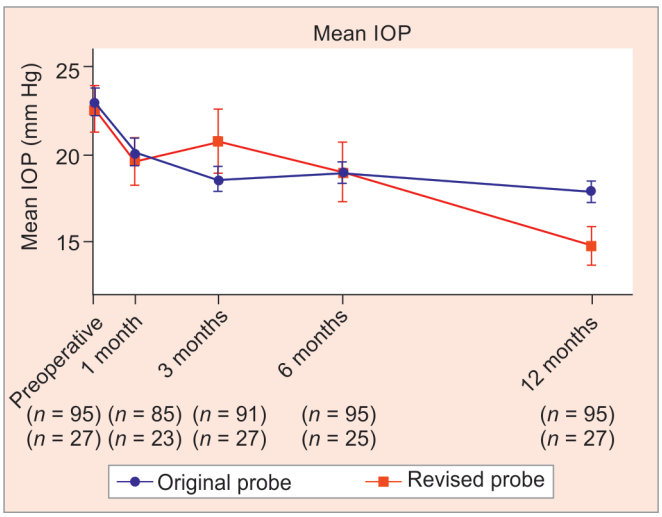

Fig. 4: MP-TLT mean IOP (mm Hg). MP-TLT mean IOP (mm Hg) using original vs revised probe

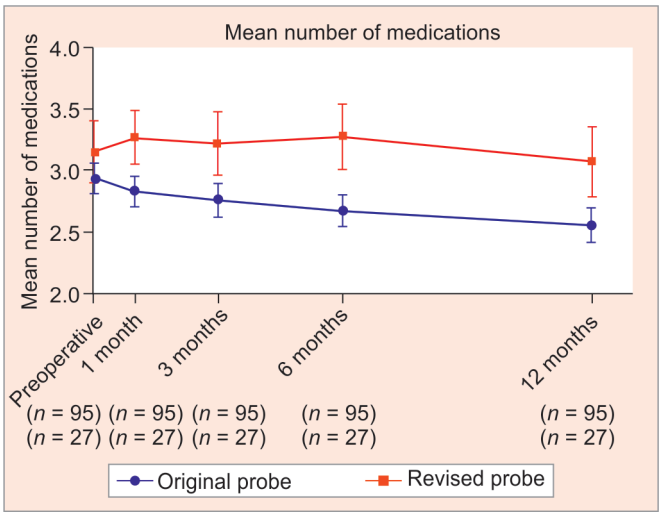

Fig. 5: MP-TLT mean number of medications. MP-TLT mean number of medications

Table 3: SSIs within 12 months

n (%)	*Original (n = 95)*	*Revised (n = 27)*
Trabeculectomy	3 (3.2%)	0
Ahmed glaucoma valve	3 (3.2%)	3 (11.1%)
Xen with phacoemulsification	17 (17.9%)	1 (3.7%)
Hydrus with phacoemulsification	2 (2.1%)	1 (3.7%)
TS-CPC	12 (12.6%)	3 (11.1%)

Table 4: Additional laser procedures within 12 months

n (%)	*Original (n = 95)*	*Revised (n = 27)*
Repeat MP-TLT	42 (44.2%)	6 (22.2%)
MLT	0 (0%)	1 (3.7%)
SLT	1 (1.0%)	0 (0%)

MLT, MicroPulse® laser trabeculoplasty; MP-TLT, MicroPulse® transscleral laser therapy; SLT, selective laser trabeculoplasty

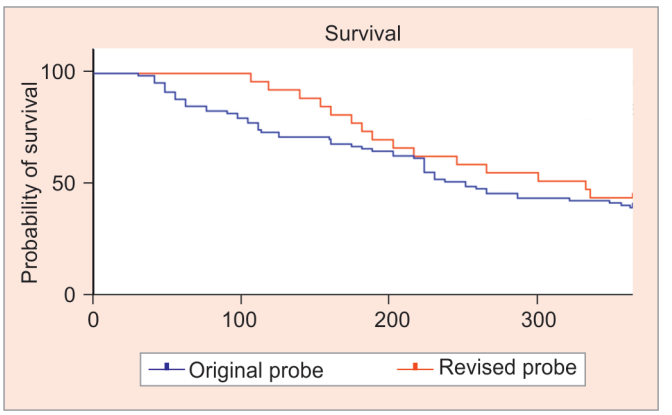

Fig. 6: Survival curve

Akiyama et al. examined short-term outcomes of 40 patients, half of which used the revised probe.[14] They found no difference in pre- and postoperative IOP between the original and revised probe at 3 months.[14] Another 3-month comparative study of the revised vs original probes by Hadjokas et al. also found no significant difference in the IOP-lowering effect of the probes at 3 months. In the revised probe and original probe groups, respectively, Hadjokas et al. used higher durations (217 and 179 seconds) and energy (170 and 113 J) compared to our study and similar ones.[15] However, with longer follow-up, our study demonstrates that the revised probe can result in a significantly lower IOP at 12 months and a reduced need for repeat procedures with a low rate of SSIs within 12 months. This finding could be in part attributed to the improvement in the probe ergonomics and fiberoptic coupling, leading to more efficient and safe energy delivery to the target tissue while avoiding inadvertent energy delivery to the ocular surface and surrounding tissues, as well as the use of higher energy fluence leading to more effective treatment of ciliary bodies.

