Corneal Edema and Keratoplasty: Risk Factors in Eyes With Previous Glaucoma Drainage Devices

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• PURPOSE: To assess risk factors contributing to corneal decompensation following glaucoma drainage device (GDD) implantation.
• DESIGN: Retrospective case control study.
• METHODS: Records of 1610 eyes that underwent GDD implantation between June 1, 2009, and April 1, 2020, at the Johns Hopkins Wilmer Eye Institute were reviewed. Seventy-nine eyes (5%) developed corneal decompensation, of which 46 underwent keratoplasty. These 79 cases were matched with 220 controls. Cox proportional hazard models with robust standard error estimates to account for clustering at the matched-pair level were used to assess risk factors for corneal decompensation. Kaplan-Meier survival analysis analyzed time to corneal decompensation.
• RESULTS: The mean (SD) age of cases and controls was 68 (12.3) and 60.5 (15.9) years, respectively. The mean time from GDD implantation to corneal decompensation was 32 months, and the cumulative probability of developing decompensation at 3, 6, and 9 years was 4.7%, 9.2%, and 14.8%, respectively. Final visual outcomes in cases were worse, with a final mean ± SD visual acuity (logMAR) of 1.96±1.25 relative to a mean±SD visual acuity of 1.11±1.36 in controls ($P < .001$). In the multivariable model, significant risk factors for corneal decompensation were increased age (adjusted hazard ratio [AHR] 1.39, 95% CI 1.18, 1.63; $P \leq .001$), history of Fuchs dystrophy or iridocorneal endothelial syndrome (AHR 9.18, 95% CI 5.35, 15.74; $P \leq .001$), and postoperative complications such as hypotony (AHR 3.25, 95% CI 1.85, 5.72; $P \leq .001$) and tube-cornea touch (AHR 6.37, 95% CI 3.77, 10.75; $P \leq .001$).
• CONCLUSIONS: The risk of postoperative corneal decompensation is persistent over time. Patients receiving GDDs, particularly those with advanced age, preexisting corneal pathology, and postoperative complications, should be counseled regarding their increased risk for corneal decompensation. (Am J Ophthalmol 2022;238: 27–35. © 2022 Elsevier Inc. All rights reserved.)

MEDICARE DATA AND SURVEYS OF SURGEON practice patterns have shown that the use of glaucoma drainage devices (GDDs) in the surgical treatment of glaucoma has increased significantly over the past 30 years whereas trabeculectomies have seen a corresponding decrease.[1–3] Since the 2012 Tube Versus Trabeculectomy (TVT) study demonstrated GDDs as a comparable alternative to trabeculectomy with mitomycin C in eyes with previous ocular surgery, the use of GDDs has expanded beyond refractory cases of glaucoma. The more recent Primary Tube Versus Trabeculectomy (PTVT) study found further evidence for the value of GDD even in eyes without prior surgery, though trabeculectomy retained certain advantages.[4–6]

Corneal decompensation has been found to be one of the most common long-term complications of GDDs, with the TVT study finding that 16% of tube patients developed persistent corneal edema and 8% underwent subsequent keratoplasty during 5 years of follow-up, rates twice as high as those for the trabeculectomy group, suggesting that the GDD presented greater risk of this complication.[7] In that study, persistent corneal edema was also the most common complication causing reoperation or loss of visual acuity (VA) after GDD. The Ahmed Baerveldt Comparison study similarly found a corneal decompensation rate of 20% over 5 years of follow-up, although the authors also noted that all but 12% had preexisting factors that may have contributed to development of this complication.[8] Outside of these clinical trials, retrospective analyses and case series have shown variable corneal decompensation rates between 8% and 19%.[9–12]

The mechanisms leading to corneal decompensation following GDD implantation are currently unclear. One suggested hypothesis is mechanical damage to the corneal endothelium due to fluid turbulence at the tip of the tube in the anterior chamber or trauma from intermittent corneal-

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touch related to hard blinks or eye rubbing.[13] These ideas are supported by multiple studies demonstrating that GDDs closer to the corneal endothelium can result in greater corneal endothelial cell density loss.[14–18] Other proposed mechanisms include flat or shallow anterior chamber, inflammation within the anterior chamber postoperatively, hypotony, or elevated IOP.[14,16,19–22]

