



# One-year outcomes of microhook trabeculotomy versus suture trabeculotomy ab interno

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## Abstract

**Purpose** To compare clinical success rates and reductions in intraocular pressure (IOP) and IOP-lowering medication use following suture trabeculotomy ab interno (S group) or microhook trabeculotomy ( $\mu$  group).

**Methods** This retrospective review collected data from S ( $n = 104$ , 122 eyes) and  $\mu$  ( $n = 42$ , 47 eyes) groups who underwent treatment between June 1, 2016, and October 31, 2019, and had 12-month follow-up data including IOP, glaucoma medications, complications, and additional IOP-lowering procedures. The Kaplan–Meier survival analysis was used to evaluate treatment success rates defined as normal IOP ( $> 5$  to  $\leq 18$  mm Hg),  $\geq 20\%$  reduction of IOP from baseline at two consecutive visits, and no further glaucoma surgery.

**Results** Schlemm's canal opening was longer in the S group than in the  $\mu$  group ( $P < 0.0001$ ). The Kaplan–Meier survival analysis of all eyes showed cumulative clinical success rates in S and  $\mu$  groups were 71.1% and 61.7% ( $P = 0.230$ ). The Kaplan–Meier survival analysis of eyes with preoperative IOP  $\geq 21$  mmHg showed cumulative clinical success rates in S and  $\mu$  groups were 80.4% and 60.0% ( $P = 0.0192$ ). There were no significant differences in postoperative IOP at 1, 3, and 6 months (S group,  $14.9 \pm 5.6$ ,  $14.6 \pm 4.5$ ,  $14.6 \pm 3.9$  mmHg;  $\mu$  group,  $15.8 \pm 5.9$ ,  $15.2 \pm 4.4$ ,  $14.7 \pm 3.7$  mmHg;  $P = 0.364$ , 0.443, 0.823), but postoperative IOP was significantly lower in the S group at 12 months (S group,  $14.1 \pm 3.1$  mmHg;  $\mu$  group,  $15.6 \pm 4.1$  mmHg;  $P = 0.0361$ ). There were no significant differences in postoperative numbers of glaucoma medications at 1, 3, 6, and 12 months (S group,  $1.8 \pm 1.6$ ,  $1.8 \pm 1.5$ ,  $2.0 \pm 1.6$ ,  $1.8 \pm 1.5$ ;  $\mu$  group,  $2.0 \pm 1.6$ ,  $2.0 \pm 1.6$ ,  $2.1 \pm 1.6$ ,  $2.2 \pm 1.7$ ;  $P = 0.699$ , 0.420, 0.737, 0.198).

**Conclusion** S and  $\mu$  group eyes achieved IOP reduction, but  $\mu$  group eyes had lower clinical success rates among patients with high preoperative IOP at 12 months.

## Key messages:

- Trabeculotomy, a blebless surgery, is attracting attention as a safe surgical method. Recently, trabeculotomy ab interno, which is performed within the anterior chamber using a gonioscope has been developed.
- We compared the clinical success rates and reductions in intraocular pressure (IOP) and IOP-lowering medication use following suture trabeculotomy ab interno (S group; 122eyes) or microhook trabeculotomy ( $\mu$  group; 47eyes).
- The S and  $\mu$  groups achieved IOP reduction, but the  $\mu$  group had a lower survival rate in patients with high preoperative IOP.

**Keywords** Gonioscopy-assisted suture trabeculotomy · Microhook trabeculotomy · Trabeculotomy ab interno · Goniotomy · MIGS

This study was completed at the Hyogo College of Medicine, Department of Ophthalmology, Nishinomiya, Hyogo, Japan.

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## Introduction

Glaucoma is a major vision-threatening disease worldwide, which is generally controlled by the reduction of intraocular pressure (IOP) [1]. When IOP-lowering eyedrops are ineffective, glaucoma surgery is considered. Trabeculectomy is a gold standard filtering surgery but hypotony immediately after the surgery is a serious adverse event. Trabeculectomy works well and it can maintain the visual field for a long time. In cases where trabeculectomy is not successful, glaucoma drainage implants (e.g., Ahmed valve and Baerveldt implant) are widely used. However, bacterial infection of the bleb and hypotony maculopathy are major serious adverse events related to these surgeries [2]. Accordingly, trabeculectomy (a blebless surgery) is receiving attention because of its potential for greater safety.

During trabeculectomy, the juxtacanalicular trabecular meshwork (TM) and inner wall of Schlemm's canal (SC) are incised to reduce the resistance of aqueous fluid outflow. The procedure is performed with a metal probe inserted through the scleral flap, which comprises an ab externo approach [3]. Recently, trabeculectomy ab interno has been introduced, involving gonioscope use within the anterior chamber [4]. The advantages of the ab interno procedure are the absence of injury to the conjunctiva and sclera, reduced damage to Descemet's membrane and the iris, and the creation of a wider incision in the TM. Suture trabeculectomy and microhook ab interno trabeculectomy have recently become common procedures in Japan. Suture trabeculectomy requires a complicated manipulation and considerable surgeon experience, but enables up to 360° incision [5]. The microhook trabeculectomy approach, introduced by Tanito et al. [6], is easier to perform within a shorter operation time, compared with suture trabeculectomy; microhook trabeculectomy incises up to approximately 240° (8 clock h) of the TM. A longer incision may accelerate the reduction in IOP, but might cause incision-associated hyphema or other side effects.

