



The Double-Deck Viscoelastic Technique: a Novel Surgical Technique to Protect the Corneal Endothelium in Penetrating Keratoplasty of Aphakic Silicone Oil-Dependent Eyes after Severe Ocular Injury

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ABSTRACT

Introduction: The purpose of this study is to summarize the benefits of the double-deck viscoelastic technique (DDVT), a novel and cost-effective surgical technique that creates a barrier to hinder silicone oil (SO) from connecting and damaging the corneal endothelium in aphakic and SO-dependent eyes.

Methods: Five SO-dependent and aphakic eyes underwent double-deck viscoelastic embedment and penetrating keratoplasty (PKP) in this retrospective case series. At 1, 6, 12, 18, and 24 months after surgery, clinical outcomes including best corrected visual acuity (BCVA), intraocular pressure (IOP), corneal endothelial cell density (ECD), and double-deck viscoelastic layer imaging were evaluated. A Heidelberg

Retina Tomograph confocal microscope was used to measure ECD. Ultrasound biomicroscopy (UBM) was used to image the double-deck viscoelastic layer.

Results: Postoperatively, the BCVA of the patients ranged from hand motion detection to 20/200, and their IOP was between 7 and 10 mmHg. The two-deck viscoelastic layer remained mostly static. Patients showed varying degrees of ECD reduction, with ECD loss rates in the first 6 months ranging from 6.7 to 75.8 cells/mm²/month and then declining to 2.2–14.3 cells/mm²/month.

Conclusion: In SO-dependent aphakic eyes, double-deck viscoelastic embedment could effectively inhibit SO-corneal endothelium interaction. This technique could lower the pace of ECD loss and lengthen the time of corneal transparency, giving aphakic and silicone oil-dependent patients the opportunity to accept PKP surgery and get better vision quality.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s40123-022-00594-9>.

Keywords: Silicone oil-dependent eyes; Aphakic eyes; Penetrating keratoplasty; Viscoelastics

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Key Summary Points

Patients with aphakic and silicone oil-dependent eyes usually do not have the chance to receive fresh donor allogenic corneal grafts owing to SO-induced keratopathy.

This article describes the double-deck viscoelastic technique (DDVT), a novel and cost-effective surgical procedure that creates a barrier to stop silicone oil (SO) from harming the endothelium of corneal grafts.

This technique could provide more chances for individuals with silicone oil dependence and aphakia eyes to accept penetrating keratoplasty surgery.

DIGITAL FEATURES

This article is published with digital features, including a video, to facilitate understanding of the article. To view digital features for this article go to <https://doi.org/10.6084/m9.figshare.21286557>.

INTRODUCTION

Patients with aphakic and silicone oil-dependent eyes are usually determined to be unsuitable for accepting penetrating keratoplasty (PKP) surgeries and receive fresh donor allogenic corneal grafts. This is because retained silicone oil (SO) would cause the failure of corneal grafts owing to its cytotoxic effects on corneal endothelial cells [1, 2]. Silicone oil-dependent eyes have severe ciliary body dysfunction, which is usually caused by trauma and repeated surgeries, and would atrophy if the SO were removed. However, the remaining retina of these eyes could bring some vision to the

patients. In this case, if the problem of SO-induced keratopathy of aphakic and silicone oil-dependent eyes could be solved, it would give these patients more opportunities to accept PKP surgeries and gain better vision.

Artificial iris diaphragms [3] and SO retention sutures [4, 5] have shown positive effects in preventing SO from migrating into the anterior chamber and contacting the cornea, but these surgical methods remain limited by their high costs and operating complexities. Keratoprostheses in oil-filled eyes still have about a 10% possibility of melting [6] and also are expensive.

In this study, we employed an easy and cost-effective method to approach shielding the endothelium of PKP allogenic corneal grafts from SO contact in SO-dependent eyes: the double-deck viscoelastic technique (DDVT). Two kinds of viscoelastics were stacked to form a barrier between the corneal endothelium and the SO surface. Long-term best correct visual acuity (BCVA), intraocular pressure (IOP), and changes in corneal endothelial cell density (ECD) were measured to evaluate the validity of this novel surgical technique.

