BMJ Open Ophthalmology

A comparison of the 1-year surgical outcomes of *ab externo* trabeculotomy and microhook *ab interno* trabeculotomy using propensity score analysis

Sotaro Mori, Yusuke Murai, Kaori Ueda, Mari Sakamoto, Takuji Kurimoto, Yuko Yamada-Nakanishi, Makoto Nakamura

To cite: Mori S, Murai Y, Ueda K, *et al*. A comparison of the 1-year surgical outcomes of *ab externo* trabeculotomy and microhook *ab interno* trabeculotomy using propensity score analysis. *BMJ Open Ophthalmology* 2020;**5**:e000446. doi:10.1136/bmjophth-2020-000446

Received 22 January 2020
Revised 13 February 2020
Accepted 19 February 2020

Department of Surgery, Division of Ophthalmology, Kobe University Graduate School of Medicine, Kobe, Japan

Correspondence to
Dr Makoto Nakamura;
manakamu@med.kobe-u.ac.jp

ABSTRACT

Objective To compare the 1-year outcomes of trabeculotomy *ab externo* (*ab externo* TLO) and trabeculotomy *ab interno* using a microhook (*ab interno* TLO) for glaucoma patients using propensity score analysis.

Methods and analysis The medical charts of 65 consecutive patients who underwent *ab externo* TLO and those of 69 patients who underwent *ab interno* TLO were reviewed. Logistic regression analysis was conducted to calculate the propensity score using 1:1 matched analysis, which indicates the likelihood of surgical success at 12 months. We set the outcome-related covariates as age, glaucoma type, mean deviation, preoperative intraocular pressure (IOP), the number of preoperative glaucoma eye drops and the presence or absence of combined cataract surgery. Fifty eyes per each surgery group were subsequently compared.

Results The mean preoperative IOP was 32.5±11.2 mm Hg in the *ab externo* TLO group and 28.4±7.8 mm Hg in the *ab interno* TLO group (p=0.08). The mean postoperative IOP at 12 months was 18.3±7.4 mm Hg in the former group and 17.8±6.3 mm Hg in the latter (p=0.91). When surgical success was defined as a postoperative IOP of between 5 and 21 mm Hg with a more than 20% IOP reduction from baseline and no additional glaucoma surgery, the rate at 12 months was 78% in the *ab externo* TLO group and 74% in the *ab interno* TLO group (p=1.00).

Conclusion The 1-year success rate was not significantly different between *ab externo* and *ab interno* TLO.

Key messages

What is already known about this subject?

- Trabeculotomy *ab externo* is one of the established glaucoma surgeries to reduce intraocular pressure (IOP) particularly for childhood glaucoma, exfoliation glaucoma and steroid glaucoma. Recently, a microhook for trabeculotomy *ab interno* has been developed as an option for micro-invasive glaucoma surgery device. However, there have been no studies, including randomised clinical trials, to compare the efficacy and safety between the standard trabeculotomy *ab externo* and the newly developed trabeculotomy *ab interno* using a microhook.

What are the new findings?

- This study conducted a quasi-randomised comparison of the efficacy and safety between the two procedures using a propensity score analysis. The 1-year surgical success rate turned out to be excellent (74%–78%) and similar between the two procedures with infrequent complications.

How might these results change the focus of research or clinical practice?

- Given no damage on the conjunctiva and sclera tissue and the shorter surgery time involved, trabeculotomy *ab interno* using a microhook may become an alternative to trabeculotomy *ab externo* for reducing IOP in patients with early stage glaucoma.

INTRODUCTION

Trabeculotomy (TLO) is known as an effective surgical procedure used for managing glaucoma. In *ab externo* TLO, the Schlemm's canal is identified either by peeling off a scleral flap or by making an incision in the scleral wall over the Schlemm's canal before a metal probe is inserted into the canal and rotated into the anterior chamber to perforate the inner wall of the canal. The *ab externo* TLO procedure has been shown to reduce intraocular pressure (IOP) not only in patients with childhood glaucoma[1 2] but also in adult patients with primary open angle glaucoma (POAG), steroid glaucoma and exfoliation glaucoma, at early stages.[3–5]

Compared with trabeculectomy, TLO is a safer procedure with less frequency of the development of sight-threatening bleb-associated infection and hypotony due to its nature of reconstructing physiological aqueous humour drainage, while it has less magnitude in terms of IOP lowering ability. The mean postoperative IOP was reported to range from 12.3 to 18.4 mm Hg,[3–5] thus

discouraging its application for patients with advanced glaucoma who require lower target IOP.