To the best of our knowledge, no studies have compared the efficacy and adverse events between suture trabeculectomy and microhook ab interno trabeculectomy. Here, we compared the treatment outcomes between suture trabeculectomy and microhook ab interno trabeculectomy.

## Patients and methods

This retrospective observational study was conducted at the Hyogo College of Medicine Hospital. The Institutional Review Board of Hyogo College of Medicine approved this study (No. 3535), which followed the tenets of the Declaration of Helsinki.

Patients were included if they had undergone suture trabeculectomy or microhook trabeculectomy at the Hyogo College of Medicine Hospital from June 1, 2016, to October 31, 2019, and had more than 12 months of follow-up. The exclusion criteria were as follows: prior glaucoma surgery, non-open-angle glaucoma (e.g., angle-closure glaucoma, pediatric glaucoma, and neovascular glaucoma), and corneal opacity that impaired angle visualization. The following data were extracted from medical records: age, sex, glaucoma type, lens status, surgical procedure (suture trabeculectomy ab interno or microhook trabeculectomy), presence or absence of simultaneous cataract surgery, range of SC incision, incidences of postoperative hyphema and transient IOP elevation, and requirement for additional glaucoma surgery.

Data regarding IOP and glaucoma drug scores were collected preoperatively and at 1 day, 1 week, and 1, 3, 6, and 12 months postoperatively. IOP was measured using a Goldmann applanation tonometer (Haag-Streit Diagnostics, Köniz, Switzerland). The glaucoma drug score was the number of glaucoma eye drop medications used by each patient: combination glaucoma drops were assigned 2 points whereas single glaucoma medications and oral carbonic anhydrase inhibitors were assigned 1 point. The extent of the SC incision was determined in 30° increments, up to a maximum of 360°, from surgical records. Postoperative hyphema was assessed by determining whether coagula- or niveau-forming hyphema in the anterior chamber persisted until 1 day or 1 week postoperatively. Transient postoperative IOP elevation was recorded as an IOP of  $\geq 25$  mmHg between 1 week and 3 months postoperatively, followed by a reduction to  $\leq 21$  mmHg.

## Surgical procedures

Suture trabeculectomy ab interno (S-LOT) was performed by a single surgeon (MT) and microhook trabeculectomy was performed by two surgeons (MT and HY). Both procedures were conducted as follows. Topical 4% lidocaine was applied preoperatively and standard sterile preparations were performed. After the induction of intracameral anesthesia using preservative-free 1% lidocaine, the anterior chamber was filled with an ophthalmic viscosurgical device (1% Healon®; AMO, Santa Ana, CA, USA). A surgical gonio lens (Volk, Mentor, OH, USA) was used to observe the TM. Approximately 30° of microscope tilt, combined with approximately 45° of head tilt, was required to achieve an optimal gonioscopic view of the angle. For patients aged  $> 50$  years and/or those with a vision-reducing cataract, simultaneous phacoemulsification was performed with an additional 2.4-mm corneal incision.

S-LOT procedures were as follows, using a modified 360° suture trabeculotomy technique. First, a near-limbal corneal port was created on the temporal side using a 2.2-mm slit knife (Alcon, Fort Worth, TX, USA). Second, the SC was incised through a temporal corneal incision at an angle of 15° on the nasal side using a 20-gauge V-Lance Knife (Alcon). Third, the rounded tip of a 5–0 nylon suture was inserted into the SC using 25-gauge disposable forceps. Fourth, the suture was pulled through the same opening after it had been passed around the SC perimeter. When the suture could not advance further into SC, it was removed from the temporal corneal incision site to perform SC incision for the inserted range. Additionally, a suture was inserted into the opposite side of the SC incision site, then pulled through the tip of the 5–0 nylon suture. Finally, the surgeon attempted a 360° SC incision, as long and wide as possible.

Microhook trabeculotomy procedures were as follows. A temporal, nasal, upper corneal incision was created with a 20-gauge V-Lance Knife (Alcon). This incision was used to incise the SC, by means of the Tanito trabeculotomy microhook™ (Handaya, Tokyo, Japan), within the range of two to three quadrants.

### Outcome measures

The main outcome measure was clinical success, defined as follows: normal IOP ( $> 5$  to  $\leq 18$  mmHg),  $\geq 20\%$  IOP reduction from baseline at two consecutive visits, and no requirement for further glaucoma surgery. The Kaplan–Meier survival analysis was used to evaluate the clinical success rates. Secondary measures were any differences in changes in the IOP and glaucoma drug scores, as well as the rates of adverse events and additional glaucoma surgeries, between the S and  $\mu$  groups.

### Statistical analyses

The Mann–Whitney *U*-test or the Wilcoxon signed-rank test was used to assess group differences in continuous variables including age, follow-up duration, pre- and postoperative IOP values, glaucoma drug score, and SC opening range. Fisher's exact test or Pearson's  $\chi^2$  test was used to assess group differences in categorical variables including sex, type of glaucoma, rate of simultaneous cataract surgery, and absence of transient IOP elevation. Analyses were performed with JMP Pro, version 14.0.0 (SAS Institute, Cary, NC, USA). Kaplan–Meier survival analyses were conducted to assess the long-term clinical success rates, which were compared using the log-rank test. For all analyses, *P* values and two-sided 95% confidence intervals were reported for point estimates. Statistical significance was defined as  $P < 0.05$ .