METHODS

Cases

This retrospective case series comprised five eyes from five patients with complex retinal detachment treated by repeated PPV and SO tamponade. Silicone oil had to be retained in all these eyes because of the dysfunction of ciliary body and the consequently persistent ocular hypotony.

Five eyes from five patients with complex retinal detachments were included in this retrospective case series. All patients had a history of PPV and SO tamponade, and the SO had to be kept in all these eyes owing to ciliary body malfunction and the consequent continuous ocular hypotony. Five eyes underwent penetrating keratoplasty combined with double-deck viscoelastic technique (PKP-DDVT) from July 2018 to May 2020.

Ethics Approval

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Peking University Third Hospital (approve number: IRB00006761-M2020456). Consent was obtained from all patients for publication of the data and images presented in the article.

Data Collection and Examinations

Patients' demographic characteristics (age, sex, ethnicity), ocular information (operative eye, BCVA, IOP, ocular and surgical histories, lens status) were collected. Slit-lamp examination and photography were used throughout the course. BCVA, IOP, and ECDs were recorded at 1, 3, 6, 12, 18, and 24 months postoperatively. ECDs were measured by confocal microscopy using the Heidelberg Retina Tomograph with the cornea module (HRT III; Heidelberg, Germany). At 6, 12, 18, and 24 months after surgery, ultrasound biomicroscopy (UBM) was used to track changes in the thickness of the double-deck viscoelastic layer.

Surgical Technique and Postoperative Care

An experienced vitreoretinal and corneal surgeon (Yun Feng) performed all surgeries at Peking University Third Hospital. All patients underwent general anesthesia.

The conjunctival sac was prepared using 5% povidone-iodine and then washed with sterilized normal saline. The operation began with the placement of standard three-port 23-gauge PPV trocars 3.5 mm from the limbus. The recipient corneal bed was prepared using vacuum trephines (Medin-ural, Russia), and curved corneal scissors were used to separate the opaque recipient central cornea from its bed. A temporary keratoprosthesis was sewn to the recipient bed with 7-0 sutures. PPV was performed using the

Constellation Vitreoretinal Surgical System (Alcon, Fort Worth, TX, USA) and a no-contact wide-angle panoramic viewing system (Oculus, Munich, Germany). The central vitreous gel was removed and the proliferative vitreoretinopathy membranes were peeled off with illuminated microforceps. A 360° scleral depression was made to ensure complete exposure and removal of the anterior vitreous base. Endolaser photocoagulation was performed around the retinal tear and vitreous base. A silicone oil (RT SIL-OL 5000, Carl Zeiss Meditec AG) tamponade was performed by injection before PKP.

The double-deck viscoelastic technique (DDVT) was then performed (Fig. 1 and in the PKP-DDVT surgery video in the online/HTML version of the manuscript and at the digital features link under the abstract). To prepare the donor cornea graft, a dispersive ophthalmic viscoelastics (DisCoVisc; Alcon) was used to coat the corneal endothelium as the first layer. Then a cohesive viscoelastic (ViscAid, MBI) was covered evenly onto the first viscoelastic layer and formed the second layer. A vacuum trephine (Medin-ural, Russia) was used to cut the donor cornea along with the viscoelastic layers. In all cases, the diameter of the donor graft was 0.50 mm greater than that of the recipient cornea, which was at least 0.25 mm greater than that of the lesion. The temporary keratoprosthesis was then removed and the donor corneal graft with viscoelastic layers coated on its endothelial surface was sewn to the recipient bed with 10-0 sutures. If necessary, additional cohesive viscoelastic was added into anterior chamber to further push back the SO.

In the first 3 months postoperatively, 0.1% tacrolimus eye drops (Senju Pharmaceutical Co., Ltd., Japan), 0.5% levofloxacin eye drops (Santen Pharmaceutical Co., Ltd, Japan), and 1% prednisolone acetate ophthalmic suspension (Allergan Pharmaceutical Co., Ltd., Ireland) were administered. The frequency of medication administration decreased gradually over 6 months.