Recent trends for micro-invasive glaucoma surgery (MIGS) has prompted the reappraisal of the utility and significance of TLO. Many devices, including trabectome,[6–10] the Kahook dual blade[11] and iStent,[12] have been developed with the aim of reconstructing the physiological aqueous outflow facility. Recently, Dr Masaki Tanito also developed a microhook for *ab interno* TLO.[13–15] MIGS that uses such a device approaches the trabecular meshwork interiorly, which is visualised through a goniolens, and, unlike conventional *ab externo* TLO, preserves the conjunctiva and sclera intact. Due to the short operation time and the minimal invasiveness, MIGS has become increasingly popular worldwide. However, there exist few reports that compare the effectiveness and safety of *ab externo* TLO and *ab interno* TLO.[10]

In Kobe University Hospital, *ab externo* TLO was mainly used until December 2014, before trabectome surgery and *ab interno* TLO using the Tanito microhook were introduced in November 2014 and February 2017, respectively.

Tanito *et al* originally cut the trabecular meshwork at two quadrants (approximately 240°) during the microhook *ab interno* TLO.[13–15] However, we experienced substantial post-surgical hyphema in some patients. Because of this, we performed *ab interno* TLO for one quadrant (approximately 120°) since October 2017, as performed in *ab externo* TLO.

The purpose of this study was to evaluate whether or not the surgical outcome was similar for *ab externo* TLO and one quadrant *ab interno* TLO. To cope with any shortcomings due to the retrospective nature of the study, we utilised propensity score analysis for minimising the influence of the confounding factors and compared the outcomes of the two procedures in a quasi-randomised fashion.[16]

METHODS

We reviewed the medical charts of 65 consecutive patients who underwent *ab externo* TLO between May 2012 and December 2015 and those of 69 patients who underwent single-quadrant *ab interno* TLO between October 2017 and November 2018 at Kobe University Hospital. We excluded patients who had a past history of glaucoma surgery or who were under 20 years of age at the time of the surgery. Only the first eye was included if both eyes underwent the surgery.

The study adhered to the tenets of the Declaration of Helsinki. Patients were not directly involved in the design of this study.

IOP was measured using a Goldmann applanation tonometer twice per session, and the average value was used. When the difference between the two measurements exceeded 1 mm Hg, a third measurement was carried out, and the median of the three measurements was designated as the IOP of the session.

Best-corrected decimal visual acuity (VA) was measured using a Landolt ring chart and was converted to the logarithm of minimal angle resolution (logMAR) for statistical analysis. In this study, a VA of 0.01 and counting finger denoted a logMAR of 2.0, while hand motion was scored as 2.9.[17] There were no patients whose VA was light perception nor no light perception.

We used the Swedish interactive threshold algorithm standard 30-2 programme of the Humphrey visual field analyser (Carl Zeiss-Meditec) to measure the visual field. The mean deviation was then analysed. Non-contact specular microscopy (Noncon Robo SP-8000; Konan Medical) was used to measure corneal endothelial cell density (ECD).

The surgical technique of the *ab externo* TLO was as follows: a 4×4 mm^2 square external scleral flap of approximately one half of the scleral thickness was created at an inferotemporal or superior area. Next, a 3.5×3.5 mm^2 internal scleral flap with a thin residual scleral bed retained was created to expose the Schlemm's canal. Two metal probes (trabeculotome, Handaya Inc) were inserted into the Schlemm's canal in opposite directions and then rotated by a total of approximately 120° to perforate and cut the trabecular meshwork. The internal flap was dissected to accomplish deep sclerectomy (DS). Following this, the external scleral flap was secured by 10-0 nylon and the conjunctiva by 8-0 Vicryl (Ethicon Inc).

Meanwhile, the *ab interno* TLO was performed as previously reported.[13–15] In brief, a temporal corneal side port was created before the aqueous humour was replaced by a viscoelastic material. After rotating the patient's head and the surgical microscope in opposite directions to produce an approximate 90° viewing angle, the anterior chamber angle was visualised using the Swan-Jacob lens (Ocular Instruments). A straight-type Tanito *ab interno* TLO (Inami & Co, Ltd) was inserted through the side port, and the inner wall of the trabecular meshwork at the nasal 120° (from 1 to 5 o'clock in the right eye and from 7 to 11 o'clock in the left eye) was incised. The viscoelastic material was removed through irrigation with BSS (Alcon Laboratories, Inc) through the side port.