## Results

### Patient characteristics

Overall, 169 eyes from 146 patients were included in this study: 122 eyes from 104 patients who underwent suture trabeculotomy (S group) and 47 eyes of 42 patients who underwent microhook trabeculotomy ( $\mu$  group). Patient characteristics are shown in Table 1. The mean age and sex did not significantly differ between the two groups. In addition, there were no significant differences in preoperative IOP, glaucoma drug score, glaucoma type, rate of lens absence, and rate of simultaneous cataract surgery between the two groups. Preoperative IOP  $\geq 21$  mmHg was observed in 88 eyes (72.1%) in the S group and 35 eyes (74.5%) in the  $\mu$  group. The extent of SC incision was significantly greater in the S group ( $336.9 \pm 51.9^\circ$ ) than in the  $\mu$  group ( $215.1 \pm 32.7^\circ$ ;  $P < 0.0001$ ).

### Kaplan–Meier survival analysis

Kaplan–Meier curves for all eyes are shown in Fig. 1. The Kaplan–Meier survival analysis indicated that the cumulative clinical success rates in the S and  $\mu$  groups at 1 year postoperatively were 71.1% and 61.7%, respectively; these did not significantly differ between groups (log-rank test,  $P = 0.230$ ). Among eyes with a preoperative IOP  $\geq 21$  mmHg, the cumulative clinical success rates in the S and  $\mu$  groups at 1 year postoperatively were 80.4% and 60.0%, respectively ( $P = 0.0192$ ; Fig. 2).

### Other outcomes

IOP significantly decreased after surgery in the S and  $\mu$  groups ( $P < 0.00001$  for all time points). In the S and  $\mu$  groups, the postoperative IOP tended to be lower with combined phacoemulsification than with LOT alone. The postoperative IOP values for all eyes are shown in Fig. 3 and Table 2. For eyes with a preoperative IOP  $\geq 21$  mmHg, these values are shown in Fig. 4 and Table 3. Analysis of all eyes showed no significant differences in postoperative IOP from 1 day to 6 months postoperatively; at 12 months postoperatively, the IOP was significantly lower in the S group than in the  $\mu$  group (S group,  $14.1 \pm 3.1$  mmHg;  $\mu$  group,  $15.6 \pm 4.1$  mmHg;  $P = 0.0361$ ). Analysis of eyes with a preoperative IOP  $\geq 21$  mmHg showed similar results; at 12 months postoperatively, the IOP was significantly lower in the S group than in the  $\mu$  group (S group,  $14.4 \pm 3.4$  mmHg;  $\mu$  group,  $16.1 \pm 4.1$  mmHg;  $P = 0.0438$ ).

Postoperative glaucoma drug scores are shown in Table 4. The postoperative glaucoma drug score was

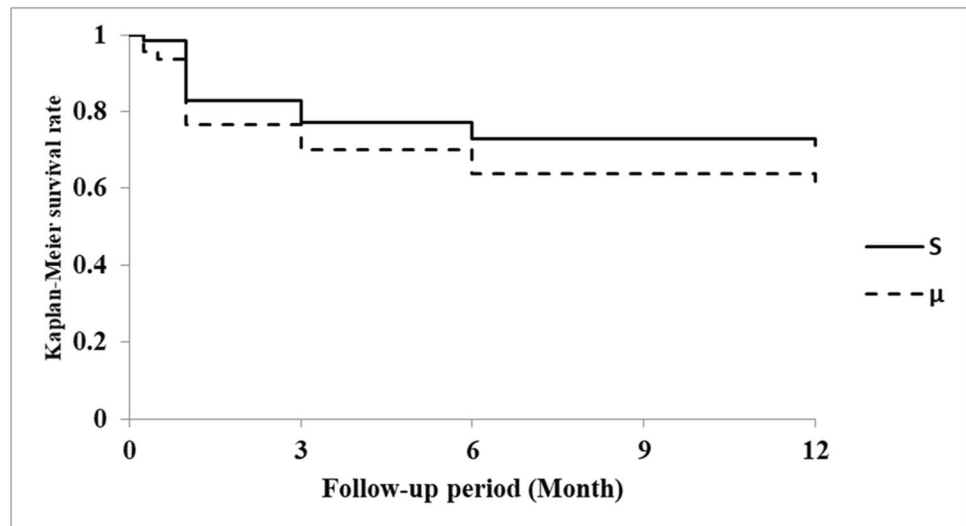
**Table 1** Patient characteristics

	Total 145 patients (169 eyes)	S group 104 patients (122 eyes)	$\mu$ group 42 patients (47 eyes)	<i>P</i> value
Age (mean $\pm$ SD) years	69.2 $\pm$ 12.3	69.2 $\pm$ 11.9	69.1 $\pm$ 13.5	0.830
Sex (male), <i>n</i> (%)	75 (51.7)	50 (48.0)	26 (61.9)	0.183
Preoperative IOP, mean $\pm$ SD (mmHg)	27.6 $\pm$ 10.0	27.7 $\pm$ 10.0	27.3 $\pm$ 10.2	0.767
Preoperative IOP $\geq$ 21 mmHg, <i>n</i> (%)	123 (72.8)	88 (72.1)	35 (74.5)	0.848
Preoperative the number of glaucoma medications, mean $\pm$ SD	4.0 $\pm$ 1.1	4.0 $\pm$ 1.0	3.9 $\pm$ 1.2	0.873
Type of glaucoma				0.734
POAG, <i>n</i> (%)	88 (52.1)	64 (52.5)	24 (51.1)	
Exfoliative, <i>n</i> (%)	42 (24.9)	32 (26.2)	10 (21.3)	
Steroid-induced, <i>n</i> (%)	17 (10.1)	12 (9.8)	5 (10.6)	
Others, <i>n</i> (%)	22 (13.0)	14 (11.5)	8 (17.0)	
Lens status				0.622
Phakic, <i>n</i> (%)	118 (69.8)	87 (71.3)	31 (65.9)	
Pseudophakic, <i>n</i> (%)	51 (30.2)	35 (28.7)	16 (34.0)	
Combined cataract extraction, <i>n</i> (%)	99 (68.3)	72 (59.0)	27 (57.4)	0.991
Extent range of incision in SC, mean $\pm$ SD (degrees)	303.0 $\pm$ 72.3	336.9 $\pm$ 51.9	215.1 $\pm$ 32.7	<b><i>&lt; 0.0001</i></b>