In addition to the retrospective design, other limitations of our study include the overrepresentation of the white race and significantly more eyes undergoing treatment with the original probe. There is also potential for intereye bias given some patients contributed both eyes to our analysis. Another limitation is the use of nonstandardized and lower than currently recommended energy settings, which are evolving and critical to the success of MP-TLT. The current recommendation for the revised probe per the latest consensus guideline is to use higher total energy and fluence, starting with 2.5 W power, 160 seconds total duration, and 20 seconds per hemisphere sweep velocity, adjusting 25% above and below this parameter based on patient-specific factors.[12,29] Larger randomized controlled studies analyzing the long-term effects of MP-TLT utilizing the revised probe with standardized energy settings are necessary to confirm its long-term safety and efficacy.

Conclusion

This study demonstrated MP-TLT using the revised probe resulted in lower mean IOP at 12 months with a similar moderate success rate of 40% and no adverse events, even in severe glaucoma patients.

Clinical Significance

This is the first long-term study evaluating the revised probe for the MP3 device. The revised probe may result in an improved and longer-lasting IOP lowering effect, while maintaining an excellent safety profile compared to the original probe.

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Appendix A

Total Energy and Fluence Calculations

The parameters of power (Watts) and treatment duration (seconds) are set with each treatment. The duty cycle of 31.3% (or 0.313) is a standard part of the MicroPulse technology.

The average arc length 3.8 mm posterior to the limbus is 22 mm.

Eq A.1:

$$\text{Sweep velocity} = \frac{\text{arc length}}{\text{sweep time}}$$

Ex.

$$\frac{22 \text{ mm}}{10 \text{ seconds}} = 2.2 \text{ mm/second}$$

The laser spot size is 0.7 mm diameter for the original probe and 0.6 mm for the revised probe. Dwell time is the amount of time each 0.7 mm arc length segment receives treatment.

Eq. A.2:

$$\text{Dwell time} = \frac{\text{spot size}}{\text{arc length}} \times \text{sweep time} = \frac{\text{spot size}}{\text{sweep velocity}}$$

Ex.

$$\frac{0.7 \text{ mm}}{22 \text{ mm}} \times 10 \text{ seconds} = 0.318 \text{ seconds}$$

Eq. A.3:

$$\text{Total energy (J)} = \text{Power (W)} \times \text{Duty cycle} \times \text{Total duration of treatment}$$

Ex.

$$2.074 \text{ W} \times 0.313 \times 175 \text{ seconds} = 113.6 \text{ J}$$

Fluence also depends on the area of treatment. The area of the laser spot with a diameter of 0.7 mm is

$$\pi\left(\frac{0.07 \text{ cm}}{2}\right)^2 = 0.0038 \text{ cm}^2$$

The area of the laser spot with a diameter of 0.6 mm is

$$\pi\left(\frac{0.06 \text{ cm}}{2}\right)^2 = 0.0028 \text{ cm}^2$$

Eq. A.4:

$$\text{Fluence (J/cm}^2\text{)} = \text{Power (W)} \times \text{Duty cycle} \times \frac{\text{dwell time}}{\text{area}}$$

Ex.

$$2.074 \text{ W} \times 0.313 \times \frac{0.318 \text{ seconds}}{0.0038 \text{ cm}^2} = 54.3 \text{ J/cm}^2$$

Below are the pertinent energy calculation values for this study's treatment groups.

Table A1: Treatment energy calculation values

Treatment	*Original probe*	*Revised probe*
Average power (watts)	2.07	2.30
Duty cycle	31.3%	31.3%
Total treatment duration (seconds)	175	111
Number of sweeps	3	4
Sweep time (seconds)	10	20
Arc length (mm)	22	22
Sweep velocity (mm/second)	2.2	1.1
Dwell time (seconds)	0.318	0.545
Area (cm^2)	0.0038	0.0028
Total energy (J)	113.6	79.9
Average fluence (J/cm^2)	54.3	140.1
Range of fluence (J/cm^2)	52.4–59.0	122.0–152.4