In both procedures, the patients postoperatively received topical antibiotics, 0.1% betamethasone sodium phosphate (Shionogi & Co) and 2% pilocarpine (Santen Pharmaceutical Co), which was terminated by 2–4 weeks according to the degree of intraocular inflammation.

The primary endpoint of this study was the success period of the surgery. The secondary endpoints were IOP, glaucoma drug score, logMAR VA and IOP at 1 week, 1 month, 3 months, 6 months, 9 months and 12 months postoperatively.

The surgery was defined as successful after 1 month and later when the eyes met both criteria as follows: IOP was between 5 and 21 mm Hg with more than 20% reduction from the most recent preoperative IOP and no additional glaucoma surgery was required. When IOP fell out of the success range at two consecutive time points,

we judged that the surgery reached a failure at the first time point.

Logistic regression analysis was conducted to calculate the propensity score using 1:1 matched analysis, which indicates the likelihood of surgical success at 12 months. We set the outcome-related covariates as age, glaucoma type, mean deviation and preoperative IOP, as well as the number of preoperative glaucoma eye drops and the presence or absence of combined cataract surgery. To obtain the propensity score, a surgical procedure was not included in the logistic regression analysis. Fifty eyes per each surgery group were compared after removing the confounding factors.

In terms of the glaucoma drug score, any monotherapy of eye drops was given one point, while a fixed combination of these and an oral carbonic anhydrase inhibitor was given two points.

The last observation carried forward (LOCF) method was adapted to impute any missing continuous value data. We defined the transiently elevated IOP when the postoperative IOP values exceeded the preoperative IOP values within 2 weeks.

A comparison of the success rates up to 1 year after surgery between the two groups was carried out using Kaplan-Meier survival analysis and a log rank test. The success rates at 12 months postoperatively and the frequency of transiently elevated IOP were compared using Fisher's exact tests. Other quantifiable parameters were compared using the Mann-Whitney U test. The longitudinal changes in the parameters were compared using the mixed-effects model.

Statistical analysis was performed using MedCalc (MedCalc Software V.19.1.3) and SPSS Statistics (V.20, IBM). P<0.05 was considered as statistically significant.

RESULTS

The demographic details of the subjects are presented in table 1. There were no significant differences between the two groups in terms of age, number of eyes, sex, glaucoma type, preoperative IOP, mean deviation, phakic status, ECD or concomitant cataract surgery. Following the comparison, the glaucoma drug score was significantly higher in the *ab interno* TLO group (4.9±1.1) than in the *ab externo* TLO group (4.3±1.4) (p=0.02, Mann-Whitney U test). The preoperative logMAR VA was worse in the *ab externo* TLO group (0.19±0.52) than in the *ab interno* group (0.04±0.22) (p<0.01, Mann-Whitney U test).

Table 2 summarises the postoperative outcomes at 12 months for both groups. The success retention rate was almost the same for the *ab externo* TLO group (78%) and the *ab interno* TLO group (74%) (p=1.00, Fisher's exact test), which was also confirmed by the log rank test (p=0.56) on the Kaplan-Meier survival curves (figure 1). The mean postoperative IOP was not significantly different between the *ab externo* TLO (18.3±7.4 mm Hg) and the *ab interno* TLO (17.8±6.3 mm Hg) groups (p=0.91, Mann-Whitney U test).

The *ab externo* TLO group tended to show lower postoperative glaucoma drug scores (2.6±1.9) than the *ab interno* TLO group (3.1±1.6) (p=0.06, Mann-Whitney U test), but the differences in preoperative and postoperative drug scores between the two groups did not reach statistical

Table 1 Preoperative patient demographics

	Ab externo TLO (n=50)	*Ab interno* TLO (n=50)	P value
Mean age (SD)	66.0 (16.9)	66.6 (15.7)	0.98*
Right eye (%)	22(44)	18(36)	0.54†
Men (%)	25(50)	26(52)	1.00†
Combined cataract surgery (%)	10(20)	12(24)	0.81†
Preoperative HVF MD (SD), dB	−11.0 (7.8)	−13.6 (8.6)	0.14*
Preoperative IOP (SD), mm Hg	32.5 (11.2)	28.4 (7.8)	0.08*
Preoperative glaucoma drug score (SD)	4.3 (1.4)	4.9 (1.1)	0.02*
Phakia(%)	23(46)	17(34)	0.77*
Preoperative logMAR visual acuity	0.19 (0.52)	0.04 (0.22)	<0.01*
Preoperative corneal endothelial cell density (SD), cells/mm^2	2600.5 (346.9)	2391.9 (592.2)	0.09*
Glaucoma type			
Primary open angle glaucoma (%)	15(30)	22(44)	0.21†
Exfoliation glaucoma (%)	17(34)	17(34)	
Steroid-induced glaucoma (%)	9 (18)	4 (8)	
Other secondary glaucoma (%)	9 (18)	7 (14)	