Bold italic font indicates statistical significance ( $P < 0.05$ )

S group, gonioscopy-assisted suture trabeculotomy;  $\mu$  group, microhook trabeculotomy. IOP, intraocular pressure; SD, standard deviation; POAG, primary open-angle glaucoma; SC, Schlemm's canal

**Fig. 1** Kaplan–Meier curves for surgical success in all eyes, using the following criteria: normal IOP ( $> 5$  to  $\leq 18$  mmHg),  $\geq 20\%$  IOP reduction from baseline at two consecutive visits, and no requirement for further glaucoma surgery. Lines representing suture trabeculotomy ab interno (—) and microhook trabeculotomy (---) are shown for reference



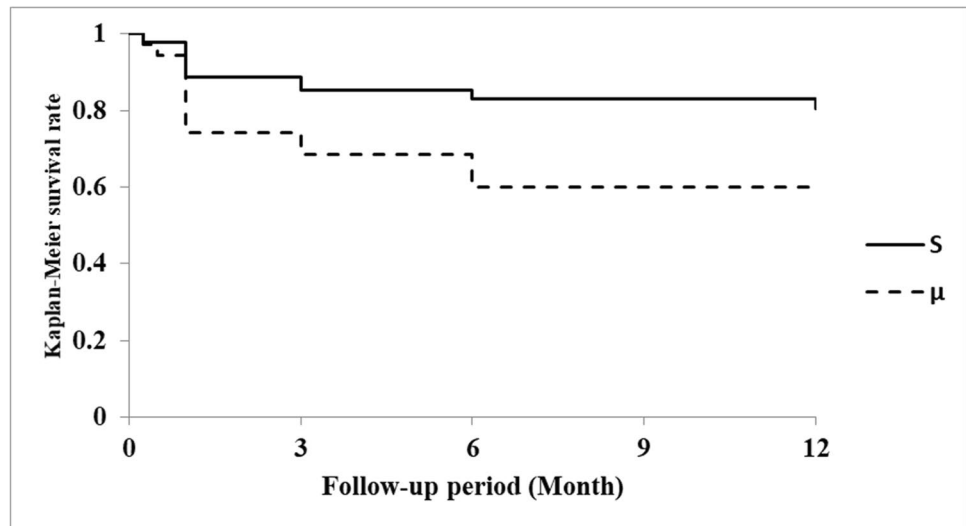
significantly lower than the preoperative glaucoma drug score in the S and  $\mu$  groups ( $P < 0.00001$  for all time points). There were no significant differences in postoperative glaucoma drug score at any time point between the two groups. The proportions of glaucoma medication-free eyes are in Table 5. Table 5 shows the percentage of complete success: normal IOP ( $> 5$  to  $\leq 18$  mmHg),  $\geq 20\%$  without any eye drops, and qualified success: normal IOP ( $> 5$  to  $\leq 18$  mmHg),  $\geq 20\%$  with IOP-lowering eye drops.

There were no significant differences in these proportions between the groups at 3, 6, and 12 months postoperatively.

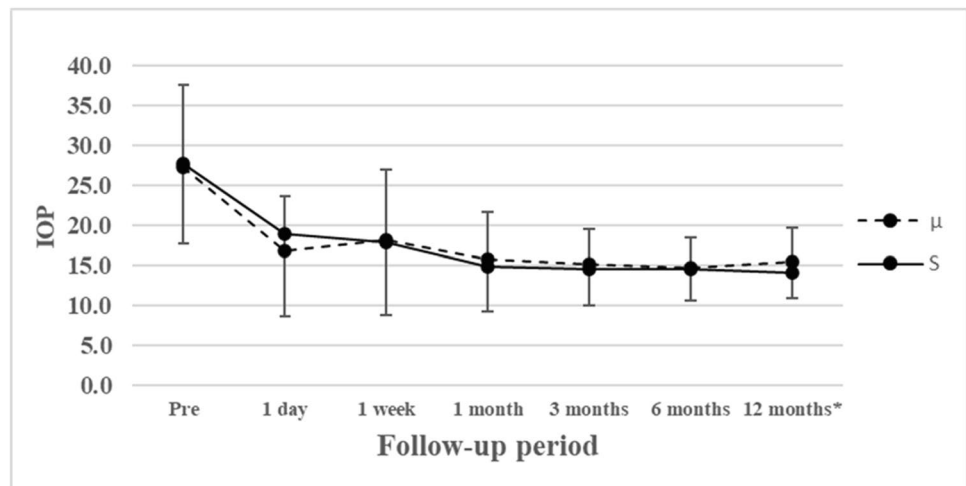
### Safety

HypHEMA at 1 day postoperatively was observed in 72 eyes (59.0%) in the S group and 24 eyes (51.1%) in the  $\mu$  group. At 1 week postoperatively, hypHEMA was observed in 56 eyes (45.9%) in the S group and 17 eyes (36.2%) in the  $\mu$  group. The proportions of eyes with hypHEMA at 1 day and 1 week

