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Using Ultrasound Cyclo-Plasty as A Preventive Glaucoma Treatment for Eyes Undergoing Boston Keratoprosthesis Type I Implantation

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ABSTRACT

Purpose

To study the benefit of performing Ultrasound Cyclo-Plasty (UCP) using High-Intensity Focused Ultrasound (HIFU) as a glaucoma treatment in eyes undergoing Boston kerato-prosthesis type I and to evaluate the control of intraocular pressure and glaucoma progression postoperatively.

Methods

This is a retrospective study review of cases that underwent Boston Kerato-prosthesis type 1 implantation with UCP treatment at the same time in Ocular Hypertension (OHT), glaucoma suspects or glaucoma patients.

Results

Fourteen patients (14) underwent a BKpro implant combined with UCP procedure. Mean age 53,2 ± 20 years (range 26 to 81 years). 10 males and 4 females, 5 right eyes and 9 left eyes. The average duration of follow-up was 36 months (range 6 to 70 months). Mean IOP was reduced from 21.7 ± 6.6 mm Hg to 15.86 ±4.02 which was sustained in longer follow up periods 15.1 ± 4.3. at the last visit, corresponding to a mean IOP reduction of 23%. Only two patients required further glaucoma surgical intervention. Vision improved to better than 20/80 in five patients, better than 20/200 in two and four remained unchanged in the 20/200-20/400 vision group and two patients had worsening of vision.

Conclusions

For a mean follow-up of 3 years and ranging up to more than 5 years, the glaucoma progression or the conversion from Glaucoma Suspect (OHT) into a Glaucoma according to our criteria and definition, was only seen in 1 case (7,14%). The complications cannot be associated with the UCP treatment and might be related to the BKpro + UCP surgery itself. UCP, in combination of BKpro, seems to be a safe procedure to slow down the progression of glaucoma in cases undergoing BKpro.

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Introduction

All corneal transplant surgeries have a chance of developing glaucoma in almost 30% of them [1]. Boston Keratoprosthesis (BKpro) has become an excellent way of restoring sight in cases where a corneal transplant has a high chance of failure. BKpro, at least theoretical and experimental, has the possibility to restore vision to 20/20 [2]. It has been reported graft retention of 96% [3]. Among the common and devastating complications of BKpro, glaucoma is frequent and difficult to manage; some of the eye candidates for the BKpro already suffer secondary glaucoma as a consequence of the etiology, previous procedures or induce by the chronic used of the medication like steroids to reduce the rejections [4,5]. Some studies have shown that more than half of the patients had glaucoma previous to the BKpro surgery, with 40% having previous incisional glaucoma surgery, high use of antiglaucoma medication and even though almost 25% progress after the BKpro surgery during the follow-up period [5].

Glaucoma is difficult to diagnose and follow in BKpro patients due to the limitation in the evaluation of the visual field, where 10-2 seems to be the most repeatable, difficulties in the view of the optic nerve head or analysis of the nerve fiber layer, the spectral domain OCT can help in the evaluation but probably the most important factor is the lack of reliability on the Intraocular Pressure (IOP) measurement [6-8]. The Intraocular Pressure (IOP) elevation is usually multifactorial, progressive angle closure, steroids response and a combination of both. The progression of the angle closure can happen 6 months post-surgery in eyes without a history of previous angle closure, this slow progression can happen without any symptoms [9]. The extensive and necessary use of steroids to reduce the rate of failure can increase the IOP; in normal population, it will happen in 30% patients.

IOP is affected in corneal pathology, surgery or because of the prosthetic cornea [10,11]. The majority of surgeons rely on the digital IOP [12]. Alternative methods like transpalpebral tonometry or scleral pneumotonometer show a correlation with corneal reads, where the scleral IOP is higher, and the scleral measurements are more accurate in the lower values of the IOP [13-17]. Glaucoma in BKpro patients can be managed with medical therapy, but 50 to 75% of the cases require surgery [18]. The management of patients with preexisting glaucoma seems to be more difficult than when the glaucoma develops after the BKpro. Glaucoma seems not to affect the retention of the graft [19].

The most common surgeries are glaucoma drainage devices or cyclophotocoagulation lasers. Retina complications appeared more often when the tubes were implanted before [20]. Glaucoma Drainage Devices (GDD) have been advocated as the main treatment pillar of secondary glaucoma in BKpro cases, but device-related complications such as vision threatening have been reported [21]. Another treatment option is laser cyclophotocoagulation but it is usually reserved for late-stage glaucoma [22].

Ciliary Body (CB) treatment with High-Intensity Focused Ultrasound (HIFU), In early experiments show HIFU to be an effective and well-tolerated method of reducing intraocular pressure [23]. The histologic changes that HIFU induces are a selective and controlled thermal ablation of the distal part of the ciliary body, and this effect is independent of the degree of tissue pigmentation with limited damage to adjacent structures. The decrease of intraocular pressure is by two mechanisms: first, reducing aqueous humour production and second by increasing uveoscleral outflow [24]. Recently, the results at 3 years of the use of (UCP) Ultrasound Cyclo-plasty for refractory glaucoma with a therapeutic success of 55 % in 75% of the patients with only one application, with a significant reduction of IOP between 33% to 43%, low rate of complications in 104 patients [25]. The BKPro patients who underwent glaucoma surgeries in an early stage retained vision significantly better compared to patients with late intervention [26]. To our knowledge, no studies on the combined use of UCP and Kpro have been done, neither at the same setting nor later.

This retrospective study aims to determine if using UCP at the same time as the BKPro implantations will lower the IOP and the number of medications required to control glaucoma with a low rate of complications and a good safety profile.

Study Design

This is a single-center study, at King Khaled Eye Specialist Hospital, retrospective review of cases that underwent a Boston Kerato-prosthesis type 1 implantation combined with the UCP procedure as a treatment procedure for glaucoma. The aim was to slow down the risk of glaucoma progression or to avoid the conversion from Ocular Hypertension (OHT) or Glaucoma suspect into a well-established Glaucoma.

