Stepwise Combination of Femtosecond Astigmatic Keratotomy With Phacoemulsification and Toric Intraocular Lens Implantation in Treatment of Very High Postkeratoplasty Astigmatism

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Purpose: To report the outcomes of stepwise combined femtosecond astigmatic keratotomy (FSAK) and phacoemulsification with toric intraocular lens (IOL) implantation in the treatment of very high astigmatism after either penetrating keratoplasty or deep anterior lamellar keratoplasty.

Methods: This is a retrospective, interventional case series including 8 eyes of 6 patients with very high astigmatism [≥8.00 diopter (D)] after either penetrating keratoplasty or deep anterior lamellar keratoplasty who underwent FSAK, followed by phacoemulsification and toric IOL implantation. Outcome measures were corneal and manifest astigmatism and uncorrected and best spectacle-corrected visual acuity (UCVA, BSCVA).

Results: The average age was 58.9 ± 5.1 years. The average follow-up time was 40.9 ± 43.8 months. Outcome measure changes after both FSAK and toric IOL implantation were: corneal astigmatism improved from 13.56 ± 4.81 D to 4.48 ± 2.83 D ($P < 0.001$), manifest astigmatism improved from 9.15 ± 3.86 to 1.46 ± 0.88 D ($P = 0.011$), UCVA improved from 1.69 ± 0.45 LogMAR (Snellen equivalent ~20/980) to 0.23 ± 0.11 LogMAR (Snellen equivalent ~20/33, $P < 0.001$), and BSCVA improved from 1.01 ± 0.71 LogMAR (Snellen equivalent ~20/200) to 0.19 ± 0.11 LogMAR (Snellen equivalent ~20/30, $P = 0.015$). BSCVA and UCVA at the last follow-up were 20/40 or better in all patients. All procedures were uneventful. Two eyes underwent photorefractive keratectomy after FSAK to regularize and further reduce astigmatism before toric IOL implantation. One patient underwent temporary compression suturing because of FSAK overcorrection.

Conclusions: Combined stepwise use of FSAK and phacoemulsification with toric IOL implantation was an effective and apparently safe approach in patients with very high postkeratoplasty astigmatism. Additional treatment using photorefractive keratectomy may be beneficial in some cases.

Key Words: astigmatic keratotomy, femtosecond, toric, IOL, keratoplasty, DALK, PKP

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High astigmatism is a common finding after keratoplasty, with average postkeratoplasty corneal astigmatism ranging between 4 and 6 diopters (D).[1–3] This is an important factor that influences visual outcomes and patient satisfaction.[4–6] Although mild degrees of astigmatism can be managed with spectacles, soft toric contact lenses, or gas permeable contact lenses, higher degrees of astigmatism may require surgical management, with as many as 8%–20% of postkeratoplasty patients requiring surgical intervention to correct intolerable astigmatism.[7,8]

Surgical options to correct postkeratoplasty astigmatism include photorefractive surgery,[9,10] astigmatic keratotomy,[11] toric phakic intraocular lenses (IOLs),[12] and toric IOLs.[13] Although these techniques are effective in reducing postkeratoplasty astigmatism, they are limited by the magnitude of astigmatism that can be corrected. Cases of very high astigmatism may not be amenable to full correction by a single surgical procedure, and a combined approach could yield better outcomes.[10,14]

Patients with postkeratoplasty astigmatism who develop a cataract can benefit from phacoemulsification and implantation of a toric IOL to address both their cataract and astigmatism.[13] In cases where astigmatism is very high, a surgical procedure can be performed before toric IOL implantation to reduce astigmatism to a level where a toric IOL can be used more predictably.

In this study, we report the outcomes of a combined approach to treat very high astigmatism after either penetrating keratoplasty (PKP) or deep anterior lamellar keratoplasty (DALK), using femtosecond astigmatic keratotomy (FSAK), followed by phacoemulsification and toric IOL implantation.

METHODS

A retrospective chart review was performed, including patients who underwent FSAK, followed by phacoemulsification and toric IOL implantation at the TLC laser center (Toronto, Canada), for the treatment of very high astigmatism (corneal astigmatism ≥8.00 D) after PKP or DALK between 2010 and 2017. All procedures were performed by 2 corneal surgeons (D.S.R and C.C.C). This study received Research Ethics Board approval from the University of Toronto and was conducted in compliance with the tenets of the Declaration of Helsinki.