*Mann-Whitney U test.
†Fisher's exact test.
ab externo TLO, trabeculotomy *ab externo*; *ab interno* TLO, trabeculotomy *ab interno* using a microhook; HVF, Humphrey visual field; IOP, intraocular pressure; logMAR, logarithm of minimal angle resolution; MD, mean deviation.

Table 2 Surgical outcome

	Ab externo TLO (n=50)	*Ab interno* TLO (n=50)	P value
Success rate (%)	39(78)	37(74)	1.00*
Postoperative mean IOP (SD), mm Hg	18.3 (7.4)	17.8 (6.3)	0.91†
Change in IOP (SD), (%)	40.5 (22.5)	34.4 (25.4)	0.15†
Postoperative glaucoma drug score (SD)	2.6 (1.9)	3.1 (1.6)	0.06†
Change in glaucoma drug score (SD)	1.7 (2.1)	1.5 (2.3)	0.71†
Postoperative logMAR visual acuity	0.25 (0.35)	0.05 (0.23)	0.04†
Change in logMAR visual acuity (SD)	−0.03 (0.30)	0.01 (0.14)	0.43†
Postoperative corneal endothelial cell density (SD), cells/mm^2	2630.7 (320.9)	2369.9 (633.2)	0.08†
Change in corneal endothelial cell density (SD), %	+1.4 (9.2)	−1.2 (10.5)	<0.0001†

*Fisher's exact test.
†Mann-Whitney U test.
ab externo TLO, trabeculotomy *ab externo*; *ab interno* TLO, trabeculotomy *ab interno* using a microhook; IOP, intraocular pressure; logMAR, logarithm of minimal angle resolution.

significance (ab externo TLO: 1.7±2.1; *ab interno* TLO: 1.5±2.3; p=0.71, Mann-Whitney U test). There was no significant difference in the postoperative ECD between the two groups (*ab externo* TLO: 2630.7±320.9 cells/mm^2, *ab interno* TLO: 2369.9±633.2 cells/mm^2, p=0.08), while it had increased (1.4%±9.2%) in the *ab externo* TLO group and had decreased (−1.2%±10.5%) in the *ab interno* group. The changes in preoperative and postoperative ECD were statistically significant between the two groups (p<0.0001).

Figure 2 shows the time course for the changes in IOP and glaucoma drug score. In both groups, the postoperative IOP and the glaucoma drug scores were significantly reduced at all postoperative observation points compared with the preoperative values (mixed-effects model, p<0.0001). The mean IOP was distributed within the range of between 16 and 18 mm Hg at any point after 1 week postoperatively in both groups, while the glaucoma drug score gradually increased over time. There were no significant intergroup differences in terms of postoperative mean IOP or glaucoma drug score at any follow-up point.

The scatter plots representing VA before and after surgery are shown in figure 3. In both groups, there was a significant correlation between the preoperative and postoperative VA at 12 months (Pearson correlation coefficient, *ab externo* TLO: r=0.846, p<0.0001, *ab interno* TLO: r=0.800, p<0.0001). The postoperative VA in the *ab externo* TLO group (0.25±0.35) was significantly worse than in the *ab interno* TLO group (0.05±0.23) (p=0.04, Mann-Whitney U test), but there was no significant difference in the changes to preoperative and postoperative VA between the two groups (*ab externo* TLO: −0.03±0.30, *ab interno* TLO: 0.01±0.14, p=0.43, Mann-Whitney U test). Three patients in the *ab externo* TLO group and two in the *ab interno* TLO group showed a deterioration of more than 0.3 in logMAR VA compared with the preoperative

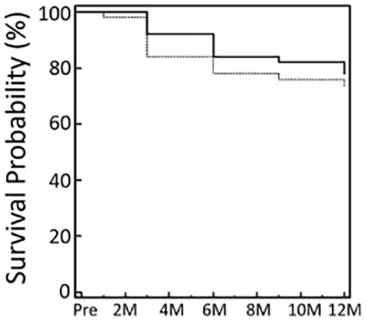

Figure 1 Kaplan-Meier survival curves showing the surgical outcomes of each surgery type. The solid lines indicate trabeculotomy *ab externo* and the dotted lines indicate trabeculotomy *ab interno* using a microhook. Note that there are no significant differences between the two groups. Pre denotes preoperative; 2M, 2 months; 4M, 4 months; 6M, 6 months; 8M, 8 months; 10M, 10 months; and 12M, 12 months postoperatively.