This project was approved by the Institutional Review Board (IRB) of KKESH with the reference number RD/26001/IRB/0310-20 (IRB Nº RP 2052-R) and adhered to the principles of the Declaration of Helsinki. Patients or the public were not involved in the design, conduct, reporting, or dissemination plans of our research.

Preoperative and postoperative data were collected from the clinical files of all the patients who underwent surgery from 2018 to 2021 for this combined surgery. Data include age, gender, IOP preoperatively and in the last visit, use of hypotensive medications before surgery and in the last visit, visual acuity postop, corneal horizontal diameter measured by white to white or with a calliper, B-Scan for axial length (these measures are needed for the selection of the UCP probe) and Optic Nerve Head (ONH) direct evaluation with 90 or 78 D lens in the postop, preop evaluation was not possible by any means due to the opacity of the media. Documentation of the ONH by fundus photos (Figure 2) and Nerve fiber layer (NFL) OCT (Figure 3) was done as soon as the clarity of the media allowed it; visual field (Humphrey or Goldman) and anterior segment OCT (AS-OCT) (Figure 4)

Preoperative and postoperative IOP was measured using a rebound tonometer (iCare IC100 from iCare®) in the peripheral corneal 4 quadrants. Six (6) measures per quadrant plus a reliable measure (low SD) with Meditronic Solan pneumotonometer model 30 classic (Meditronic Technologies®) in corneoscleral limbus temporal side were taken. A total of 25 measures (6 x 4 = 24 + 1= 25) and the mean was used as the average IOP in all the visits. In the same way, digital verification was done (soft, normal or hard globe).

Glaucoma progression was defined as the change in the ONH, NFL or Visual field in consecutive visits in all or one of the tests. Risk of progression was defined as an increase of IOP compared with previous visits or the need to increase hypotensive medication, whatever event was registered. Hypotony was defined by a soft globe estimated by digital palpation or tonometry when IOP measurement < 6 mmHg. The visits were every 3 months (4 visits in a year), during which IOP measurements, ONH evaluation, visual field, fundus photos, and NFL OCT were done.

Regarding Glaucoma, stability is considered when the IOP level is controlled with the same or less medication before the surgery; there is no change in ONH or NFL on a structural test or fundus photos or no Visual field changes. The final status (stability or progression) was described in terms of both anatomical and functional conditions. Progression is referred to as the need to increase medications, change in the ONH, NFL, or VF happens, or another glaucoma surgical procedure is needed The Boston K-Pro's anatomical success was defined as device retention, regardless of the BCVA. Functional success refers to anatomical device retention with a BCVA of 20/400 or better.

Inclusion Criteria

All eyes underwent Boston K-Pro implantation combined with UCP from October 2018 till January 2021.

Exclusion Criteria
Patients are not suitable for treatment in combination. Pregnancy, Eyelid abnormalities e.g.: entropion, ectropion, tight or short lid fornices, large globes with axial length more than 30 mm, a corneal diameter that could not be determined either by white-to-white or with a caliper (UCP probe size decision require these 2 measures) All surgeries were done by expert surgeons, the UCP by a Glaucoma consultant (K.S) and the BKpro by a cornea specialist (J.M.V).

UCP Procedure
The procedure was performed in the operating room under peribulbar, sub-tenon or general anaesthesia. The ultrasound device (EyeOP1; Eye Tech Care, Rillieux-La-Pape, France) has been previously described in detail (23) [27]. In short, the EyeOP1 device consists of two elements: a control unit with a foot pedal and a single-use, sterile disposable EyeOP-Pack, with 2 elements: a positioning cone and a therapy probe. The therapy probe is available in 3 sizes, with different ring diameters (11mm, 12 mm and 13 mm), and each is equipped with 6 piezoelectric components (transducers). The probe size was determined based on ocular parameters (white-to-white or corneal horizontal diameter measured with a calliper and the axial length) before the surgery.

The coupling cone was placed in contact with the eye, and the ring probe containing the six piezoelectric transducers that produce the ultrasound beams was inserted inside. Their proper centering over the ocular surface represents a crucial step for the correct targeting of the ciliary body. A sterile, balanced solution was used to fill the empty spaces to ensure ultrasound acoustic propagation.

UCP treatment consists of sequential automatic activation of each of the six transducers for a total duration of less than 3 min. At the end of the initial 6 sectors, the therapy probe was rotated into the coupling cone, and 2 additional sectors were treated in the inferior area.

The following parameters were used for all treatments: operating frequency, 21 MHz; number of sectors activated, 8; acoustic power, 2 – 3 W; duration of each of the 6 shots, 8 sec; time between shots, 20 sec.

After the UCP Treatment had been done, the Boston K-pro was Implanted as Follows:

Boston K-pro Procedure
Implantation of a Boston BKpro type 1 was like the PKP (Penetrating Keratoplasty) procedure. Because healthy corneal endothelial tissue is not needed for clear vision, a poor-quality donor cornea is sufficient. The procedure is performed in the operating room under any kind of anesthesia (peribulbar Anaesthesia, sub-tenon or general). It is recommended that the prosthetic is prepared under the microscope. After preparing an 8.5 mm corneal graft in a secure field, a 3.0 mm central hole will be made in the center of the donor graft. An adhesive patch is used to fix the K-pro to be assembled. The front plate of K-pro is squeezed against the adhesive to be stuck with the stem up and plate down. Applying viscoelastic over the stem, then joining graft to the stem. Use the white pin to align the graft down to the stem. Add more viscoelastic on the endothelial surface, and then a back plate is applied on the stem. Then, the posterior 8.0-mm plate with the holes is placed through the stem. Use your finger to push down the back plate onto the stem. In click-on design, use a white pin to push the back plate to click into the grove on the stem, while in Snap-on design, usually an audible snap is heard. Finally, the titanium locking ring is placed and secured using the wrench provided with the prosthesis. This effectively creates a sandwich composed of the prosthetic front plate, donor cornea tissue, and prosthetic back plate, all secured with the locking ring. After the K-pro parts assembly with the donor cornea, suturing into the patient's cornea is done in regular suturing technique as in PKP. If the patient is phakic, cataract extraction should be performed. If there is visualization, a standard phacoemulsification technique can be performed. Alternatively, extracapsular cataract or open sky lens extraction can be performed, leaving the posterior capsule intact. Anterior vitrectomy is performed as needed. Once the prosthetic is assembled and the cataract is no longer present, surgery is like a standard PKP with minor modifications. Sixteen interrupted sutures are placed radially using 9-0 nylon. Because the prosthetic is made of a rigid PMMA material, there is no concern about suture-induced astigmatism. There should be no leak in the interface where all sutures are placed.