Data collected included baseline demographics, laser parameters, subsequent procedures, uncorrected visual acuity (UCVA), best spectacle-corrected visual acuity (BSCVA), corneal topography with corneal astigmatism (OPD Scan II ARK 10000; NIDEK, Tokyo, Japan), manifest sphere and cylinder, and intraoperative and postoperative complications.

Outcome measures included changes in UCVA, BSCVA, corneal astigmatism (analysis of corneal astigmatism changes was based on preoperative and postoperative topography data), and manifest astigmatism. For outcome analysis of FSAK only, postoperative data were obtained from the follow-up visit that preceded toric IOL implantation or any other refractive procedure performed after FSAK. For outcome analysis of toric IOL implantation, data were obtained from the last follow-up visit. In 3 eyes, attempted preoperative manifest refraction did not improve UCVA, and therefore, preoperative BSCVA and UCVA were considered identical. In 1 eye, attempted postoperative (post-Toric IOL) manifest refraction was not consistent and yielded BSCVA that was no better than UCVA, and therefore, postoperative BSCVA and UCVA were considered identical.

Surgical Technique

FSAK

Complete removal of all graft sutures was required at least 3 months before the procedure, with verification of refractive stability. The steep astigmatism axis was determined using corneal topography. In cases of significant irregular astigmatism with no discernible steep axis, FSAK was not performed. Arcuate keratotomy was performed using the FS (2 eyes) and iFS (6 eyes) IntraLase systems (Johnson and Johnson Vision; Jacksonville, FL) under topical anesthesia (proparacaine 0.5%). The horizontal and steep axes were marked at the slit lamp to reduce the effect of cyclotorsion in the supine position. The eyelids were prepared with Betadine sponges. Ultrasound pachymetry was performed (Corneo-Gage; Sonogage Inc, Cleveland, OH) to determine graft thickness along the circumference of the planned incision. Paired symmetric arcuate incisions were centered around the graft center and on the topographic location of the steep axis. The incisions were positioned 0.5 mm anterior to the graft–host junction with the incision depth set at 90% of the thinnest measured ultrasound pachymetry. Incision angles (length of the incisions) were set according to the following nomogram: 8 to 10 D of astigmatism was treated with a 45- to 65-degree arc length, 10 to 15 D with a 70- to 75-degree arc length, and greater than 15 D with a 90-degree arc length. The laser's limbal suction ring was then applied and the cone positioned so that the fluid meniscus was at least beyond the graft–host junction. Once the procedure was complete, the suction was released and the ring was removed.

Postoperatively, the patients received topical tobramycin and dexamethasone (TobraDex; Alcon, Mississauga, Canada) 4 times daily for 1 week. Thereafter, they were placed back on their antirejection topical steroid maintenance dose.

Toric IOL Implantation

After stabilization of the refractive error post-FSAK, confirmed by manifest refraction and 2 stable successive corneal topographies performed 1 month apart, the patients were scheduled for phacoemulsification and toric IOL implantation. The average time between FSAK and toric IOL implantation was 15.7 ± 9.0 months (range 4–26 months). There were 6 Acrysof IQ Toric IOLs (1× SN6AT4, 1× SN6AT5, 1× SN6AT7, and 3× SN6AT9; Alcon, Ft. Worth, TX) and 2 Tecnis Toric IOLs (ZCT600; Abbot Medical Optics, Abbot Park, IL) implanted after phacoemulsification (cataract grading is detailed in Table 1). Toric IOL placement axis was determined according to the keratometric values obtained using topography, tomography (Pentacam; Oculus Optikgeräte, Wetzlar, Germany), and biometry (IOLMaster 500; Carl Zeiss Meditech AG, Jena, Germany), with surgery performed only in cases where good correlation of astigmatism magnitude and axis was found between the devices.

Cataract procedures were performed under intracameral anesthesia (lidocaine 1%) through a 2.4-mm temporal clear corneal incision within 30 degrees of the horizontal plane, positioned as close as possible to the graft–host junction. The steep implantation astigmatism axis was marked preoperatively to reduce the effect of cyclotorsion in the supine position.