**Fig. 2** Kaplan–Meier curves for surgical success in eyes with preoperative IOP  $\geq 21$  mmHg, using the following criteria: normal IOP ( $> 5$  to  $\leq 18$  mmHg),  $\geq 20\%$  IOP reduction from baseline at two consecutive visits, and no requirement for further glaucoma surgery. Lines representing suture trabeculotomy ab interno (—) and microhook trabeculotomy (---) are shown for reference. S group, 88 eyes (72.1%);  $\mu$  group, 35 eyes (74.5%)



**Fig. 3** IOP for suture trabeculotomy ab interno (—) or microhook trabeculotomy (---) in the 12-month follow-up period. \*IOP at 12 months postoperatively was significantly lower in the S group than in the  $\mu$  group (S group,  $14.1 \pm 3.1$  mmHg;  $\mu$  group,  $15.6 \pm 4.1$  mmHg;  $P=0.0361$ ). Lines representing suture trabeculotomy ab interno (—) and microhook trabeculotomy (---) are shown for reference



were not significantly different between the two groups. Because of uncontrolled IOP elevation, hyphema washout was conducted in seven eyes (5.7%) in the S group and one eye (2.1%) in the  $\mu$  group (Table 6).

Postoperative transient IOP elevation occurred in 25 eyes (20.4%) in the S group and 10 eyes (21.3%) in the  $\mu$  group; the proportion of eyes with transient IOP elevation did not significantly differ between groups. Additional glaucoma surgery was performed in 11 eyes (9.0%) in the S group and four eyes (8.5%) in the  $\mu$  group; this proportion did not significantly differ between groups (Table 6).

## Discussion

In this study, we compared the postoperative results of trabeculotomy ab interno between suture and microhook approaches. The clinical success rates at 12 months

postoperatively were similar (71.1% in the S group and 61.7% in the  $\mu$  group), although there was a tendency toward a greater clinical success rate in the S group. The Kaplan–Meier survival analysis in eyes with a preoperative IOP of  $\geq 21$  mmHg showed a significantly greater clinical success rate at 12 months postoperatively in the S group than in the  $\mu$  group. At 12 months postoperatively, the IOP showed a significantly greater reduction in the S group than in the  $\mu$  group, although postoperative drug scores and the proportion of drug-free eyes did not significantly differ between groups. These results indicate that suture trabeculotomy lowers IOP over a longer duration, especially in eyes with higher preoperative IOP, compared with microhook trabeculotomy.

The main differences between these two procedures were the extent of SC incision and the overall surgical method. Suture trabeculotomy ideally enables a  $360^\circ$  incision, although some eyes do not allow a complete  $360^\circ$