Postoperatively, patients were treated topically with Moxifloxacin, Prednisolone and cycloplegic drops; the regime of drops is adjusted according to the BKpro clinic evaluation. Antiglaucoma medication was re-started based on the previous medication used by the patient and adjusted to the level of IOP obtained; this medication was reduced if the level of IOP was kept low and no signs of progression were observed. Medication was increased if, on the contrary, the IOP level was observed to be high or signs of progression were observed.

The Antiglaucoma medication was chosen according to the criteria of less inflammatory medication and no general contraindications. α2-agonists and β-blockers were among the first medication used, alone or fix combinations.

Primary and Secondary Outcome Measures
- IOP variation compared to baseline visit
- Glaucoma progression (Described as a change in the ONH, NFL or Visual field).
- Risk of glaucoma progression (Defined as: increase of IOP compared with previous visits or needs of increased medication, whatever event was registered)
- Loss of sight related to glaucoma
- Per and postoperative complications related to UCP procedure.

Statistical Analysis
All eyes underwent Boston K-Pro implantation combined with UCP from October 2018 till January 2021.

Statistical analysis was performed using R v 4.3. Counts and percentages were used to summarize categorical variables. The mean ± standard deviation (SD) and the median/interquartile range (IQR) were used to summarize continuous normal and non-normal variables, respectively. The R package eye was used to convert qualitative data to Snellen quantitative values for analysis purposes as follows

Qualitative data	Snellen value
NLP	20/20000
LP	20/10000
HM	20/4000
CF	20/2000

In addition, the package was used to convert Snellen values to logMaR values. The chi-square test of independence was used to assess the association between categorical variables. The categories were constructed as follows

Category	Range
Near normal vision	20/20 to 20/70
Moderate low vision	20/80 to 20/160
Severe low vision	20/200 to 20/400
Profound low vision	20/500 to LP
Blindness	NLP

McNemar's test assessed whether the change in IOP categories significantly differed before and after surgery. A paired t-test was used to assess whether the change in IOP and VA significantly differed before and after surgery. The sign rank test was used to compare the VA categories before and after surgery. Hedge's g was used as a measure of effect size. Hypothesis testing was performed at the 5% level of significance.

Results

Table 1: Descriptive Statistics for the Study Sample

	[ALL]	N
	N=14	
Gender:		14
F	4 (28.6%)	
M	10 (71.4%)	
Age	53.2 (20.0)	14
Eye:		14
OD	5 (35.7%)	
OS	9 (64.3%)	
Weight	81.0 (19.3)	14
Height	164 (8.20)	14
Graft:		14
Primary	2 (14.3%)	
Regraft	12 (85.7%)	
# graft:		14
0	2 (14.3%)	
1	5 (35.7%)	
2	5 (35.7%)	
3	2 (14.3%)	
PKP:		14
No	1 (7.14%)	
Yes	13 (92.9%)	
Glaucoma:		14
Congenital glaucoma	1 (7.14%)	
Glaucoma suspect	2 (14.3%)	
No	4 (28.6%)	
POAG	2 (14.3%)	
Secondary glaucoma	5 (35.7%)	
# preop glaucoma meds:		14
1	2 (14.3%)	
2	6 (42.9%)	
3	1 (7.14%)	
4	5 (35.7%)	
Previous glaucoma surgery:		14
CPC	1 (7.14%)	
No	9 (64.3%)	
Trabeculectomy + CPC	1 (7.14%)	
Tube	3 (21.4%)	
Anestesia type:		14
GA	1 (7.14%)	
Peribulbar	13 (92.9%)	
UCP sectors:		14
6	6 (42.9%)	
8	8 (57.1%)	
Lensectomy:		14
ECCE	1 (7.14%)	
ICCE	1 (7.14%)	
IOL REMOVE	7 (50.0%)	
Lensectomy	1 (7.14%)	
No	1 (7.14%)	
Yes	3 (21.4%)	
Anterior vitrectomy:		14
No	1 (7.14%)	
Yes	13 (92.9%)	
Corneal vascularization:		14
No	5 (35.7%)	
Yes	9 (64.3%)	
VA PREOP:		14
1/200	2 (14.3%)	
2/200	2 (14.3%)	
20/200	1 (7.14%)	
3/200	2 (14.3%)	
HM	7 (50.0%)	
IOP preop	21.7 (6.58)	14
Axial length (AXL)	24.6 (2.35)	14
Pre-opration VA (logMAR):		14
1	1 (7.14%)	
2	4 (28.6%)	
2.3	9 (64.3%)	

Of the overall 14 patients, 10 were male (71.4%) and 4 were female (28.6%). The average age of the patients is 53.2 ± 20 years. Two-thirds of the patients (64.3%) had the left eye (OS) involved, while 35.7% had the right eye (OD) affected. The average weight of the participants is 81.0 ± 19.3 kg, and the average height is 164 ± 8.2 cm. Most patients (85.7%) had undergone a re-graft. The presence of glaucoma was noted, with 28.6% not having glaucoma, 35.7% having secondary glaucoma, and smaller proportions being congenital glaucoma and glaucoma suspect. A large portion of the group, 92.9%, had a history of penetrating keratoplasty (PKP) surgery. In terms of glaucoma medication, 42.9% of the patients were on two preoperative glaucoma medications, and 35.7% were on four.