Statistical Analysis

Data were recorded in Microsoft Excel (2016; Microsoft Corp, Redmond, WA) and analyzed using SPSS version 23 (SPSS Inc, Chicago, IL). The calculation of the mean gain in visual acuity (VA) and VA line change was made on the basis of the VA values obtained with a Snellen chart and rounded to the nearest line, which were converted into LogMAR. Astigmatism vector analysis was performed at the corneal plane (vertex of 12 mm) using the Alpins method.[15]

Continuous variables such as VA and astigmatism were compared within subjects using either the Wilcoxon nonparametric test or the Student t test for dependent variables. All tests were 2-tailed, and the threshold for statistical significance was defined as a P value <0.05.

RESULTS

Eight eyes of 6 patients aged 58.9 ± 5.1 years were included. There were 2 female patients (33.3%) and 3 right eyes (37.5%). The average follow-up time was 40.9 ± 43.8 months (range 6–110 months). There were 4 PKP grafts and 4 DALK grafts. Indication for keratoplasty was keratoconus in 7 eyes and corneal scarring secondary to herpes zoster in 1 eye.

TABLE 1. Individual Case Outcomes

				Preoperative				Post-FSAK	Additional Procedure After FSAK			Posttoric IOL			
Case	Age* (yr)	Graft Type	Graft Indication	UCVA (Snellen)	Manifest Refraction (S)/(C) × (A)	BSCVA (Snellen)	Corneal Astigmatism (D)	Corneal Astigmatism (D)	Procedure	Postop Corneal Astigmatism (D)	Cataract Grade	UCVA (Snellen)	Manifest Refraction (S)/(C) x (A)	BSCVA (Snellen)	Corneal Astigmatism (D)
1	61	DALK	KCN	20/400	−2.00/−10.25 × 83	20/100	13.91	10.68	Compression Sutures	3.43	NS + 1, AC + 2	20/30	+0.75/−2.00 × 175	20/25	3.06
2	64	DALK	HZV	CF	†	CF	9.65	4.08	—	—	NS + 3, PSC + 3	20/40	0.00/−0.75 × 100	20/30	5.75
3	63	DALK	KCN	CF	−9.25/−14.00 × 95	20/200	9.85	4.76	—	—	NS + 2	20/40	−2.00/−2.25 × 180	20/40	4.52
4	54	PKP	KCN	CF	†	CF	14.71	6.61	WO-PRK	6.52	NS + 1	20/30	+0.50/−2.00 × 13	20/30	6.11
5	55	PKP	KCN	CF	+1.25/−11.00 × 173	20/25	11.69	3.62	—	—	NS + 2	20/40	+0.75/−1.00 × 165‡	20/40	3.99
6	50	DALK	KCN	20/400	†	20/400	18.20	6.06	TG-PRK	2.27	NS + 2	20/40	+2.00/−2.25 × 58	20/30	2.17
7	62	PKP	KCN	CF	−0.50/−6.00 × 45	20/100	22.33	10.27	—	—	NS + 2, AC + 2	20/40	§	20/40	9.76
8	62	PKP	KCN	20/160	−3.25/−4.50 × 118	20/40	8.11	2.00	—	—	NS + 2, AC + 2	20/20	Plano	20/20	1.06

*Age at the time of FSAK.
†In cases 2, 4, and 6, preoperative manifest refraction was unsuccessful in improving preoperative UCVA (preoperative BSCVA and UCVA were considered identical).
§In case 7, manifest refraction posttoric IOL was inconsistent and yielded BSCVA that was not better than UCVA and, therefore, was not recorded (postoperative BSCVA and UCVA were considered identical).
‡After realignment of a rotated IOL.
A, axis; C, cylinder; HZV, herpes zoster scarring; KCN, keratoconus; S, sphere; TG-PRK, topography-guided photorefractive keratectomy; WO-PRK, wavefront-optimized photorefractive keratectomy.

All procedures were uneventful. There were no astigmatic procedures performed before FSAK in any of the eyes, and none of the eyes had preoperative graft–host disjunction issues requiring prior wound revision. Three eyes (37.5%) underwent an additional astigmatic procedure after FSAK: One eye underwent compression suturing and 2 eyes underwent photorefractive keratectomy (PRK). There were no astigmatic procedures performed after toric IOL implantation. Target refraction in all cases was plano. Individual case outcomes are presented in Table 1.