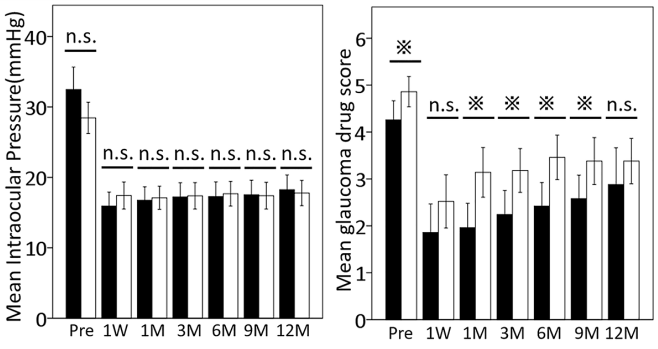

Figure 2 Time course of the mean intraocular pressure and the glaucoma drug score. The black bars indicate trabeculotomy *ab externo* and the white bars indicate trabeculotomy *ab interno* using a microhook. The error bar indicates SD. The postoperative value at 1 year was not significantly different between the two groups. Pre denotes preoperative; 1W, 1 week; 1M, 1 month; 3M, 3 months; 6M, 6 months; 9M, 9 months; 12M, 12 months postoperatively; n.s. denotes not significant and ※, p<0.05.

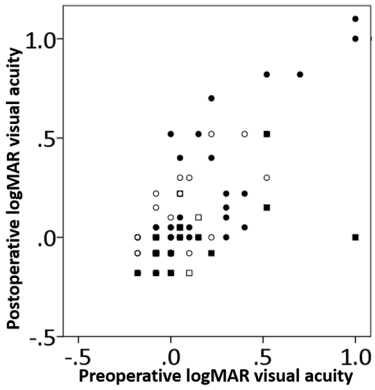

Figure 3 Scatter plots of preoperative and postoperative 1 year after surgery logMAR visual acuity. The closed circles represent patients who underwent trabeculotomy *ab externo* TLO without cataract surgery, and the closed squares represent patients who underwent this procedure with cataract surgery. The open circles represent patients who underwent trabeculotomy *ab interno* using a microhook without cataract surgery and the open squares represent patients who underwent this procedure with cataract surgery. Both groups showed significant correlations between the two periods in terms of logMAR visual acuity (Pearson correlation coefficient, *ab externo* TLO: r=0.846, p<0.0001, *ab interno* TLO: r=0.800, p<0.0001).

values. In two eyes, central visual field damage progressed probably due to the transient IOP elevation. In the remaining one eye, the reason was the development of bullous keratopathy as mentioned below.

Table 3 lists the surgery-related adverse events of the two groups.

Table 3 Adverse events

	Ab externo TLO (n=50)	*Ab interno* TLO (n=50)	P value*
Hyphema with niveau (%)	10(20)	8 (16)	0.80
Transient increase in IOP (%)	12(24)	18(36)	0.28
Additional glaucoma surgeries (%)	9 (18)	11(22)	0.80
Trabeculectomy	8 (16)	9 (18)	1.00
Tube shunt surgery	1 (2)	2 (4)	1.00
Vitreous haemorrhage (%)	1 (2)	2 (4)	1.00
Descemet membrane rupture (%)	3 (6)	0 (0)	0.24
Transient hypotony (%)	1 (2)	0 (0)	1.00
Cystoid macular oedema (%)	0 (0)	1 (2)	1.00
Bullous keratopathy (%)	0 (0)	1 (2)	1.00

*Fisher's exact test.
ab externo TLO, trabeculotomy *ab externo*; *ab interno*, trabeculotomy *ab interno* using a microhook; IOP, intraocular pressure.