Previous glaucoma surgeries were varied, with the majority (64.3%) having no prior surgery, and the remainder having undergone different types of interventions, including cyclophotocoagulation (CPC) and tube implantation. Nearly all patients (92.9%) received peribulbar anesthesia, and the UCP sectors treated were either 6 or 8, with 42.9% and 57.1% of patients undergoing treatment in each respective number of sectors.

In terms of lens status, 50% of the patients had an intraocular lens removed, and a significant majority (92.9%) underwent an anterior vitrectomy. Corneal vascularization was present in 64.3% of the patients, and the preoperative visual acuity indicated that half of the patients had a vision of hand motion (HM), and others had varying levels of impaired vision, with 14.3% having a visual acuity of 1/200. The mean intraocular pressure was 21.7 ± 6.58 mmHg, and the average axial length of the eyes was 24.6 ± 2.35 mm.

The mean follow-up duration of the first set of follow-up was 20.59 ± 13.05 months. The median follow-up at the first set of follow-up was 17.53 (3.87 – 40.10) months. At the second set of follow-up, the mean follow-up duration was 37.1 ± 26.9 months. The median follow-up of the second set of follow-up was 40.4 (9.3 – 59.7) months.

Table 2: Summary Statistics for Visual Acuity

Time	n	min	max	median	q1	q3	iqr	mean	sd
Preop	14	1.00	2.30	2.30	2.00	2.30	0.30	2.12	0.35
FU1	14	0.10	3.00	0.80	0.50	1.20	0.70	0.99	0.80
FU2	10	0.20	3.00	0.80	0.38	1.15	0.78	1.04	0.93

The average logMAR which has decreased from 2.12 ± 0.35 to 0.99 ± 0.8. The statistical analysis suggests that this change was statistically significant ($p < 0.001$). The reduction persisted at the longer follow-up (1.04 ± 0.93) with no statistically significant difference in the average log MAR between FU1 and FU2 ($P = 0.9$).

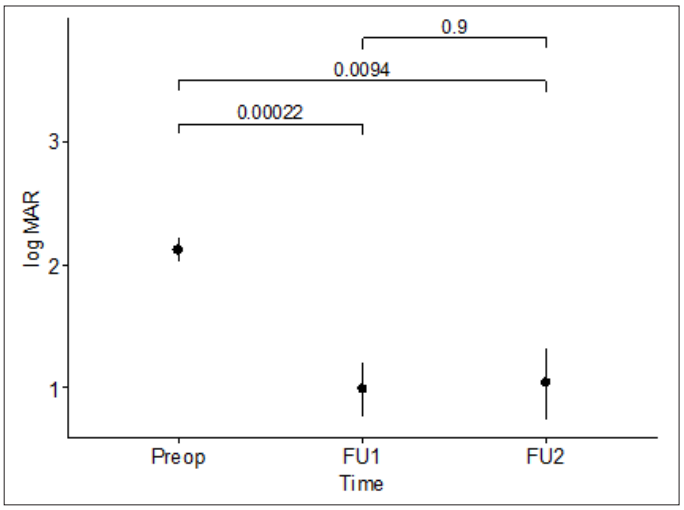

Figure 1: Change in Visual Acuity (logMAR) Before and After Surgery

The graph is showing a decrease in logMAR from preoperative to postoperative, meaning there is an improvement in visual acuity after surgery. Each line connects pre- and post-surgery measurements for individual patients. The lines indicate the average logMAR at each time point. Statistical analysis was performed using paired t-test.

Statistical analysis showed that the average log MAR was significantly lower at FU1 than pre-operative log MAR ($P < 0.001$). In addition, the difference in logMAR between baseline and FU2 was statistically significant ($P = 0.009$) suggesting a sustained improvement in visual acuity.

Table 3: Comparison of Visual Acuity Categories Before and After Surgery (FU1)

Before surgery	Post-surgery					Total
	Near normal	Moderate low	Severe low	Profound low	Blindness	
Near normal	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (100 %)
Moderate low	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (100 %)
Severe low	0 (0 %)	1 (100 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (100 %)
Profound low	5 (38.5 %)	2 (15.4 %)	4 (30.8 %)	1 (7.7 %)	1 (7.7 %)	13 (100 %)
Blindness	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)
Total	5 (35.7 %)	3 (21.4 %)	4 (28.6 %)	1 (7.1 %)	1 (7.1 %)	14 (100 %)

Before surgery, no patients were in the Near Normal or Moderate Low categories. One patient had Severe Lows and improved to Moderate Low vision post-surgery. Thirteen patients were in the Profound Low category; post-surgery, five improved to Near Normal vision, two improved to Moderate Low vision, four remained at Severe Low vision, one worsened to Profound Low vision, and one to Blindness. No patients were categorized as Blind pre-surgery, and this category remained empty post-surgery. Overall, post-surgery, there is a noticeable improvement for most patients. Statistical analysis using sign rank test showed that the change was statistically significant (P = 0.003).

Table 4: Comparison of VA Categories Between FU1 and FU2 (n = 10)

FU1	FU2					Total
	Near normal	Moderate low	Severe low	Profound low	Blindness	
Near normal	3 (75 %)	1 (25 %)	0 (0 %)	0 (0 %)	0 (0 %)	4
Moderate low	0 (0 %)	0 (0 %)	2 (100 %)	0 (0 %)	0 (0 %)	2
Severe low	0 (0 %)	1 (50 %)	1 (50 %)	0 (0 %)	0 (0 %)	2
Profound low	0 (0 %)	0 (0 %)	0 (0 %)	1 (100 %)	0 (0 %)	1
Blindness	0 (0 %)	0 (0 %)	0 (0 %)	0 (0 %)	1 (100 %)	1
Total	3	2	3	1	1	10

A comparison of visual acuity categories between the first (FU1) and second (FU2) sets of follow-ups revealed some changes in patients' vision. Of the patients with near normal vision at FU1, 75% maintained this category at FU2, while 25% declined to moderate low vision. All patients initially categorized with moderate low vision progressed to severe low vision. Severe low vision cases at FU1 showed mixed outcomes, with 50% improving to moderate low vision and 50% remaining unchanged. The single patient with profound low vision at FU1 remained in this category at FU2, as did the patient with blindness. These findings suggested stability in the majority of the cases.