Astigmatism and Spherical Equivalent

Corneal astigmatism improved significantly after FSAK and toric IOL implantation from 13.56 ± 4.81 D (range 8.11–22.33 D) before FSAK to 4.48 ± 2.83 D (range 0.45–9.76 D) after toric IOL implantation ($P < 0.001$). Improvement after FSAK was significant, from 13.56 ± 4.81 D (range 8.11–22.33 D) to 6.01 ± 3.10 D (range 2.00–10.68 D, $P < 0.001$). The change after phacoemulsification and toric IOL implantation was nonsignificant, from 4.62 ± 2.69 (range 2.00–10.27 D) to 4.48 ± 2.83 D (range 0.45–9.76 D, $P = 0.671$) (Fig. 1).

Manifest astigmatism improved significantly after FSAK and toric IOL implantation from 9.15 ± 3.86 D (range 4.50–14.00 D) before FSAK to 1.46 ± 0.88 D (range 0.00–2.25 D) after toric IOL implantation ($P = 0.011$). Improvement after FSAK was significant, from 9.15 ± 3.86 D (range 4.50–14.00 D) to 5.38 ± 1.73 D (range 3.75–9.25 D, $P = 0.044$). Improvement after phacoemulsification and toric IOL implantation was also significant, from 4.31 ± 1.09 D (range 2.00–5.00 D) to 1.46 ± 0.88 D (range 0.00–2.25 D, $P < 0.001$) (Fig. 1). Vector analysis of the astigmatic treatment effect is shown in Table 2.

Manifest spherical equivalent was −7.32 ± 5.17 D (range −3.50 to −16.25 D) preoperatively and −6.59 ± 5.41 D (range −1.00 to −16.75 D) after FSAK ($P = 0.107$). After toric IOL implantation, manifest spherical equivalent improved significantly from −5.38 ± 4.93 D (range −1.00 to −16.75 D) to −0.45 ± 1.27 D (range +0.875 to −3.125 D, $P = 0.011$).

Visual Acuity

UCVA improved significantly after FSAK and toric IOL implantation from 1.69 ± 0.45 LogMAR (Snellen equivalent ~20/980) before FSAK to 0.23 ± 0.11 LogMAR (Snellen equivalent ~20/33) after toric IOL implantation ($P < 0.001$). Improvement after FSAK was significant, from 1.69 ± 0.45 LogMAR (Snellen equivalent ~20/980) to 1.13 ± 0.59 LogMAR (Snellen equivalent ~20/270, $P = 0.032$). Improvement after phacoemulsification and toric IOL implantation was also significant, from 1.09 ± 0.47 D (Snellen equivalent ~20/250) to 0.23 ± 0.11 LogMAR (Snellen equivalent ~20/33, $P = 0.001$).

BSCVA improved significantly after FSAK and toric IOL implantation from 1.01 ± 0.71 LogMAR (Snellen equivalent ~20/200) before FSAK to 0.19 ± 0.11 LogMAR (Snellen equivalent ~20/30) after toric IOL implantation ($P < 0.001$). The change after FSAK was nonsignificant, from 1.01 ± 0.71 LogMAR (Snellen equivalent ~20/200) to 0.64 ± 0.38 LogMAR (Snellen equivalent ~20/90, $P = 0.083$). Improvement after phacoemulsification and toric IOL implantation was significant, from 0.54 ± 0.38 LogMAR (Snellen equivalent ~20/70) to 0.19 ± 0.11 LogMAR (Snellen equivalent ~20/30, $P = 0.034$) (Fig. 2). BSCVA and UCVA after toric IOL implantation were 20/40 or better in all patients.

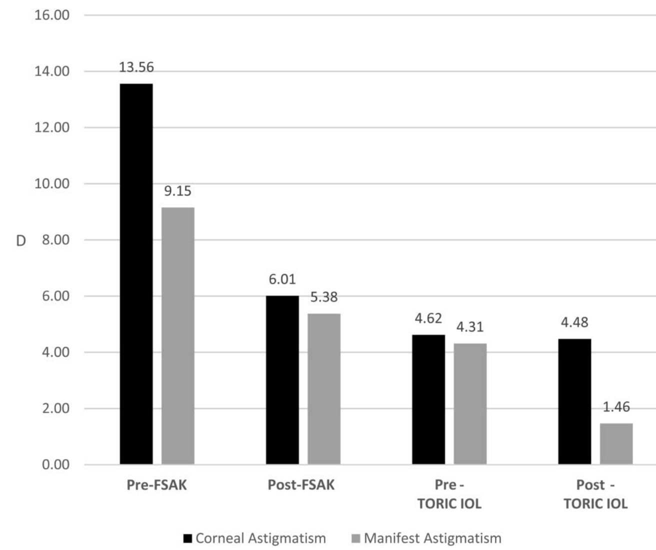

FIGURE 1. Mean corneal and manifest astigmatism: pre- and post-FSAK; prephacoemulsification and post-phacoemulsification, and toric IOL implantation.