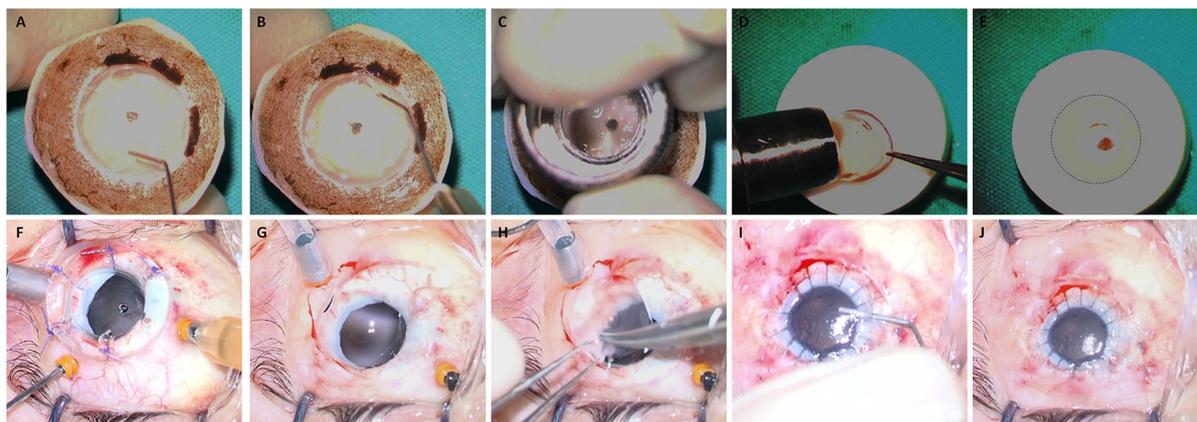


Fig. 1 The double-deck viscoelastic technique. **A** Coat first viscoelastics layer (dispersive) on endothelial surface; **B** coat second viscoelastics layer (cohesive) on the first layer; **C–E** vacuum trephine cut the corneal graft; **F**,

G remove the temporary keratoprosthesis; **H** sew the donor corneal graft with double-deck viscoelastic layers; **I** replenish some dispersive viscoelastics if necessary; **J** operation completed

RESULTS

Clinical Characteristics

The patients' clinical characteristics are summarized in Table 1. Numerous comorbid conditions existed, including aphakia, aniridia, corneal endothelium decompensation, recurring retinal detachment, and SO dependency. All patients underwent complex courses of treatment of the anterior and posterior segments. Three of the five patients were observed for a total of 24 months, one for a total of 12 months, and one for a total of 3 months after the surgeries. Patients 1 and 2 had accepted traditional PKP in aphakia and SO-tamponaded status, and back then the corneal grafts clouded 9 and 6 months after PKP, respectively.

Pre- and Postoperative Ocular Status

The images before and after the PKP-DDVT operation are shown in Fig. 2. During the follow-up period, patients' corneal grafts remained transparent (Fig. 2), and their IOPs remained stable at 7–10 mmHg (Table 2). Visual acuity was improved in four eyes, postoperative BCVA ranged from finger counting to 20/200 (Table 2). Four eyes had increased BCVA.

Patients' fundus status were stable postoperatively (Fig. 2), without further retinal proliferation.

Postoperative Anterior Segmental Status

In all five eyes, UBM examination revealed dark regions of viscoelastic layer between the corneal endothelium and SO interface. The thickness of the viscoelastic layer remained steady during the observation between 6 and 24 months postoperatively (Fig. 3).