There has been limited investigation of the risk factors associated with corneal decompensation following GDD implantation. In 2019, Knier and associates[23] investigated all reasons for keratoplasty at a tertiary care center and noted that patients who underwent keratoplasty following GDD implantation often had comorbid corneal disease such as Fuchs dystrophy and pseudophakic bullous keratopathy, a history of uveitis, or a history of multiple intraocular procedures. However, these factors were not statistically analyzed because the study focused on the outcome of keratoplasty rather than GDD as an exposure. Given the significant rise in GDD popularity, it is important to assess this common surgical complication because of the profound effect it can have on postoperative VA loss, long-term patient discomfort, additional surgery, and further increase in cost of care. Thus, the purpose of this study is to examine the rate and associated risk factors for corneal decompensation and keratoplasty among glaucoma patients treated with GDD implantation.

METHODS

A retrospective review of medical records of 1610 eyes that underwent GDD implantation by 8 surgeons from June 1, 2009, to April 1, 2020, at the Wilmer Eye Institute and its affiliated surgical centers was performed. Seventy-nine eyes (5%) of 79 patients subsequently developed postoperative corneal decompensation, of which 46 underwent keratoplasty. Of the 46 keratoplasty patients, 39 (85%) underwent Descemet stripping endothelial keratoplasty, 5 (11%) underwent penetrating keratoplasty, and 2 (4%) underwent keratoprosthesis. There was a concurrent GDD revision procedure, either trimming or repositioning, in 23 of 46 (50%) eyes that underwent keratoplasty. The 79 cases were matched with 220 control eyes from 220 patients. Thus, the case-control population was composed of 298 eyes of 298 patients. The study abided by the Declaration of Helsinki and was Health Insurance Portability and Accountability Act (HIPAA) compliant. The study protocol was reviewed and approved by the Johns Hopkins Medicine Institutional Review Board, which issued a waiver of consent.

• **PATIENT IDENTIFICATION AND STUDY DESIGN:** Billing records were used to identify patients who underwent GDD procedures coded as aqueous shunt to an extraocular reservoir without graft (*Current Procedural Terminology* [*CPT*] code 66179) or with graft (*CPT* code 66180). *CPT* code 66180 was used to identify all aqueous shunts before 2015. Patients who had undergone keratoplasty were identified using the following *CPT* codes: 65730, 65750, and 65755 for penetrating keratoplasty; 65756 for endothelial keratoplasty; and 65770 for keratoprosthesis. Clinical notes, slitlamp examination findings, and operative notes were reviewed to gather data on patients who met inclusion/exclusion criteria. The presence of corneal edema was identified via a diagnosis of corneal edema recorded into the patient record or documentation of corneal edema in the slitlamp findings portion of clinical encounters.

To determine risk factors for corneal decompensation, matched cases and controls were identified. Cases were defined as patients aged ≥18 years with a history of nonjuvenile glaucoma and GDD implantation with subsequent keratoplasty or development of persistent corneal edema. To exclude transient postoperative edema, corneal decompensation was defined as persistent corneal edema present for at least 3 consecutive months postoperatively without resolution (starting at any postoperative point) and also present at the last follow-up within the study period. Two or 3 unique controls were matched to each case based on the surgeon performing the GDD implantation, the date the GDD surgery was performed, and sufficient duration of follow-up (see below). Controls were also aged ≥18 years with a history of nonjuvenile glaucoma and GDD implantation, but they did not undergo keratoplasty or experience corneal decompensation following GDD implantation.

To allow for sufficient time for corneal decompensation to occur, a necessary criterion for controls was a minimum follow-up time of either 6 months or the follow-up time of their matched case, whichever was longer. Thus, 100% of controls exceeded their matched case in time at risk for corneal decompensation. If the control eye's GDD date could not be matched within 2 years of the case's GDD date using this criterion, then a case was used from another surgeon to prioritize temporal matching. This occurred in 7 of 220 control eyes. All eyes with a history of corneal decompensation or keratoplasty prior to the GDD implantation were excluded.

• **BASELINE DATA:** Preoperative data such as age at time of GDD implantation, sex, race, history of trauma, lens status (phakic, pseudophakic, or aphakic), prior uveitis, prior herpetic eye disease, history of diabetes mellitus, prior intraocular surgeries, and history of Fuchs dystrophy or iridocorneal endothelial (ICE) syndrome were collected via chart review.