Additional Refractive Procedures

One eye (case no. 1) underwent compression suturing of FSAK incisions before toric IOL implantation because of a FSAK overcorrection of 10.68 D. Sutures were removed 6 months later, with corneal astigmatism overcorrection decreasing to 3.43 D at 116 degrees (preoperative corneal astigmatism was 13.91 D at 5 degrees). Two eyes underwent PRK after FSAK to regularize and further reduce astigmatism

TABLE 2. Astigmatism Results (Alpins Method) at the Final Follow-Up

	Corneal Astigmatic Effect of FSAK	Manifest Astigmatic Effect of Toric IOL
SIA (D)	14.30 ± 6.25	2.96 ± 0.75
Angle of error (degrees)	0.25 ± 7.34	5.00 ± 15.64
Magnitude of error (D)	0.74 ± 6.17	−0.71 ± 0.78
Correction index (geometric)	1.09 ± 0.40	0.85 ± 0.27
Coefficient of adjustment	1.05 ± 0.44	1.28 ± 0.39
Difference vector magnitude (D)	6.01 ± 3.10	1.44 ± 0.87
Index of success (geometric)	0.43 ± 0.16	0.46 ± 0.42

SIA, surgically induced astigmatism.

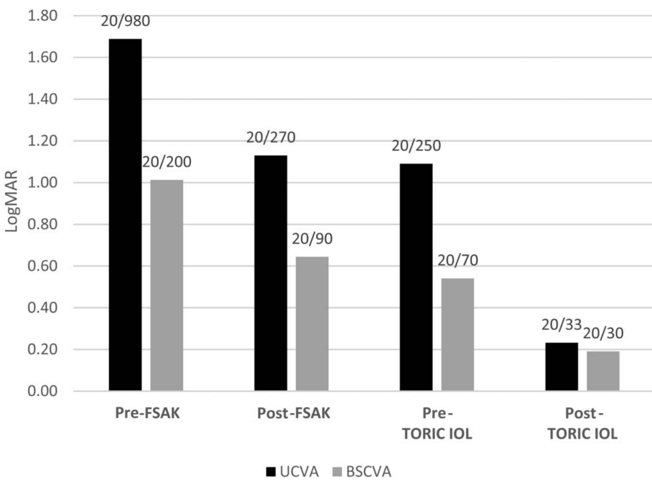

FIGURE 2. Mean UCVA and BSCVA: pre- and post-FSAK; prephacoemulsification and postphacoemulsification, and toric-IOL implantation.

before toric IOL implantation: one eye (case no. 6) underwent topography-guided PRK (TG-PRK) and 1 eye (case no. 4) underwent wavefront-optimized PRK because of insufficient quality of acquired topography images to enable TG-PRK. One eye (case no. 5) had postoperative rotation of the toric IOL which required realignment. After realignment, UCVA and BSCVA were both 20/40 with a stable manifest refraction of +0.75/−1.00 × 165 degrees.

DISCUSSION

High astigmatism after keratoplasty is not uncommon, substantially limiting UCVA and BSCVA and posing a significant treatment challenge. In this study, we evaluated the efficacy of a stepwise approach, combining FSAK followed by phacoemulsification with toric IOL implantation, in the treatment of very high postkeratoplasty astigmatism. Improvement in BSCVA and UCVA was substantial, with all patients achieving BSCVA and UCVA of 20/40 or better. To the best of our knowledge, this is the first study describing the outcomes of combined FSAK and toric IOL implantation in the treatment of very high postkeratoplasty astigmatism.