Change in IOP

Table 5: Summary Statistics for Visual Acuity

var	variable	n	min	max	median	q1	q3	iqr	mean	sd
Preop	val	14	12	36	20.50	18.00	25.55	7.54	21.68	6.58
FU1	val	14	7	21	15.00	14.25	20.00	5.75	15.86	4.02
FU2	val	10	10	26	15.00	14.00	15.00	1.00	15.10	4.43

The average IOP decreased in all patients at the first set of follow-ups except patients 1, 4, and 12 with an average reduction from 21.7 ± 6.58 to 15.86 ± 4.02. The statistical analysis suggests that this change was statistically significant ($p < 0.001$). In addition, the reduction in IOP was significantly different between baseline and FU2 (P = 0.013). The reduction was sustained at FU2 compared to FU1 (15.10 ± 4.43, P = 0.61).

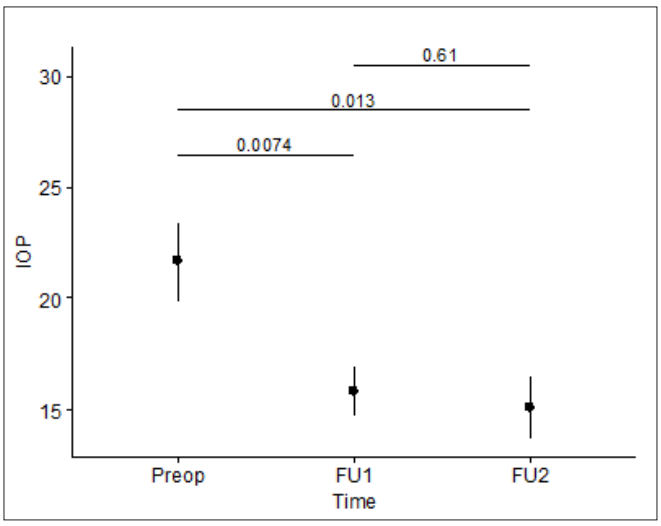

Figure 2: Change in VA Before and After Surgery

The graph is showing a decrease in logMAR from preoperative to postoperative, meaning there is an improvement in visual acuity after surgery. Each line connects pre- and post-surgery measurements for individual patients. The red lines indicate the average logMAR at each time point. Statistical analysis was performed using paired t-test

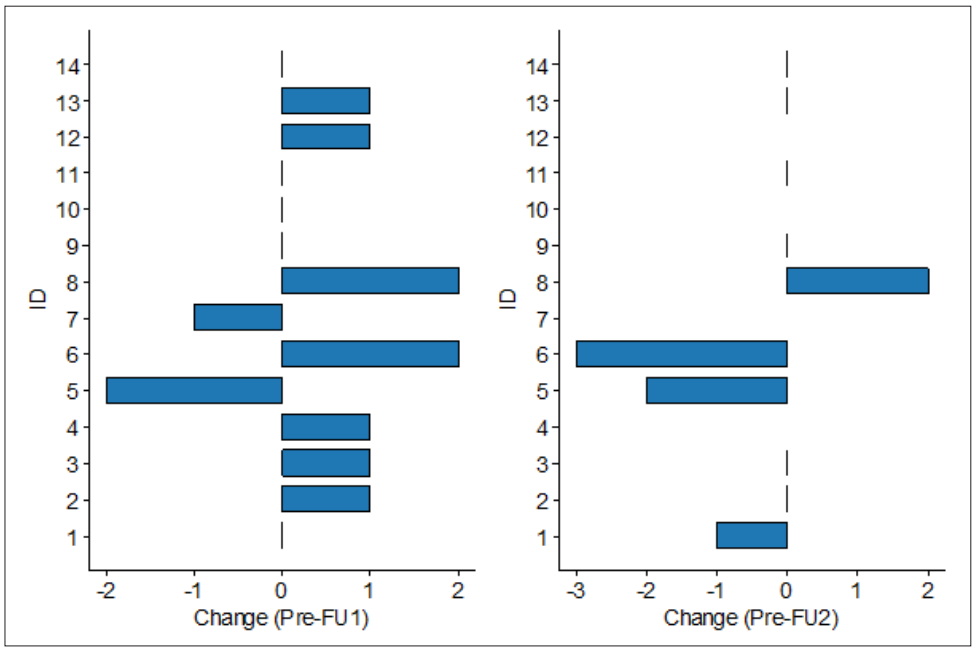

Figure 3: (a) Change in Medications per Patient (b) Overall Change in Glaucoma Medications Before and After Surgery

Glaucoma medications were reduced in seven patients, did not change in five patients and were increase in two patients. The change was not statistically significant (P = 0.16) using paired t-test. At FU2 (n = 10), the medications did not change in 6 patients, decreased in 1 patient, and increased in 3 patients. The difference was not statistically significant compared to baseline (P = 0.363).