• **INTRAOPERATIVE AND POSTOPERATIVE DATA:** The following intraoperative data were collected: location of tube in the eye (anterior chamber, pars plana, or sulcus) and type of tube used (valved Ahmed vs non-valved Baerveldt).

The following postoperative data were collected: GDD revision technique (ligation, removal, erosion repair, or reposition), date of GDD revision procedure, presence of

tube-cornea touch, flat or shallow anterior chamber, infection (including suture abscess, blebitis, and endophthalmitis), postoperative elevated IOP, postoperative hypotony, and repeat GDD procedure that involved placement of a second tube. Postoperative elevated IOP was defined as elevated IOP requiring an additional surgical procedure or 2 or more IOP readings of at least 30 mm Hg without resolution for a minimum of 3 months. To exclude transiently elevated IOP following GDD implantation, the elevated IOP must have occurred after at least 3 months postoperatively. Postoperative hypotony was similarly defined, with a threshold IOP of 5 mm Hg or below for a maximum of 5 mm Hg for 3 months, starting 3 months after GDD implantation. Keratoplasty was considered an "end" event for cases, and all postoperative data were collected prior to the keratoplasty.

• **FUNCTIONAL OUTCOMES AND MEASUREMENTS:** Best-available visual acuity (VA), excluding pinhole measurements, and IOP were collected preoperatively and at the final follow up visit within the study period. For cases that underwent keratoplasty, the final follow up visit was the last preoperative date prior to the keratoplasty. When multiple IOP values were provided for a specific visit, preference was given for those obtained via applanation.

• **STATISTICAL ANALYSIS:** Univariate and multivariable Cox proportional hazard models with robust standard error estimates to account for clustering at the matched-pair level were used to assess risk factors for corneal decompensation. Because matched eyes were treated by the same surgeon and close in date, the outcomes may be correlated. The robust standard error approach was implemented to account for the clustering that may arise from the matching cases and controls. A Kaplan-Meier survival analysis was used to determine time to event for corneal decompensation in cases among the overall GDD population. The nonparametric log-rank test of equality between the survivor functions for the unilateral and bilateral eyes was performed to determine whether progression to postoperative corneal decompensation differs between the 390 bilateral eyes and the 1220 unilateral eyes.

Snellen VA measurements were converted to logarithm of the minimum angle of resolution (logMAR) values for purposes of statistical analysis. For visual acuities recorded as count fingers, hand motion, and light perception, logMAR values of 2, 3, and 4 were used, respectively. For baseline characteristics, Student t tests and χ^2 or Fisher exact tests were performed to compare continuous (age and IOP) and categorical (sex, race, presence of comorbidities or complications, etc) variables, respectively.

RESULTS

The mean follow-up duration was 3 years 9 months for cases and 5 years 3 months for controls. The mean time from GDD implantation to onset of persistent corneal edema was 32 months (range: 3-98 months). The mean time from GDD implantation to keratoplasty was 41 months (range: 4-109 months).

• **BASELINE DATA:** The baseline characteristics of the study population are included in Table 1. The mean ± SD age of the cases and controls was 68.0 ± 12.3 years and 60.5 ± 15.9 years, respectively. The mean ± SD IOP measured at the preoperative visit in the total study population was 26.2 ± 9.5 mm Hg for cases and 26.3 ± 10.0 mm Hg for controls. Of the 6 patients with ICE syndrome, 3 (50%) had Chandler syndrome, whereas 3 (50%) were not specified.

• **RISK FACTOR ANALYSIS:** The results of the univariate and multivariable Cox proportional hazard models are presented in Table 2. All variables with statistical significance ($P < .05$) in the presented univariate model were included in the multivariable model. In the univariate model, a higher risk of corneal decompensation was associated with an increased age at the time of GDD implantation (hazard ratio [HR] 1.44, 95% CI 1.24, 1.67); postoperative hypotony (HR 4.46, 95% CI 2.74, 7.28); a history of either Fuchs dystrophy or ICE syndrome (HR 7.29, 95% CI 4.23, 12.6); and an increased number of prior glaucoma surgeries, which included trabeculectomy, laser trabeculoplasty, laser iridotomy, or diode cyclophotocoagulation (HR 1.39, 95% CI 1.10, 1.74). Several postoperative GDD complications were also associated with corneal decompensation, including tube-cornea touch (HR 5.14, 95% CI 2.87, 9.20), flat chamber (HR 1.92, 95% CI 1.11, 3.30), postoperative infection (HR 2.42, 95% CI 1.15, 5.07), and tube revision (HR 2.98, 95% CI 1.93, 4.60).