We found the similar frequency of hyphema with a niveau, transient increase in IOP, additional glaucoma surgeries and vitreous haemorrhage between the two groups. In the *ab externo* TLO group, one patient became transient hypotony which was defined as IOP less than 5 mm Hg. It was due to the filtration of aqueous humour through the scleral flap, which made a small conjunctival bleb for 2 weeks after surgery. In the *ab interno* TLO group, one eye experienced cystoid macular oedema probably because of a concomitant cataract surgery. Another eye became bullous keratopathy. The eye had unmeasurable corneal endothelial cells density even before surgery, although transparency was kept at the surgery. Hyphema and vitreous haemorrhage spontaneously subsided, and cystoid macular oedema was resolved after non-steroid anti-inflammatory drug eye drop instillation.

DISCUSSION

In this study, *ab externo* TLO and *ab interno* TLO demonstrated a similar IOP lowering effect up to 12 months postoperatively. In other words, there were no significant differences in terms of success rate, mean IOP, IOP reduction rate or the changes in glaucoma drug score between the two groups.

Previous studies reported that *ab externo* TLO achieved mean postoperative IOPs ranging from 12.3 to 18.4 mm Hg,[3–5] while Tanito *et al* showed that *ab interno* TLO had a mean postoperative IOP of 11.8±4.5 mm Hg at 9.5 months postoperatively.[14] Compared with these reports, our present postoperative IOP at 1 year was higher in both procedures (*ab externo* TLO: 18.3±7.4 mm Hg, *ab interno* TLO: 17.8±6.3 mm Hg). We believe that the poorer effectiveness in this study was a result of the fact that our subjects included many patients who had used multiple glaucoma drugs for a long period and the fact that we applied the LOCF method to obtain our mean IOP, in which the values from patients with surgical failure were also included.

Although a propensity score adjustment was carried out, the preoperative glaucoma drug score in the *ab interno* TLO group (4.9±1.1) was significantly higher than that in the *ab externo* TLO group (4.3±1.4). We believe this is because the periods of prevalence for the two types of surgery were different. For example, during the *ab externo* TLO era, brimonidine and ripasudil were not available in Japan. Nevertheless, the postoperative drug score did not change between the two groups, indicating that *ab interno* TLO is, in fact, effective in reducing IOP.

Previous reports demonstrated that many confounding factors affect the surgical outcomes of TLO. Surgery involving elderly patients[3 18] and concomitant cataract surgery[7 8 10 19] generally had better outcomes. Meanwhile, some reported that exfoliation glaucoma patients showed better outcomes compared with POAG patients,[3] while others found the opposite outcome.[20] Steroid glaucoma was shown to have better results compared with POAG.[5] Higher preoperative IOP was reported to result in lower surgical success rates.[3 9] In addition, the history

of previous glaucoma surgeries including laser surgery, which was excluded from the enrolment criteria in this study, had a negative impact.[8 21]

Given the various aforementioned factors that affect surgical outcomes, this study utilised propensity score analysis to minimise the effects of the confounding factors and to ensure the preoperative parameters were as comparable as possible between the two surgery groups. This analysis demonstrated a similar IOP lowering effect of *ab interno* TLO to that of *ab externo* TLO.

Note that our *ab externo* TLO included a DS procedure. DS has generally been regarded as stand-alone non-penetrating filtration surgery in Europe and the USA,[22 23] while in Japan, DS has primarily been performed in conjunction with *ab externo* TLO, either to avoid the transiently elevated IOP after TLO[4 10] or to enhance the IOP lowering effect of TLO.[10] However, our results showed that DS did not have an additional IOP lowering effect and did not reduce the chance of transiently elevated IOP after *ab externo* TLO compared with *ab interno* TLO.

Few reports have compared the surgical outcomes of *ab externo* TLO and *ab interno* TLO in patients with adult glaucoma. Nakano *et al* demonstrated that *ab externo* TLO with DS tended to exhibit more IOP reduction after 3 years postoperatively compared with trabectome surgery, but the difference was not significant.[10] Unlike *ab interno* TLO using the Tanito hook, *ab interno* trabeculectomy using the trabectome dissects and removes the trabecular meshwork, providing a potentially higher IOP lowering effect.

Tanito *et al* noted that the transiently elevated IOP after *ab interno* TLO, which was defined as more than 30 mm Hg in the early preoperative period, was 9%.[14] Unexpectedly, the frequency of the transiently elevated IOP was not different between *ab interno* TLO and *ab externo* TLO. At the early postoperative stage of *ab externo* TLO, a small fraction of the aqueous humour is drained out of the eye beside the scleral flap,[3] while *ab interno* TLO involves a completely water-tight procedure. In addition, since our *ab externo* TLO included DS, we expected to find a higher frequency of transiently elevated IOP in the *ab interno* TLO group. Trabectome surgery[6–8] and *ab interno* TLO[14] demonstrated a hyphema appearance rate ranging from 41% to 79.5%, which was comparable with that of *ab externo* TLO (90.1%).[4] Because of the retrospective nature of this study, we counted the number of eyes with hyphema from medical charts only when they formed a niveau. Probably for this reason, the frequency of postoperative hyphema was much less than the previous reports, although more cases may have exhibited milder hyphema in our cohort. Collectively, the transiently elevated IOP after *ab interno* TLO will occur less than anticipated.