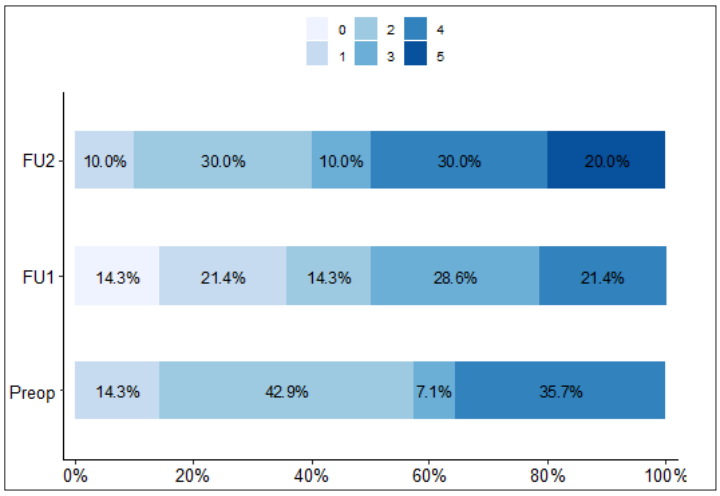

Table 6: Number of Medications used at the Different Time Points

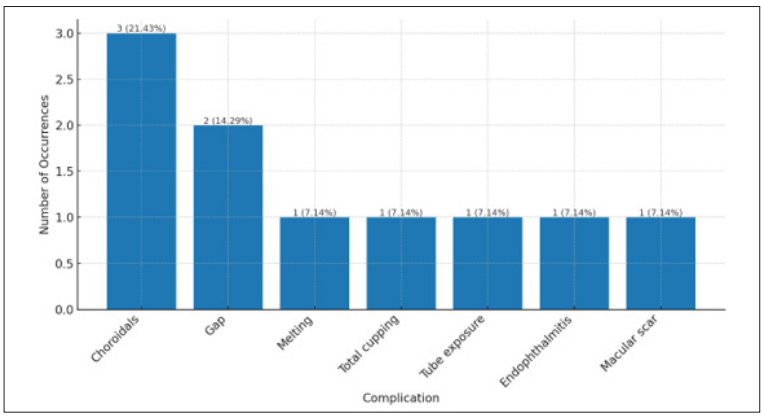

Figure 4: Distribution of Eye Complications

Choroidals were the most frequently noted complication, recorded 3 times, representing 21.43%. This is followed by tube exposure and endophthalmitis, each observed once, accounting for 7.14%. Less common complications, such as gap, melting, macular scar, and irving Gass. Three patients required surgery for complications and two required new glaucoma surgeries.

Patient no.	Gender	Age	Primary diagnosis	Glaucoma	Previous glaucoma surgery	VA PREOP	VA FU1	VA FU2	IOP preop	IOP FU1	IOP FU2	Longest FU period (Months)	new surgery
1	F	40	chemical burn	Secondary glaucoma	no	1/200	20/25	20/30	17	21	15	70	AGV
2	F	42	chemical burn	Glaucoma suspect	no	3/200	20/60	20/40	18	15	15	70	no
3	F	40	chemical burn	Glaucoma suspect	no	3/200	20/50	20/30	18	15	15	40	no
4	M	57	pseudophakic bullos keratopathy	no	no	HM	20/40		12	14		6	no
5	M	76	measles	Secondary glaucoma	no	HM	20/200	20/80	26	20	17	60	Mp-CPC
6	M	46	congenital glaucoma	Congenital glaucoma	tube	2/200	1/200	1/200	19	15	26	60	no
7	M	26	trauma	no	tube	HM	20/160		24	12		31	eviceration for endophthalmitis
8	M	64	Keratoconos	POAG	tube	HM	NLP	NLP	29	20	10	64	no
9	M	48	Congenital Hereditary Endothelial dystrophy	Secondary glaucoma	Trabeculectomy + CPC	HM	20/100	20/200	36	20	14	37	no
10	M	81	Trachoma	no	no	2/200	20/300		20	20		16	no
11	M	26	neurothrophic Keratopathy	no	no	HM	20/70	20/80	21	7	10	41	no
12	M	81	Perforated Microbial Keratopathy	POAG	no	1/200	20/300		13	15		7	no
13	F	80	Pseudophakic Bullos Keratopathy	Secondary glaucoma	CPC	HM	20/300	20/300	29	12	15	38	no
14	M	38	aniridia, Congenital Cataract	Secondary glaucoma	no	20/200	20/80	20/200	21	16	14	41	no

Discussion

This study is aimed towards studying the benefits of performing Ultrasound Cycloplasty (UCP) using High-Intensity Focused Ultrasound (HIFU) as a glaucoma treatment in cases of Boston keratoprosthesis type 1, to the best of our knowledge such a novel technique has not been described in the literature before. The main treatment goal of glaucoma is to lower or stabilize the intraocular pressure. Aptel et al. have described in a pilot study published in 2011 that HIFU can be considered as an effective and well tolerated method to reduce IOP in cases of refractory glaucoma [28]. Crnej et al. in 2014 described that glaucoma in cases of BKPro remains a challenge despite aggressive attempts to halt its progression and that glaucoma surgery should be attempted either before or simultaneously with the BKpro surgery [29]. Patients known to have glaucoma are more likely to have a visual acuity of 20/200 or less when undergoing BKPro [30]. In BKpro, 28-44% of patients with prior glaucoma had worsening of their glaucoma and 50-66.7% of patients without prior glaucoma developed glaucoma post BKPro transplant. Glaucoma intervention post BKPro was done in 36-60% of patients [31,32].

In our study, we combined HIFU with the BKPro procedure in 14 patients and monitored the effect it will have on controlling the IOP, maintaining vision and the need for glaucoma surgery. The patients were 10 (71.4%) males and 4 (28.6%) females of which 13 (92.9%) patients had a prior PKP. Glaucoma was known in 8 (57.1%), 4 (28.6%) did not have glaucoma and 2 (14.3) were glaucoma suspect, 9 patients (64.3%) had no previous glaucoma surgeries. The average IOP pre-op 21.7 was reduced to 15.86 and 15.10. Glaucoma medications were reduced in seven patients, did not change in five and increased in two. Surgery was needed in only two cases 14.2% in comparison to the literature where glaucoma surgery was needed in up to 60% of cases. Vision improved to better than 20/80 in five patients, better than 20/200 in two and four remained unchanged in the 20/200-20/400 vision group and two patients had worsening of vision. Our results demonstrate that combining an effective glaucoma procedure with the BKPro had a positive effect in maintaining the intraocular pressure. Antiglaucoma medications were still needed in 85.7% of patients.