The multivariable model identified 4 risk factors for corneal decompensation, which were increased age (adjusted hazard ratio [AHR] 1.39, 95% CI 1.18, 1.63), postoperative hypotony (AHR 3.25, 95% CI 1.85, 5.72), tube-cornea touch (AHR 6.37, 95% CI 3.77, 10.75), and a history of Fuchs dystrophy or ICE syndrome (AHR 9.18, 95% CI 5.35, 15.74). Tube revision surgeries and postoperative infections were significant in the univariate module but not the multivariable model. In a cross-tabulation, these 2 variables were found to be highly associated, with 3 of 240 eyes (1.3%) without tube revision experiencing postoperative infection and 10 of 59 eyes (16.9%) with tube revision experiencing postoperative infection.

• **SURVIVAL ANALYSIS:** A Kaplan-Meier survival analysis was performed to analyze time to corneal decompensation in all study patients following GDD implantation and is presented in Figure 1. The proportion of eyes without postoperative corneal decompensation at 3, 6, and 9 years post-GDD implantation were 95.3%, 90.8%, and 85.2%, respectively. The log-rank test showed that the survival functions for corneal decompensation are not statistically different

TABLE 1. Demographic and Baseline Characteristics of 299 Study Eyes Prior to Glaucoma Drainage Device Implantation at a Tertiary Care Center, Grouped by Cases and Controls

	Cases (No. of Eyes = 79)	**Controls** (No. of Eyes = 220)	***P* Value**
Age, y, mean ± SD	68.0 ± 12.3	60.5 ± 15.9	<.001
Sex			.610
Male	36 (45.6)	93 (42.3)	
Female	43 (54.4)	127 (57.7)	
Race			.210
Caucasian	33 (41.8)	89 (40.5)	
Black	31 (39.2)	105 (47.7)	
Other	15 (19.0)	26 (11.8)	
Lens status			.870
Phakic	30 (38.0)	90 (40.9)	
Pseudophakic	46 (58.2)	120 (54.5)	
Aphakic	3 (3.8)	10 (4.5)	
Tube type			.170
Ahmed	23 (29.1)	83 (37.7)	
Baerveldt	56 (70.9)	137 (62.3)	
GDD location			.150
Anterior chamber	70 (88.6)	204 (92.7)	
Pars plana	4 (5.1)	12 (5.5)	
Sulcus	5 (6.3)	4 (1.8)	
History of trauma	7 (8.9)	21 (9.6)	.850
History of diabetes	22 (27.8)	79 (35.9)	.190
History of uveitis	23 (29.1)	71 (32.3)	.600
History of herpetic eye disease	3 (3.8)	8 (3.6)	>.999
History of Fuchs or ICE syndrome			<.001
Fuchs dystrophy	8 (10.1)	1 (0.5)	
ICE syndrome	6 (7.6)	0 (0)	
IOP (mm Hg), mean (SD)	26.2 (9.5)	26.3 (10.0)	.940

GDD = glaucoma drainage device, ICE = iridocorneal endothelial, IOP = intraocular pressure.
Unless otherwise noted, values are n (%).

($P = .144$) between the unilateral and bilateral eyes in the 1610-eye population.

• **VISUAL OUTCOMES:** The VA outcomes of cases and controls are shown in Table 3. Cases are further grouped into eyes without keratoplasty and those with keratoplasty for further comparison. Cases had a mean ± SD (Snellen equivalent) baseline VA of 0.71 ± 0.74 (20/100), whereas controls had a mean ± SD baseline VA of 0.71 ± 0.82 (20/100) ($P = .944$). At the final visit, visual outcomes in patients who experienced corneal decompensation, either with or without keratoplasty, post-GDD were worse, with a mean ± SD VA of 1.96 ± 1.25 (20/1800) at final follow-up relative to a mean ± SD VA of 1.11 ± 1.36 (20/250) in patients without corneal decompensation ($P < .001$). These data are also displayed in Figure 2, with the medians and the 25th and 75th quartiles represented in the box and whisker plots.