In this study, we found vitreous haemorrhage in three cases. All these patients had exfoliation glaucoma, in which blood in hyphema likely went down into vitreous cavity due to zonular dehiscence. Although, fortunately, hyphema and subsequent vitreous haemorrhage spontaneously subsided in the current cohorts, we sometimes experienced patients with severe hyphema and prolonged vitreous haemorrhage, in which additional surgical intervention such as anterior chamber irrigation and aspiration and pars plana vitrectomy was, rarely even emergently, required to reduce IOP or/and improve VA. As mentioned, two patients experienced VA reduction over 0.3 logMAR unit due to transient IOP elevation. Therefore, we must be aware of the risk of irreversible visual functional damage after TLO, whether *ab externo* or *ab interno* approaches, in glaucomatous eyes, particularly eyes with exfoliation glaucoma, with advanced stages. In relation to this, we also must note that approximately 20% of cases that underwent TLO, whether *ab externo* or *ab interno* approaches, required additional glaucoma surgeries.

There were no significant differences in preoperative and postoperative ECD between the two groups. However, despite the almost equal frequency of concomitant cataract surgeries in both groups, the *ab interno* TLO group showed a higher ECD reduction rate than the *ab externo* group ($p<0.0001$, Mann-Whitney U test). The more intraocular procedures involved in *ab interno* TLO may have contributed to this higher ECD reduction. However, the difference seemed to arise from the paradoxical increase in postoperative ECD with *ab externo* TLO, the reason for which is markedly unclear. Given the fairly low ECD reduction rate, the *ab interno* TLO is clinically acceptable, even from a safety point of view.

This study had several limitations. For one, while propensity score analysis is essentially a quasi-randomised experiment, it can minimise the known preoperative confounding factors to allow us to compare the causal effects[16]; unlike prospective randomised clinical trials, propensity score analysis is not able to randomise unknown confounding factors and loses some samples through the 1:1 matching analysis. Meanwhile, because a sample size was not calculated a priori, our result of there being no difference in surgical outcomes between the two groups does not confirm the authentic equivalence of *ab interno* TLO and *ab externo* TLO. Moreover, we could not precisely evaluate the postoperative anterior chamber haemorrhaging or peripheral anterior synechiae formation, which may have affected the outcomes. Finally, our study was a single-institution study involving only Japanese patients, and future research that includes other racial subjects in multiple facilities is required to confirm and generalise our pilot-study results.

In conclusion, the success rate at 12 months after surgery was not significantly different between *ab externo* and *ab interno* TLO. The reduction of IOP and the glaucoma drug scores in the two groups also showed no significant difference. Given the fact that it keeps the conjunctiva and sclera tissue free from damage and given the short surgery time involved, *ab interno* TLO is a promising method for reducing IOP in patients with early stage glaucoma.

Acknowledgements The authors thank 'Enago (www.enago.jp)' for the English language review.

Contributors Conceptualisation: TK, YY-N and MN; data sampling: SM, YM and KU; data analysis: SM and MS; drafting: SM and MN; critical reading and reviewing: TK, YY-N and MS; submission: MN.

Funding This study was partly presented at the 8th World Glaucoma Congress 2019 held in Melbourne.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval This study was approved by the Institutional Review Board of the Kobe University Graduate School of Medicine (No.1557).

Provenance and peer review Not commissioned; externally peer reviewed.