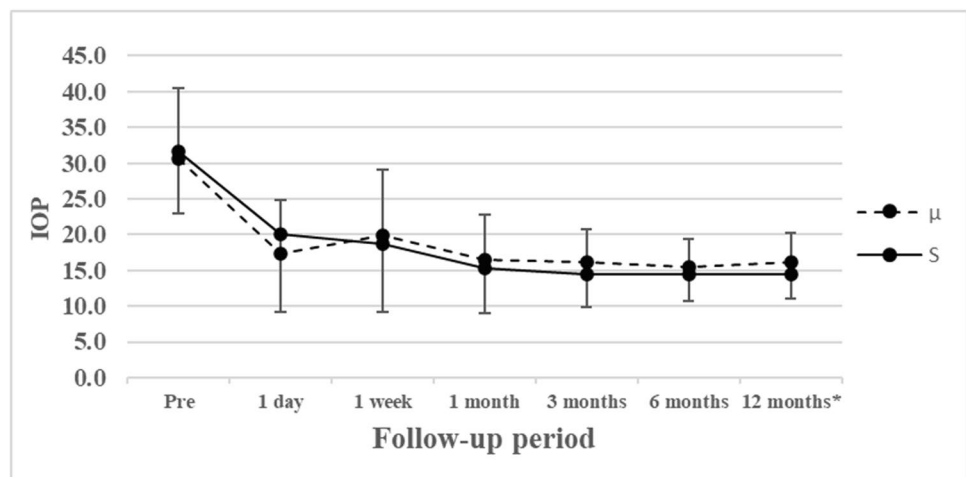
**Table 2** Changes in IOP in all eyes

	Preoperative	1 day postoperative	1 week postoperative	1 month postoperative	3 months postoperative	6 months postoperative	12 months postoperative
S group, mean (median) ± SD (mmHg)	27.7 (25.5) ± 10.0 (n = 122)	18.9 (15.5) ± 10.2 (n = 122)	18.0 (15) ± 9.1 (n = 121)	14.9 (14) ± 5.6 (n = 120)	14.6 (14) ± 4.5 (n = 116)	14.6 (14) ± 3.9 (n = 115)	14.1 (14) ± 3.1 (n = 102)
μ group, mean (median) ± SD (mmHg)	27.3 (24) ± 10.2 (n = 47)	16.9 (16) ± 6.8 (n = 47)	18.2 (14) ± 8.7 (n = 47)	15.8 (14) ± 5.9 (n = 46)	15.2 (14) ± 4.4 (n = 45)	14.7 (14) ± 3.7 (n = 43)	15.6 (16) ± 4.1 (n = 43)
P value	0.767	0.848	0.741	0.364	0.443	0.823	<b>0.0361</b>
S group with phacoemulsification, mean (median) ± SD (mmHg)	26.2 (25) ± 8.9 (n = 72)	20.2 (16.5) ± 10.6 (n = 72)	18.9 (16) ± 9.4 (n = 71)	13.7 (14) ± 2.9 (n = 71)	13.7 (14) ± 2.9 (n = 70)	14.1 (13.5) ± 3.3 (n = 70)	13.6 (14) ± 2.6 (n = 62)
μ group with phacoemulsification, mean (median) ± SD (mmHg)	22.8 (22) ± 7.1 (n = 27)	18.3 (16) ± 6.8 (n = 27)	18.7 (14) ± 9.5 (n = 27)	14.3 (14) ± 3.9 (n = 26)	14.0 (13) ± 4.2 (n = 26)	13.8 (14) ± 3.2 (n = 25)	14.6 (14) ± 3.9 (n = 25)
P value	0.0584	0.975	0.851	0.727	0.699	0.701	0.398
S group without phacoemulsification, mean (median) ± SD (mmHg)	29.8 (27) ± 11.1 (n = 50)	17.1 (14) ± 9.5 (n = 50)	16.7 (14) ± 8.6 (n = 50)	16.7 (15.0) ± 7.7 (n = 49)	15.9 (14.5) ± 6.1 (n = 46)	15.5 (16) ± 4.7 (n = 45)	14.9 (14.5) ± 3.7 (n = 40)
μ group without phacoemulsification, mean (median) ± SD (mmHg)	33.4 (31.5) ± 10.8 (n = 20)	15.0 (12.5) ± 6.5 (n = 20)	17.6 (14.5) ± 7.8 (n = 20)	17.8 (17.5) ± 7.4 (n = 20)	16.9 (17) ± 4.3 (n = 19)	16.1 (16.5) ± 4.0 (n = 18)	16.9 (17.5) ± 4.2 (n = 18)
P value	0.156	0.575	0.418	0.407	0.192	0.516	0.0602

Bold italic font indicates statistical significance ( $P < 0.05$ )

SD, standard deviation. S group, gonioscopy-assisted suture trabeculotomy; μ group, microhook trabeculotomy

**Fig. 4** IOP for suture trabeculotomy ab interno (—) or microhook trabeculotomy (---) in eyes with preoperative IOP ≥ 21 mmHg. \*IOP at 12 months postoperatively was significantly lower in the S group than in the μ group (S group, 14.4 ± 3.4 mmHg; μ group, 16.1 ± 4.1 mmHg;  $P = 0.0438$ ). Lines representing suture trabeculotomy ab interno (—) and microhook trabeculotomy (---) are shown for reference. S group, 88 eyes (72.1%); μ group, 35 eyes (74.5%)



incision; the mean incision size of suture trabeculotomy was  $336.9 \pm 51.9^\circ$  in this study. Regarding microhook trabeculotomy, the original procedure [7] involved an incision of  $> 180^\circ$  (6 clock h, two quadrants); however, recent

modifications involve smaller incisions to control postoperative transient IOP elevation [8]. In this study, microhook trabeculotomy was performed using the original method; thus, the mean extent of incision was  $215.1 \pm 32.7^\circ$ .

**Table 3** Changes in IOP in eyes with preoperative IOP  $\geq 21$  mmHg (S group, 88 eyes [72.1%];  $\mu$  group, 35 eyes [74.5%])