DISCUSSION

Our analysis of corneal decompensation after GDD implantation over an 11-year period found that advanced age, preexisting corneal pathology, and postoperative GDD complications were the most significant risk factors associated with corneal decompensation and keratoplasty. Patients with these risk factors should be counseled preoperatively regarding their increased risk for corneal decompensation, and knowledge of these risk factors can assist in guiding expectant management of corneal health following GDD implantation. The substantial rate of decompensation, which may be higher in specific groups, also highlights the need for prospective study with careful documentation of preoperative corneal status and effects of variation in GDD implantation to avoid this complication.

Corneal decompensation is recognized as a late complication of GDD implantation that has been identified in prospective studies.[7,8] Medicare claims-based data reported by Stein and associates[24] in 2008 reported a 6-year cumulative corneal edema rate of 27.8% following GDD implantation. However, it should be noted that claims-based data are limited because of their inability to confirm that the tube shunt eye was the eye with corneal edema and their reliance on the physician including the edema as a billing diagnosis. Although there has been much

TABLE 2. Cox Proportional Hazard Models for Corneal Decompensation Following Glaucoma Drainage Device Implantation in 79 Eyes Over an 11-Year Period

Predictors		Univariate Analysis		Multivariable Analysis	
	Comparison	HR	95% CI	AHR	95% CI
Sex	Female vs male	0.83	0.53, 1.27		
Race	Black vs White	0.82	0.51, 1.32		
	Other vs White	1.60	0.85, 3.00		
Age	Per 10 years	**1.44**	1.24, 1.67	**1.38**	1.18, 1.63
Lens status	Pseudophakic vs phakic	1.18	0.72, 1.94		
	Aphakic vs phakic	0.86	0.26, 2.82		
Glaucoma type	OAG vs other	1.19	0.74, 1.93		
Tube location	Anterior chamber vs other	0.60	0.31, 1.18		
Tube type	Baerveldt vs Ahmed	1.29	0.81, 2.04		
Prior glaucoma surgeries	≥1 prior surgeries	**1.39**	1.10, 1.74	1.30	0.99, 1.72
Prior incisional surgeries	≥1 prior surgeries	1.28	0.99, 1.65		
Prior trabeculectomy	Yes vs no	1.07	0.71, 1.60		
No. of GDD implantations	1 or 2 tubes	1.56	0.97, 2.52		
Postoperative complications					
Postoperative hypotony	Yes vs no	**4.46**	2.74, 7.28	**3.25**	1.85, 5.72
Postoperative elevated IOP	Yes vs no	1.54	0.80, 2.97		
Tube revision surgery	Yes vs no	**2.98**	1.93, 4.60	1.10	0.60, 1.99
Tube-cornea touch	Yes vs no	**5.14**	2.87, 9.20	**6.37**	3.77, 10.75
Flat chamber	Yes vs no	**1.92**	1.11, 3.30	1.50	0.86, 2.62
Postoperative infection	Yes vs no	**2.42**	1.15, 5.07	0.97	0.43, 2.20
Hx of Fuchs dystrophy or ICE syndrome	Yes vs no	**7.29**	4.23, 12.6	**9.18**	5.35, 15.74
Hx of uveitis	Yes vs no	0.81	0.48, 1.35		
Hx of herpetic eye disease	Yes vs no	0.94	0.36, 2.43		
Hx of diabetes	Yes vs no	0.74	0.46, 1.18		

AHR = adjusted hazard ratio, GDD = glaucoma drainage device, HR = hazard ratio, Hx = history, ICE syndrome = iridocorneal endothelial syndrome, IOP = intraocular pressure, OAG = open angle glaucoma.

Significant hazard ratios are bolded.