In Boston K-Pro patients with early glaucoma surgical intervention seems to retained vision significantly better compared to patients with late or no interventions(26). Glaucoma in Boston type 1 keratoprosthesis remains a challenge because of the high prevalence of glaucoma, fast progression and an inability to measure IOP. In eyes with pre-existing glaucoma, glaucoma drainage device before or at the time of keratoprosthesis should be considered. Most importantly, early detection and prompt treatment of IOP elevations and glaucoma progression is required to prevent poor visual outcomes(16) but glaucoma surgeries are not exempted of complications, but Li et al series suggests that glaucoma drainage device-related complications can cause significant vision loss (21). Other options are diode laser transscleral cyclophotocoagulation that seems to have beneficial long-term effects in the control of IOP and can be considered in the management of keratoprosthesis patients with refractory glaucoma [33].

Glaucoma presents in ¾ of patients that undergo Kpro surgery, they can develop the pathology if they don't have it previously, the onset and progression should be monitored with direct evaluation of Optic nerve head, nerve fiber layer and /or visual field test (18) Practically, these eyes should be considered glaucoma suspects and/or high risk, and it is therefore recommended to establish a baseline for IOP measurement, visual field and imaging of the optic nerve and optical coherence tomography of the anterior segment and optic nerve as soon these structures can be evaluated. Notably, a previous report demonstrated that reliable visual field tests could be obtained in only 59%; therefore it is advised to use structural measures the main outcome measure (28). Khoueir et al, found that Spectral domain OCT volume scans offer the possibility to enhance the evaluation of KPro patients with glaucoma by using both 2D and 3D diagnostic parameters that are easily obtained in a clinic setting. This is a reliable structural evaluations assisting in the control of progression of the glaucoma in this patients (7).

The difference in the degree of vision improvement can be explained by the different indications for which the BKPro procedure were done. Of our 14 patients, 3 were secondary to chemical burn, 2 for pseudophakic bullous keratopathy, 1 keratoconus, 1 trauma, 1 trachoma, 1 neurotrophic keratopathy, 1 perforated microbial keratopathy, 1 measles, 1 congenital glaucoma, 1 aniridia with congenital cataract, 1 congenital hereditary endothelial dystrophy. All patients with chemical burn had a near normal recovery of vision 2 of which were glaucoma suspect. Due to the novel combination of the procedure the study was limited by the number of patients. The retrospective nature of the study gave different follow up periods between patients but the overall results was a lower mean IOP that was maintained in most cases with a long period of follow-up where 11 patients had at least two and a half years of follow up period and five patients with a follow up period of more than 5 years. It is difficult to reach a final conclusion at the moment although the novel combination gave a positive effect in a number of cases within our study. These results encourage us to establish a protocol in our Kpro cases and to search for suitable candidates for the procedure. Also, these results encourage the exploration of other techniques that could be safely combined with the BKpro and to assess its effectiveness. Another limitation is regarding the technique itself, the suppliers of the UCP device recommend to use white to white measurement in combination with the axial length in order to select the right size of the probe, in most of our cases the corneal diameter has to be measured by a caliper base on the expertise of the Anterior segment and glaucoma surgeons experience which never will be as accurate as the white to white in normal corneas. It will be important to estimate in a larger series of cases if some of our complications will be presented without the UCP.

We can say that even in our small initial group of patients, UCP treatment at the same time of the BKpro gives an acceptable IOP control helping in the stabilization of the glaucoma by delaying further glaucoma surgeries and providing better visual acuity outcome without increasing the complications already related to the surgery itself.

Conflict of Interest: None of the authors has competing/conflicts of interest related to this manuscript.

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References

1. Saini C, Davies EC, Ung L, Chodosh J, Ciolino JB, et al. (2023) Incidence and risk factors for glaucoma development and progression after corneal transplantation. Eye Lond Engl 37: 2117-25.
2. Hui PC, Pereira LA, Dore R, Chen S, Taniguchi E, et al. (2020) Intrinsic Optical Properties of Boston Keratoprosthesis. Transl Vis Sci Technol 9: 10.
3. Güell JL, Arcos E, Gris O, Aristizabal D, Pacheco M, et al. (2011) Outcomes with the Boston Type 1 Keratoprosthesis at Instituto de Microcirugía Ocular IMO. Saudi J Ophthalmol. 25: 281-284.
4. Nilgun Yildirim, Huseyin Gursoy, Afsun Sahin, Ahmet Ozer, Ertugrul Colak (2011) Glaucoma After Penetrating Keratoplasty. Incidence, Risk Factors, and Management 2011: 951294.
5. Kamyar R, Weizer JS, Stein JD, Moroi SE, John D, et al. (2012) Glaucoma Associated with Boston Type 1 Keratoprosthesis. Cornea 31: 134-139.
6. Akpek EK, Karakus S, Yohannan J, Jabbour S, Sotimehin AE, et al. (2022) Reliability of Several Glaucoma Tests in Patients with Boston Type 1 Keratoprosthesis. Cornea 41: 310-316.
7. Khoueir Z, Jassim F, Braaf B, Poon LYC, Tsikata E, et al. (2019) Three-Dimensional Optical Coherence Tomography Imaging for Glaucoma Associated with Boston Keratoprosthesis Type I and II. J Glaucoma 28: 718-726.
8. Ali MH, Dikopf MS, Finder AG, Aref AA, Vajaranant T, et al. (2018) Assessment of Glaucomatous Damage Following Boston Keratoprosthesis Implantation Based on Digital Planimetric Quantification of Visual Fields and Optic Nerve Head Imaging. Cornea 37: 602-608.
9. Kang JJ, Allemann N, Cruz J de la, Cortina MS (2013) Serial Analysis of Anterior Chamber Depth and Angle Status Using Anterior Segment Optical Coherence Tomography After Boston Keratoprosthesis. Cornea 32: 1369-1374.
10. Arribas-Pardo P, Mendez-Hernandez C, Cuiña-Sardiña R, Benitez-Del-Castillo JM, Garcia-Feijoo J (2017) Tonometry after Intrastromal Corneal Ring Segments for Keratoconus. Optom Vis Sci Off Publ Am Acad Optom 94: 986-992.
11. Cacho I, Sanchez-Naves J, Batres L, Pintor J, Carracedo G (2015) Comparison of Intraocular Pressure before and after Laser in Situ Keratomileusis Refractive Surgery Measured with Perkins Tonometry, Noncontact Tonometry, and Transpalpebral Tonometry. J Ophthalmol 2015: 683895.
12. Baum J, Chaturvedi N, Netland PA, Dreyer EB (1995) Assessment of intraocular pressure by palpation. Am J Ophthalmol 119: 650-651.
13. Troost A, Yun SH, Specht K, Krummenauer F, Schwenn O (2005) Transpalpebral tonometry: reliability and comparison