	Preoperative	1 day postoperative	1 week postoperative	1 month postoperative	3 months postoperative	6 months postoperative	12 months postoperative
S group, mean (median) $\pm$ SD (mmHg)	31.7 (30) $\pm$ 8.8 (n=88)	20.0 (16) $\pm$ 10.8 (n=87)	18.7 (16) $\pm$ 9.5 (n=86)	15.3 (14) $\pm$ 6.3 (n=85)	14.5 (14) $\pm$ 4.6 (n=81)	14.4 (14) $\pm$ 3.8 (n=80)	14.4 (14) $\pm$ 3.4 (n=69)
$\mu$ group, mean (median) $\pm$ SD (mmHg)	30.6 (28) $\pm$ 9.8 (n=35)	17.3 (17) $\pm$ 7.5 (n=35)	19.9 (18) $\pm$ 9.2 (n=35)	16.5 (14) $\pm$ 6.3 (n=34)	16.2 (14) $\pm$ 4.5 (n=33)	15.5 (15) $\pm$ 4.0 (n=31)	16.1 (17) $\pm$ 4.1 (n=31)
P value	0.331	0.546	0.316	0.276	0.0557	0.177	<b>0.0438</b>
S group with phacoemulsification, mean (median) $\pm$ SD (mmHg)	30.0 (30) $\pm$ 7.6 (n=51)	21.3 (17) $\pm$ 11.3 (n=51)	19.2 (16) $\pm$ 9.9 (n=50)	13.8 (14) $\pm$ 3.0 (n=50)	13.5 (13) $\pm$ 2.9 (n=49)	14.0 (13) $\pm$ 3.6 (n=49)	13.7 (14) $\pm$ 2.7 (n=41)
$\mu$ group with phacoemulsification, mean (median) $\pm$ SD (mmHg)	26.2 (22) $\pm$ 7.4 (n=16)	20.0 (19) $\pm$ 7.8 (n=16)	22.2 (20) $\pm$ 10.3 (n=16)	14.7 (14) $\pm$ 3.6 (n=15)	15.3 (14) $\pm$ 4.6 (n=15)	14.6 (14) $\pm$ 3.8 (n=14)	15.0 (14) $\pm$ 3.8 (n=14)
P value	<b>0.0197</b>	0.802	0.177	0.544	0.302	0.526	0.396
S group without phacoemulsification, mean (median) $\pm$ SD (mmHg)	34.0 (30) $\pm$ 9.9 (n=37)	18.3 (14) $\pm$ 10.1 (n=37)	18.1 (16) $\pm$ 9.1 (n=37)	17.4 (15.5) $\pm$ 8.7 (n=36)	15.9 (16.0) $\pm$ 6.1 (n=33)	15.0 (14) $\pm$ 4.0 (n=32)	15.4 (16) $\pm$ 4.1 (n=28)
$\mu$ group without phacoemulsification, mean (median) $\pm$ SD (mmHg)	34.3 (33) $\pm$ 10.2 (n=19)	15.1 (13) $\pm$ 6.6 (n=19)	17.9 (15) $\pm$ 7.9 (n=19)	17.8 (18.0) $\pm$ 7.6 (n=19)	16.9 (17.5) $\pm$ 4.4 (n=18)	16.2 (17) $\pm$ 4.1 (n=17)	17.0 (18) $\pm$ 4.3 (n=17)
P value	0.883	0.348	0.755	0.626	0.239	0.353	0.271

Bold italic font indicates statistical significance ( $P < 0.05$ )

SD, standard deviation. S group, gonioscopy-assisted suture trabeculotomy;  $\mu$  group, microhook trabeculotomy

**Table 4** Changes in the number of glaucoma medications

	Preoperative	1 week postoperative	1 month postoperative	3 months postoperative	6 months postoperative	12 months postoperative
S group, mean (median) $\pm$ SD	4.0 (4) $\pm$ 1.0 (n=122)	1.6 (1) $\pm$ 1.6 (n=121)	1.8 (2) $\pm$ 1.6 (n=120)	1.8 (2) $\pm$ 1.5 (n=116)	2.0 (2) $\pm$ 1.6 (n=115)	1.8 (2) $\pm$ 1.5 (n=102)
$\mu$ group, mean (median) $\pm$ SD	3.9 (4) $\pm$ 1.2 (n=47)	1.5 (2) $\pm$ 1.5 (n=47)	2.0 (2) $\pm$ 1.6 (n=46)	2.0 (2) $\pm$ 1.6 (n=45)	2.1 (2) $\pm$ 1.6 (n=43)	2.2 (2) $\pm$ 1.7 (n=43)
P value	0.873	0.809	0.699	0.420	0.737	0.198

Bold italic font indicates statistical significance ( $P < 0.05$ )

SD, standard deviation. S group, gonioscopy-assisted suture trabeculotomy;  $\mu$  group, microhook trabeculotomy

Theoretically, a wider SC incision could achieve a greater IOP-lowering effect by providing a greater reduction of aqueous fluid outflow resistance. However, previous reports have shown no significant differences in postoperative outcomes according to the range of SC incision using suture and microhook trabeculotomy methods. Manabe et al. [9] reported that the extent of incision within 150° and 320° of suture trabeculotomy ab externo did not correlate with postoperative IOP reduction. In a prospective study that compared outcomes according to the extent and location of the incision among groups with a 360° incision, and an

upper- and lower-180° incision, Sato et al. [10] found no differences in IOP reduction and number of medications at 1 year postoperatively. Similarly, Mori et al. [8] compared 1-year outcomes and early surgery-related complications between one-quadrant and two-quadrant microhook trabeculotomy methods; they reported that the 1-year postoperative IOP, drug score, and Kaplan–Meier survival findings did not significantly differ between the one-quadrant and two-quadrant methods.

Using enucleated human eyes, Rosenquist et al. [11] reported that a 120° SC incision had 85% effectiveness for

**Table 5** Changes in proportion of glaucoma medication

	3 months postoperative	6 months postoperative	12 months postoperative
Complete success			
S group (%)	19.7 (24/122)	19.7 (24/122)	17.2 (21/122)
μ group (%)	19.1 (9/47)	19.1 (9/47)	19.1 (9/47)
<i>P</i> value	1.000	1.000	0.823
Qualified success			
S group (%)	52.5 (64/122)	49.2 (60/122)	50.0 (61/122)
μ group (%)	44.7 (21/47)	44.7 (21/47)	48.9 (23/47)
<i>P</i> value	0.394	0.611	1.000

Complete success: normal IOP (> 5 to ≤ 18 mmHg), ≥ 20% without any eye drops

Qualified success: normal IOP (> 5 to ≤ 18 mmHg), ≥ 20% with IOP-lowering eye drops

Bold italic font indicates statistical significance ( $P < 0.05$ )

S group, gonioscopy-assisted suture trabeculotomy; μ group, microhook trabeculotomy