Postoperative Corneal Graft Endothelial Status

Confocal microscopy was used to analyze the morphology and density of postoperative corneal transplant endothelial cells. Endothelium cells maintained their homogeneous hexagonal shape for 24 months after surgery, as illustrated in Fig. 3. The ECD decreased in varying degrees (Fig. 4). The ECDs of patients 1 and 3 marginally increased within the first 3 months postoperatively (from 1273 ± 59 to 1317 ± 79 cells/mm² and from 2315 ± 45 to 2554 ± 49 cells/mm², respectively (Table 3). From 1 to 6 months, ECDs declined at various rates, ranging from 6.7 to 75.8 cells/mm²/month (3.14–24.97%). After

Table 1 The clinical characteristics before the double-deck viscoelastic surgery

Patient no.	Age	Gender	Operative eye	Primary disease	Disease course	Lens status	Surgical histories
1	29	M	OD	Explosive trauma	15 years	Aphakic	Cornea and sclera suture (2004) PKP, Intraocular exploration, lensectomy, PPV and SO tamponade (2004) (corneal graft clouded within 10 months) SO removal, PVR stripping, retinal photocoagulation, and SO tamponade (February 2018) PKP-DDVT (July 2018.)
2	33	M	OD	Cornea laceration complicated with infective endophthalmitis	2 years	Aphakic	Cornea and sclera suture (July 2017) PKP, Lensectomy, PPV, retinal photocoagulation, SO tamponade, and intravitreal injection (August 2017) (corneal graft clouded within 6 months) SO removal, PVR stripping, retinal photocoagulation, and SO tamponade (January 2018) PKP-DDVT (February 2018)
3	34	M	OS	Rhegmatogenous retinal detachment	13 years	Aphakic	PPV and SO tamponade (2006) SO removal, PVR stripping, retinal photocoagulation, and SO tamponade (2007) SO removal, lensectomy, corneal endothelial transplantation, and retinal photocoagulation (2011) Corneal endothelial transplantation (2014) PKP-DDVT, PVR stripping, retinal photocoagulation, and SO tamponade (June 2019)
4	33	M	OS	Explosive trauma	11 years	Aphakic	Cornea and sclera suture (March 2009) Intraocular exploration, PPV, retinal photocoagulation, and SO tamponade (April 2009) PKP-DDVT, SO removal, PVR stripping, and SO tamponade (November 2019)
5	64	M	OD	Mooren, cornea perforation	1 year	Aphakic	PKP-DDVT, ECCE, PPV, and SO tamponade (May 2020)

SO silicone oil, PVR proliferative vitreoretinopathy, PPV pars plana vitrectomy, PKP penetrating keratoplasty, DDVT double-deck viscoelastic technique

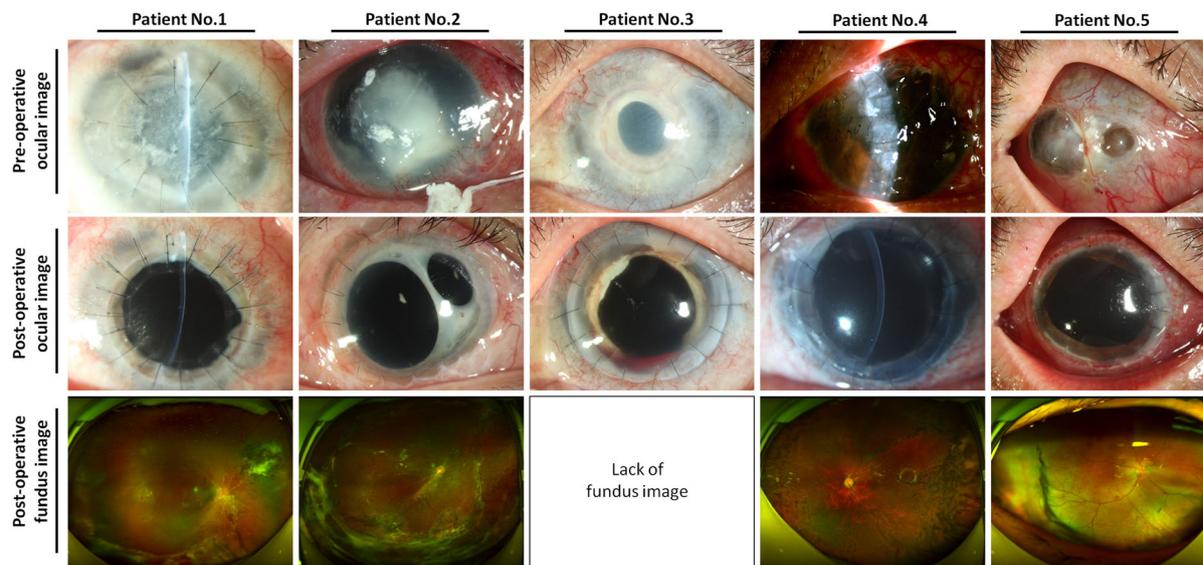


Fig. 2 Pre- and postoperative images. Preoperative images were captured 1–2 days before double-deck viscoelastic technique operation. Postoperative images were the image of the latest follow-up examination