ORCID iD

Makoto Nakamura http://orcid.org/0000-0002-6464-4302

REFERENCES

1 Akimoto M*et al*. Surgical results of trabeculotomy ab externo for developmental glaucoma. *Arch Ophthal* 1994;112:1540–4.
2 Ikeda H*et al*. Long-Term outcome of trabeculotomy for the treatment of DevelopmentalGlaucoma. *Arch Ophthal* 2004;122:1122–8.
3 Tanihara H*et al*. Surgical effects of trabeculotomy ab externo on adult eyes with primary open angle glaucoma and pseudoexfoliation syndrome. *Arch Ophthal* 1993;111:1653–61.
4 Fukuchi T, Ueda J, Nakatsue T, *et al*. Trabeculotomy combined with phacoemulsification, intraocular lens implantation and sinusotomy for exfoliation glaucoma. *Jpn J Ophthalmol* 2011;55:205–12.
5 Iwao K, Inatani M, Tanihara H. Success rates of trabeculotomy for steroid-induced glaucoma: a comparative, multicenter, retrospective cohort study. *Am J Ophthalmol* 2011;151:1047–56.
6 Minckler D, Baerveldt G, Alfaro M, *et al*. Clinical results with the trabectome for treatment of open-angle glaucoma. *Ophthalmology* 2005;112:962–7.
7 Ahuja Y, Ma Khin Pyi S, Malihi M, *et al*. Clinical results of ab interno trabeculotomy using the trabectome for open-angle glaucoma: the Mayo clinic series in Rochester, Minnesota. *Am J Ophthalmol* 2013;156:927–35.
8 Shoji N, Kasahara M, Iijima A, *et al*. Short-Term evaluation of trabectome surgery performed on Japanese patients with open-angle glaucoma. *Jpn J Ophthalmol* 2016;60:156–65.
9 Tojo N, Abe S, Hayashi A. Factors that influence of trabectome surgery for glaucoma patients. *J Glaucoma* 2017;26:835–44.
10 Kinoshita-Nakano E, Nakanishi H, Ohashi-Ikeda H, *et al*. Comparative outcomes of trabeculotomy ab externo versus trabecular ablation ab interno for open angle glaucoma. *Jpn J Ophthalmol* 2018;62:201–8.
11 Seibold LK, SooHoo JR, Ammar DA, *et al*. Preclinical investigation of ab interno trabeculectomy using a novel dual-blade device. *Am J Ophthalmol* 2013;155:524–9.
12 Nichamin LD Glaukos iStent trabecular Micro-Bypass. *Middle East Afr J Ophthalmol* 2009;16:138–40.
13 Tanito M, Sano I, Ikeda Y, *et al*. Microhook ab interno trabeculotomy, a novel minimally invasive glaucoma surgery, in eyes with open-angle glaucoma with scleral thinning. *Acta Ophthalmol* 2016;94:e371–2.
14 Tanito M, Ikeda Y, Fujihara E. Effectiveness and safety of combined cataract surgery and microhook ab interno trabeculotomy in Japanese eyes with glaucoma: report of an initial case series. *Jpn J Ophthalmol* 2017;61:457–64.
15 Tanito M. Microhook ab interno trabeculotomy, a novel minimally invasive glaucoma surgery. *Clin Ophthalmol* 2018;12:43–8.
16 Rosenbaum PR, Rubin DB. The central role of the propensity score in observational studies for causal effects. *Biometrika* 1983;70:41–55.
17 Heuer DK, Barton K, Grehn F, *et al*. Consensus on definitions of success. In: Shaarawy TM, Sherwood MB, Grehn F, *et al*, eds. *Guidelines on design and reporting of surgical trials*. Amsterdam, Kugler, 2008: 15–24.
18 Tanito M, Ohira A, Chihara E. Factors leading to reduced intraocular pressure after combined trabeculotomy and cataract surgery. *J Glaucoma* 2002;11:3–9.
19 Shinmei Y, Kijima R, Nitta T, *et al*. Modified 360-degree suture trabeculotomy combined with phacoemulsification and intraocular lens implantation for glaucoma and coexisting cataract. *J Cataract Refract Surg* 2016;42:1634–41.
20 Hara K, Takai Y, Tanito M. Outcomes after combined deep sclerectomy and trabeculotomy to treat primary open-angle glaucoma and exfoliation glaucoma. *Shimane J Med Sci* 2019;35:43–52.
21 Klamann MKJ, Gonnermann J, Maier A-KB, *et al*. Influence of selective laser trabeculoplasty (SLT) on combined clear cornea phacoemulsification and trabectome outcomes. *Graefes Arch Clin Exp Ophthalmol* 2014;252:627–31.
22 Cillino S, Di Pace F, Casuccio A, *et al*. Deep sclerectomy versus trabeculectomy with low-dosage mitomycin C: four-year follow-up. *Ophthalmologica* 2008;222:81–7.
23 Roy S, Mermoud A. Deep sclerectomy. *Dev Ophthalmol* 2017;59:36–42.