with Goldmann applanation tonometry and palpation in healthy volunteers. Br J Ophthalmol 89: 280-283.

14. Troost A, Specht K, Krummenauer F, Yun SH, Schwenn O (2005) Deviations between transpalpebral tonometry using TGDc-01 and Goldmann applanation tonometry depending on the IOP level. Graefes Arch Clin Exp Ophthalmol Albrecht Von Graefes Arch Klin Exp Ophthalmol 243: 853-258.
15. Kapamajian MA, de la Cruz J, Hallak JA, Vajaranant TS (2013) Correlation between corneal and scleral pneumatonometry: an alternative method for intraocular pressure measurement. Am J Ophthalmol 156: 902-906.
16. Vajaranant TS, Liu J, Wilensky J, Cortina MS, Aref AA (2016) Innovative Approaches to Glaucoma Management of Boston Keratoprosthesis Type 1. Curr Ophthalmol Rep 4: 147-53.
17. Fogt JS, Nau CB, Schornack M, Shorter E, Nau A, et al. (2020) Comparison of Pneumatonometry and Transpalpebral Tonometry Measurements of Intraocular Pressure during Scleral Lens Wear. Optom Vis Sci. 97: 711-719.
18. Banitt M (2011) Evaluation and management of glaucoma after keratoprosthesis. Curr Opin Ophthalmol 22: 133-136.
19. Senthil S, Mohamed A, Shanbhag SS, Durgam SS, Bagga B, et al. (2022) Glaucoma Evaluation and Management in Eyes with Boston Type 1 and Aurolab Keratoprostheses in an Indian Cohort. Cornea 41:552-561.
20. Utine CA, Arıkan G, Yardım E, Günenç Ü (2023) Management of glaucoma with Boston type 1 keratoprosthesis. Arq Bras Oftalmol 86: 137-144.
21. Li JY, Greiner MA, Brandt JD, Lim MC, Mannis MJ (2011) Long-term complications associated with glaucoma drainage devices and Boston keratoprosthesis. Am J Ophthalmol 152: 209-218.
22. Geoffrion D, Harissi-Dagher M (2020) Improving glaucoma management for the Boston keratoprosthesis type 1: tubes versus lasers. Expert Rev Ophthalmol 15: 313-320.
23. Aptel F, Charrel T, Palazzi X, Chapelon JY, Denis P, (2010) Histologic effects of a New Device for High-Intensity Focused Ultrasound Cyclocoagulation. Invest Ophthalmol Vis Sci 51: 5092-5098.
24. Posarelli C, Covello G, Bendinelli A, Fogagnolo P, Nardi M (2019) High-intensity focused ultrasound procedure: The rise of a new noninvasive glaucoma procedure and its possible future applications. Surv Ophthalmol 64: 826-834.
25. Rouland JF, Aptel F (2021) Efficacy and Safety of Ultrasound Cycloplasty for Refractory Glaucoma: A 3-Year Study. J Glaucoma 30: 428-435.
26. Lin M, Bhatt A, Haider A, Kim G, Farid M, et al. (2017) Vision retention in early versus delayed glaucoma surgical intervention in patients with Boston Keratoprosthesis type. PLoS ONE 12: e0182190.
27. Charrel T, Aptel F, Birer A, Chavrier F, Romano F, et al. (2011) Development of a miniaturized HIFU device for glaucoma treatment with conformal coagulation of the ciliary bodies. Ultrasound Med Biol 37: 742-754.
28. Aptel F, Charrel T, Lafon C, Romano F, Chapelon JY, et al. (2011) Miniaturized high-intensity focused ultrasound device in patients with glaucoma: a clinical pilot study. Invest Ophthalmol Vis Sci 52: 8747-853.
29. Crnej A, Paschalis EI, Salvador-Culla B, Tauber A, Drnovsek-Olup B, et al. (2014) Glaucoma progression and role of glaucoma surgery in patients with Boston keratoprosthesis. Cornea 33: 349-354.
30. Touma S, Harissi-Dagher M (2021) Outcomes and complications of Boston keratoprosthesis type I implantation in unilateral versus bilateral corneal blindness. Can J Ophthalmol 56: 130-136.
31. El-Khoury J, Khair D, Daoud R, Thompson P, Racine L, et al. (2023) Boston type I keratoprosthesis versus penetrating keratoplasty following a single failed corneal graft. Eye (Lond) 37: 486-491.
32. Saini C, Davies EC, Ung L, Chodosh J, Ciolino JB, et al. (2023) Paschalis EI, Pineda R, Saeed HN, Yin J, Shen LQ. Incidence and risk factors for glaucoma development and progression after corneal transplantation. Eye (Lond) 37: 2117-2125.
33. Rivier D, Paula JS, Kim E, Dohlman CH, Grosskreutz CL (2009) Glaucoma and keratoprosthesis surgery: role of adjunctive cyclophotocoagulation. J Glaucoma 18: 321-324.