Table 2 Pre- and postoperative clinical data

Patient no.	BCVA before the last surgery	IOP before the last surgery	Date of the last surgery	BCVA after the last surgery	IOP after the last surgery
1	HM/30 cm	13	2018.7	FC/30 cm	8
2	HM/30 cm	10	2018.2	20/200	10
3	HM/30 cm	7	2019.6	HM/30 cm	10
4	HM/10 cm	7	2019.11	HM/10 cm	9
5	LP/20 cm	9	2020.5	4/200	7

BCVA best corrected vision acuity, *HM* hand motion, *FC* figure counting

6 months postoperatively, the pace of ECD losing tended to slow down and leveled off, ranging from 2.2 to 14.2 cells/mm²/month between 6 and 12 months (0.63–4.47%), and 4.4 to 14.3 cells/mm²/month between 12 and 24 months (4.03–9.45%) postoperatively (Fig. 4 B).

Compared with traditional PKP in aphakic SO-dependent eyes, in which SO contacts the corneal endothelium directly (Fig. 5), DDVT separates the SO and the corneal endothelium. None of the patients who received DDVT surgery experienced corneal band-shape degeneration.

DISCUSSION

Here we describe a novel surgical technique for endothelial cell protection in aphakic and SO-dependent eyes, which, in a nutshell, entails creating a double-deck viscoelastic barrier between the SO and the endothelium of allogenic corneal graft. During the follow-up period, in all cases the SO surface remained apart from the cornea on UBM examination (as shown in Fig. 3) and all transplanted corneal grafts remained transparent.

The corneal ECD declines over time in healthy individuals at a rate of 0.6% ± 0.5 per year[7], and the loss rate accelerated in

