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

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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 17.8% in the ab externo TLO group (p=1.00).

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

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 but also in adult patients with primary open angle glaucoma (POAG), steroid glaucoma and exfoliation glaucoma, at early stages.

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, 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 blade11 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.16

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 20-2 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 mm² 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 mm² 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 interno TLO group (0.19±0.22) than in the ab externo 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/mm² | 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) | 1.00† |
| Steroid-induced glaucoma (%) | 9 (18) | 4 (8) | 0.40† |
| Other secondary glaucoma (%) | 9 (18) | 7 (14) | 0.76† |

*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/mm² | 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.

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 from the preoperative value (mixed-effects model, p>0.0001). 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...
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.

| 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, trabeculectomy ab externo; ab interno, trabeculectomy 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 conjunctivalbleb 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, 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. 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 and concomitant cataract surgery generally had better outcomes. Meanwhile, some reported that exfoliation glaucoma patients showed better outcomes compared with POAG patients, while others found the opposite outcome. Steroid glaucoma was shown to have better results compared with POAG. Higher preoperative IOP was reported to result in lower surgical success rates. 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.\(^8\)\(^9\)\(^21\)

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 trabeculectomy surgery, but the difference was not significant.\(^10\) Unlike ab interno TLO using the Tanito hook, ab interno trabeculectomy using the trabeculectomy 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%,\(^14\)\(^15\) 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. Trabeculectomy 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%).\(^3\) Because of the retrospective nature of this study, we counted the number of eyes with hyphema from medical charts only when they formed a nevius. 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 synechia 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.
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