Although the management of very high postkeratoplasty astigmatism using a single treatment modality is possible, several drawbacks exist. Although FSAK can reduce large amounts of corneal astigmatism, its predictability is limited, and therefore, some overcorrection or undercorrection can be expected.[16] The use of phacoemulsification and toric IOL implantation as a single modality in this setting can be technically challenging because even a small axis misalignment could lead to substantial overcorrection or undercorrection because of the high toric power of the implanted IOL. In addition, toric predictability in this setting may be reduced.[13,17] Lens cost should also be taken into consideration because custom-made toric IOLs are required in this setting when astigmatism is greater than 6 D. Previous studies have shown good outcomes of toric IOL implantation in high postkeratoplasty astigmatism. However, it should be noted that those studies were not exclusively limited to eyes with high astigmatism and included eyes with astigmatism as low as 1.50 to 4.25 D.[13,17–21] Performing FSAK and phacoemulsification simultaneously with toric IOL implantation (as a combined procedure) in cases of very high postkeratoplasty astigmatism may not be recommended, given our reduced ability to predict FSAK's astigmatic effect which would make it extremely hard to choose the right IOL astigmatic power. In addition, corneal astigmatism after FSAK may take anywhere from several weeks to several months to stabilize. We recommend performing toric IOL implantation only after post-FSAK corneal astigmatism and manifest astigmatism have stabilized.

Determining the optimal toric IOL axis in the setting of a preexisting keratoplasty is challenging. For this reason, we use trimodal verification preoperatively using topography, tomography, and biometry, supplemented by manifest refraction data. Surgery is performed only in cases where good correlation of astigmatism magnitude and axis is found between the devices. Recently, the use of intraoperative aberrometry has been gaining popularity in cataract surgery. This could potentially improve the accuracy of toric IOL implantation under a corneal graft. Further research on intraoperative aberrometry in the setting of preexisting keratoplasty is warranted. Although we did not perform preoperative rigid gas permeable contact lens trial, its use can be helpful in determining the potential effect of optimal refractive correction, especially in patients whose preoperative manifest refraction yields low VA. It should be noted that in cases where significant cataract is present concomitantly, the yield of a rigid gas permeable contact lens trial may be reduced.

When combining FSAK and toric IOL implantation, FSAK is used initially to "debulk" the magnitude of astigmatism, bringing it to a range correctable by standard toric IOLs more predictably. The risk of FSAK overcorrection is lower in this setting because the magnitude of astigmatism is so high that it is usually close to or higher than the maximal astigmatic effect of FSAK. Even if overcorrection occurs and the astigmatic axis flips, astigmatism magnitude is not likely to increase up to higher ranges and will still be lower than pre-FSAK astigmatism. Nevertheless, the risk of overcorrection exists, as seen in our study, with 1 patient requiring compression suturing before toric IOL implantation because of significant FSAK overcorrection.

The multimodal approach to very high postkeratoplasty astigmatism is not limited to FSAK and toric IOL implantation. Laser ablation may be added either to treat residual astigmatism after toric IOL implantation, to reduce astigmatism magnitude before toric IOL implantation, or to reduce the irregular astigmatism component before toric IOL implantation using customized topography- or wavefront-guided profiles. Previous studies have found topography- and wavefront-guided PRK effective in reducing regular and irregular postkeratoplasty astigmatism.[10,22,23] The use of customized ablation profiles to regularize the cornea and reduce irregular astigmatism can facilitate proper planning and implantation of a toric IOL.[10] In our study, 2 eyes underwent PRK after FSAK to regularize and further reduce astigmatism before toric IOL implantation (1 using TG-PRK and 1 using wavefront-optimized PRK).

In the past, some surgeons were reluctant to implant a toric IOL under PKP and DALK grafts because endothelial failure of the grafts, either as a result of IOL surgery or later on for any other reason, would require replacement of the graft with a new PKP or DALK graft, which would alter the corneal astigmatism magnitude and axis completely. More recently, Descemet membrane endothelial keratoplasty has been shown to be effective in replacing failed endothelium of PKP and DALK grafts.[24–30] This allows restoration of graft function with lower overall risks and no significant refractive shift, thus preserving the good refractive effect of a preexisting toric IOL.

In conclusion, a combined stepwise use of FSAK and phacoemulsification with toric IOL implantation was an effective and apparently safe approach in patients with very high postkeratoplasty astigmatism. Additional treatment using PRK may be beneficial in some cases.

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