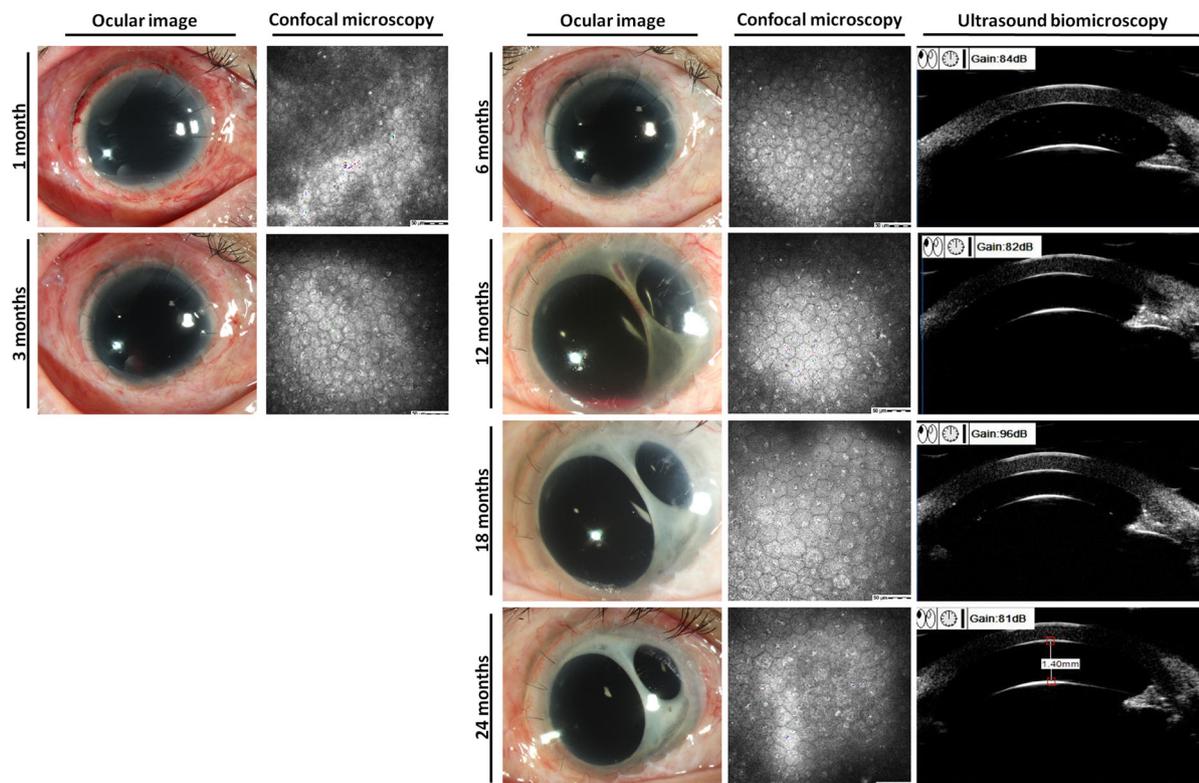


Fig. 3 Postoperative anterior segmental status (patient 2)

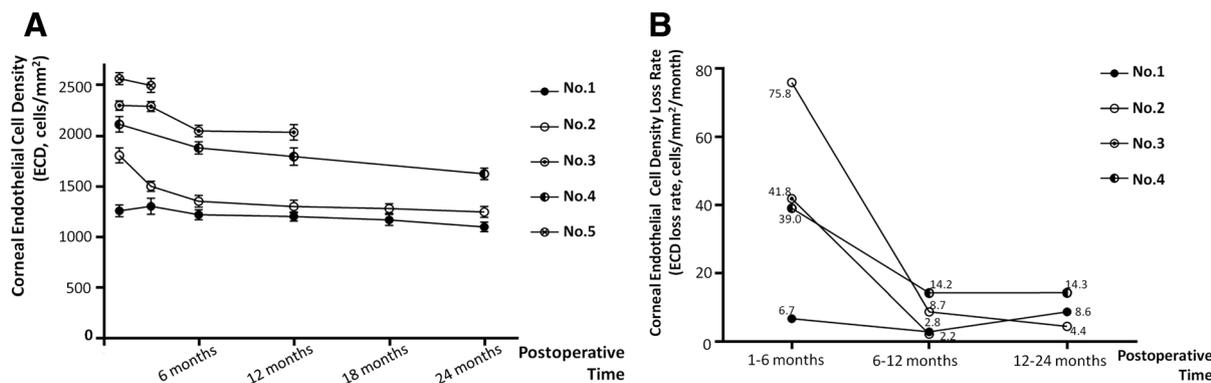


Fig. 4 Postoperative corneal endothelial cell density change. **A** Postoperative corneal endothelial cell density; **B** postoperative corneal endothelial cell density loss rate

patients who had undergone simple penetrating keratoplasty (PKP). Ono et al. [8] suggested that ECD tends to decrease exponentially after PKP, from 2722 ± 56 cells/mm² postoperatively to < 2000 cells/mm² after 12 months and 659 ± 119 cells/mm² after 10 years. Yu-Chih Hou et al. [9] reported that the ECD loss

rate is about 561.5 ± 425.7 cells/mm²/month in the first 1.5 months and decreases to 113.2 ± 121.4 cells/mm²/month from 1.5 to 6 months, and 36.6 ± 63.5 cells/mm²/month from 6 to 12 months after PKP. In SO tamponade eyes and with lens-iris diaphragm defect, the ECD decreased from 2374 ± 386

Table 3 Changes of corneal endothelial cell density (ECD, cells/mm²) after surgeries