**Table 6** Intraoperative and postoperative complications

	Total 145 patients (169 eyes)	S group 104 patients (122 eyes)	μ group 42 patients (47 eyes)	<i>P</i> value
Hyphema, <i>n</i> (%)				
Day 1	96 (56.8)	72 (59.0)	24 (51.1)	0.446
Week 1	73 (43.2)	56 (45.9)	17 (36.2)	0.332
IOP spike (≥ 25 mmHg), <i>n</i> (%)	35 (20.7)	25 (20.4)	10 (21.3)	1.000
Hypotony (IOP < 5 mmHg), <i>n</i> (%)	0	0	0	NA
Wound leaks	0	0	0	NA
Anterior chamber washout, <i>n</i> (%)	8 (2.1)	7 (5.7)	1 (2.1)	0.438
Additional glaucoma surgery, <i>n</i> (%)	15 (8.9)	11 (9.0)	4 (8.5)	1.000

Bold italic font indicates statistical significance ( $P < 0.05$ )

S group, gonioscopy-assisted suture trabeculotomy; μ group, microhook trabeculotomy. IOP, intraocular pressure; NA, not applicable

IOP reduction compared with a 360° SC incision; moreover, additional effectiveness was presumed to be achieved with incisions > 120°. Thus, our better 1-year outcomes in eyes undergoing suture trabeculotomy may be independent of the extent of the incision.

Several studies have investigated post-trabeculotomy morphological changes using anterior-segment optical coherence tomography (OCT). Akagi et al. [12] observed ciliochoroidal detachment (CCD) after ab interno trabeculotomy with a microsurgical device hand piece. At 3 days postoperatively, 42% of eyes had CCD and 58% of eyes had no CCD; postoperative CCD was associated with a lower IOP. This suggests that a non-conventional outflow pathway might be activated by trabeculotomy. Sato et al. [13] found similar results after 360° suture trabeculotomy ab interno. They hypothesized that CCD occurred more frequently in eyes subjected to 360° suture trabeculotomy compared with eyes subjected to trabectome surgery, because of the wider SC incision. However, the results showed that the presence and extent of CCD were similar for both surgical procedures: CCD was observed in 47.7% of eyes at 7 days

postoperatively. Early postoperative CCD presumably had no effect on subsequent IOP; therefore, it cannot explain later differences in the success rates between the S and μ groups.

During microhook surgery, intraoperative OCT visualized the trabeculotomy cleft. Ishida et al. [14] identified three incisional patterns (anterior-opening, middle-opening, and posterior-opening), according to the predominant locations of TM flaps. The anterior-opening pattern was reportedly predominant. To the best of our knowledge, there are no data regarding the relationship between postoperative IOP and incisional pattern. Sato et al. [13] reported that they observed the root of the iris after intraoperative TM peeling during suture trabeculotomy suggesting S-LOT might form a continuous cyclodialysis cleft and posteriorly wider circumferential TM and SC incisions, leading to unconventional outflow. We hypothesize that this difference in cleft size partly explains the difference in 12-month outcomes between the two procedures.

A previous study [15] of microhook trabeculotomy demonstrated a poor prognosis in patients with higher



preoperative IOP (e.g., those with exfoliative glaucoma). The collector channel distribution after SC differs between operated eyes and the collector channel and episcleral veins may become sclerotic under high IOP, resulting in a reduction in aqueous humor outflow function. In those eyes, a wider incision may be necessary to maintain outflow against the wound healing process. The patients in this study had undergone comparatively longer treatment at regular clinics before referral for surgery and this extended treatment might have affected the results. A recent report [16] suggested that atrophy of the collector channel system occurred depending on the degree of glaucoma. In patients with a short history of glaucoma medication, the collector channel function and subsequent function could be maintained with a more favorable surgical result.

Regarding surgical complications, a wider incision can have a greater risk of anterior chamber hemorrhage and transient IOP elevation [8]. However, there were no significant differences in such complications between the groups in the present study. Both procedures caused hyphema in almost half of the eyes and they caused a transient IOP spike in approximately 20% of eyes. Notably, the proportion of eyes that required anterior washout was higher in the S group, which generally causes unclear vision and high postoperative IOP.

There were several limitations in this study. First, the comparison was performed over a short duration (i.e., 12 months postoperatively) among a small number of participants. Second, because this was a retrospective study, postoperative IOP management was performed at the physician's discretion, which might have affected the postoperative IOP and drug score. Third, the incisional extent of microhook trabeculotomy in our study was wider than that generally used in such surgeries, which may have influenced the results. However, we presume that it is important to identify the advantages and disadvantages of each surgical method, as the initial step of glaucomatous surgery.

In conclusion, the S and  $\mu$  groups achieved an IOP reduction with a long-range SC incision while preserving the conjunctiva and sclera. The Kaplan–Meier survival analysis indicated that the cumulative clinical success rate did not significantly differ between the two groups, although eyes with high preoperative IOP had a greater clinical success rate in the S group than in the  $\mu$  group. The optimal methods of trabeculotomy, including the extent of incision, require further investigation.

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**Data availability** Available.

**Code availability** Not applicable.

## Declarations

**Ethics approval** This study was approved by the Institutional Review Board of Hyogo College of Medicine (No. 3535).

**Consent to participate** Written informed consent was obtained from all participants for participation in this study and publication of the associated images. In view of the retrospective nature of the study, all the procedures were performed as a part of a routine clinical examination.

**Consent for publication** Written informed consent was obtained from all participants for publication of the associated images.

**Conflict of interest** The authors declare no competing interests.

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