Patient no.	Postoperative ECD (/mm ²)					
	1 month	3 months	6 months	12 months	18 months	24 months
1	1273 ± 59	1317 ± 79	1233 ± 51	1216 ± 46	1183 ± 54	1112 ± 47
2	1822 ± 74	1516 ± 51	1367 ± 59	1315 ± 63	1294 ± 49	1262 ± 55
3	2315 ± 45	2554 ± 49	2064 ± 57	2051 ± 77	–	–
4	2129 ± 78	–	1895 ± 62	1810 ± 86	–	1639 ± 57
5	2579 ± 59	2511 ± 71	–	–	–	–

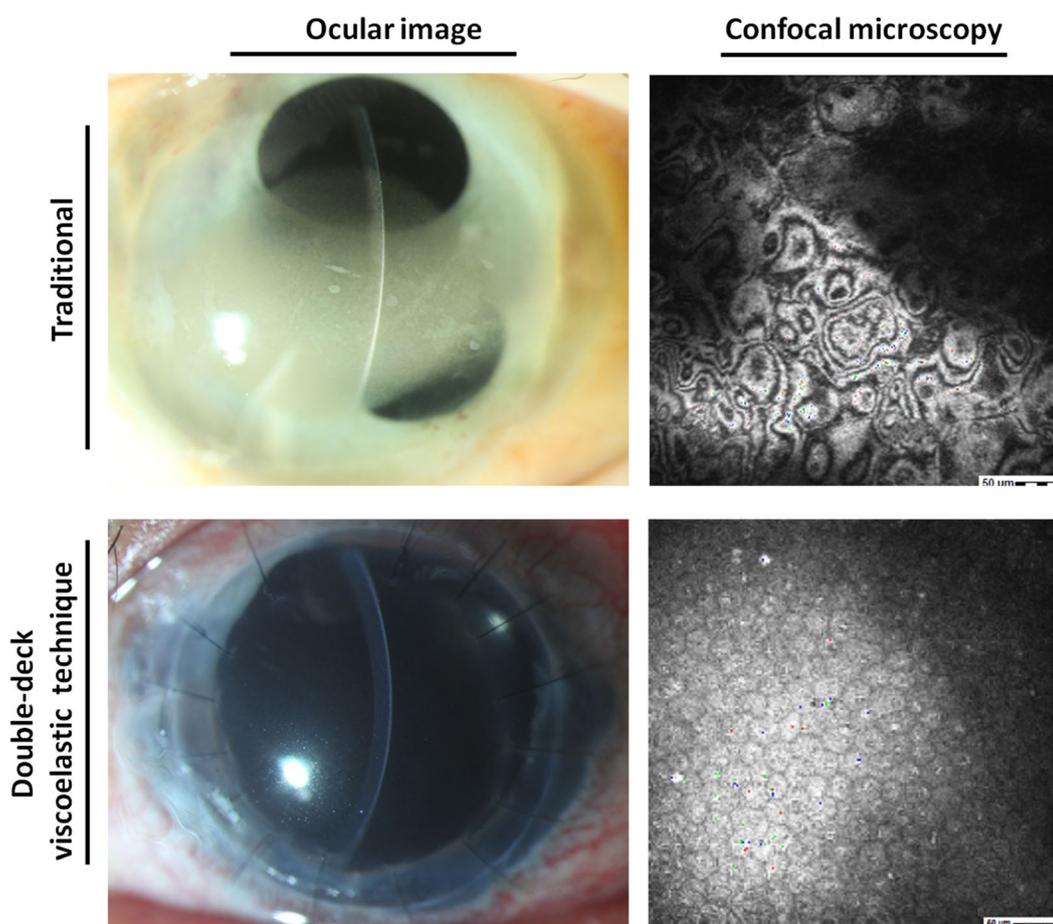


Fig. 5 Comparison of traditional surgery and double-deck viscoelastic technique operation. After traditional surgery, corneal degeneration occurred rapidly. SO contacted corneal endothelium, which meant the shape of

endothelial cells could not be detected by confocal microscopy. After double-deck viscoelastic technique operation, the corneal graft remained transparent and corneal endothelial cells showed uniform hexagon shape

cells/mm² preoperatively to 1666 ± 649 cells/mm² at 6 months (118 cells/mm²/month) and 1445 ± 437 cells/mm² at 12 months (36.83 cells/mm²/month from 6 to 12 months) postoperatively[10]. This rate is much faster than observed in phakic and pseudophakic eyes, suggesting that the direct exposure of endothelial cells to SO is a significant risk factor for ECD loss. The loss rates of ECD in our series varied from 6.7 to 75.8 cells/mm²/month in the first 6 months postoperatively, and were 2.2–14.2 cells/mm²/month between 6 and 12 months, which were slower than the rate mentioned above. Patients 1 and 2 had accepted traditional PKP in aphakia and SO-dependent situations before, and the corneal grafts kept transparency for only 9 and 6 months, respectively. While after PKP-DDVT, the corneal grafts of these two patients remained transparent at the 24-month follow-up. It should be noted that ECD densities of patients 1 and 3 increased slightly at 3 months after the operation compared with 1 month postoperatively, which we suspect might be caused by the edema reduction of corneal endothelial cells at 3 months compared with 1 month postoperatively.

The double-deck viscoelastic technique is used in cataract surgery, with complete removal of the viscoelastic material at the end of surgery to prevent IOP elevation. While in eyes with severe trauma, ciliary body dysfunction leads to hypotony upon SO removal. In other words, these eyes are SO dependent. Such eyes lack aqueous circulation, which leads to the relative fixation of the viscoelastic at the rear of the corneal endothelium to prevent SO contraction, whereas it does not cause IOP increase. Moreover, due to the lack of aqueous humor, the hydration process of viscoelastic slows down, which further maintains the intraocular pressure.

Several methods have been used to slow ECD loss in eyes with SO tamponade and lens–iris diaphragm defects. Barrier sutures, which mitigate SO contact with the corneal endothelium by enhancing SO–aqueous humor interface tension, have been reported to be safe and

effective [4, 11]. However, the operation procedures are complex, and the sutures can obstruct the visual axis. Artificial iris placement has been shown to prevent SO–cornea contact in about half of aphakic eyes [3, 12], but its widespread use is limited by its high cost. Keratoprotheses also have about a 10% possibility of melting in SO-filled eyes [6] and are also high cost. Compared with the methods above, the DDVT presented in this study is easier to perform and is more economical. It provides aphakic and silicone oil-dependent patients with long-lasting corneal transparency.

This study has a few limitations. First, there was no strict control group, which should have consisted of SO-dependent eyes without viscoelastics layers. This was because aphakic and SO-dependent eyes do not have much opportunity to accept PKP. Also, the corneal endothelium cell morphology and density could not be observed and counted by confocal microscopy in such control eyes because the SO covered the endothelium cell shape (as shown in Fig. 5). Only patients 1 and 3 have self-control. Second, the sample size and follow-up duration were limited. The main reason is also that only a few cases of aphakic and SO-dependent eyes had the opportunity to receive further corneal transplantation. The purpose of this double-deck viscoelastic technique is to give these patients such an opportunity. To further verify the efficacy of this technique, prospective randomized controlled trials with larger sample sizes ought to be carried out in the future.

CONCLUSION

In conclusion, the double-deck viscoelastic technique (DDVT) could stably block SO–corneal endothelium interaction in SO-dependent eyes with lens–iris diaphragm defect. This technique could decrease the rate of ECD loss and prolong corneal transparency time, which could provide aphakic and SO-dependent patients the opportunity to accept PKP surgeries and get better vision quality.

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Author Contributions. Yujie Cen: manuscript drafting, data analysis, data acquisition. Mingzhou Zhang: data acquisition. Yao Lu: data acquisition. Yun Feng: concept and design, surgeries operating, funding acquisition.

Disclosures. Yujie Cen, Mingzhou Zhang, Yao Lu and Yun Feng have nothing to disclose.

Compliance with Ethics Guidelines. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Peking University Third Hospital (approve number: IRB00006761-M2020456). The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Peking University Third Hospital (approve number: IRB00006761-M2020456). Consent was obtained from all patients for publication of the data and images presented in the article.

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