TABLE 3. Visual Outcomes in 79 Eyes With Corneal Decompensation Post Glaucoma Drainage Device Implantation

	Cases Without Keratoplasty(No. of Eyes = 33)	Cases With Keratoplasty(No. of Eyes = 46)	All Cases(No. of Eyes = 79)	Controls(No. of Eyes = 220)	*P* Value(Controls vs All Cases)[a]
Preoperative VA, logMAR					
Mean ± SD	0.78 ± 0.78	0.66 ± 0.72	0.71 ± 0.74	0.71 ± 0.82	.944
Median (IQR)	0.54 (0.30, 0.88)	0.48 (0.30, 0.70)	0.48 (0.30, 0.70)	0.40 (0.18, 0.88)	
VA at final visit, logMAR					
Mean (SD)	2.23 ± 1.57	1.77 ± 0.94	1.96 ± 1.25	1.11 ± 1.36	<.001
Median (IQR)	2.00 (1.00, 3.00)	1.80 (1.00, 2.00)	2.00 (1.00, 3.00)	0.54 (0.18, 1.30)	
P value [b]	<.001	<.001	<.001	<.001	

IQR = interquartile range, logMAR = logarithm of the minimum angle of resolution, VA = visual acuity.

[a] *P* values were calculated using linear mixed effects models accounting for potential correlation from matching.

[b] *P* values were calculated using Wilcoxon signed-rank test.

research analyzing the reasons for corneal endothelial cell density loss following GDD surgery, the impact of individual factors in predisposing a patient to the clinical outcome of postoperative corneal decompensation has not been fully investigated.[22] Furthermore, many studies have shown that corneal graft survival in eyes with GDD is reduced, with 5-year graft survival as low as 25%.[25–28] Thus, efforts to understand modifiable risk factors for corneal decompensation following tube shunt surgery are paramount.

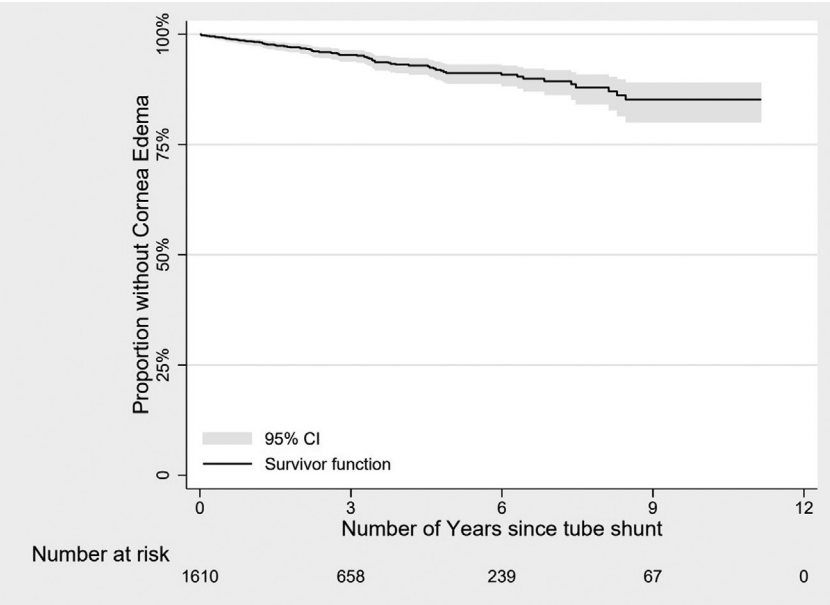

FIGURE 1. Kaplan-Meier survival analysis curve showing proportion of eyes without corneal edema following glaucoma drainage device implantation in a 1610-eye cohort. The proportion of eyes without corneal edema at 3, 6, and 9 years post glaucoma drainage device implantation were 95.3%, 90.8%, and 85.2%, respectively.

This study analyzes the effect of multiple risk factors on the development of persistent corneal edema or keratoplasty following GDD implantation. Previous studies on this topic have been limited to observational findings or the statistical analysis of just 1 or 2 variables of interest, such as tube type or type of glaucoma.[7–9,23,29] Similar to the findings of Kung and associates,[12] glaucoma type and the number of previous incisional intraocular surgeries were not associated with an increased rate of corneal decompensation in our study. Tube-cornea touch, hypotony, and history of Fuchs dystrophy or ICE syndrome were found to have the largest effects in our multivariable model. Postoperative GDD complications were also significantly associated with risk of developing corneal decompensation, as all measured complications other than elevated IOP postoperatively resulted in a significant hazard ratio.

The significance of prior corneal disease is a predictable result, as it would be expected that some of these patients may have gone on to experience corneal decompensation and require keratoplasty independent of the effect of the GDD. Although previous studies have shown that tubes closer to the cornea result in more endothelial cell loss,[14–17,30] the low number of sulcus and pars plana tubes in our study limit statistical comparison to anterior chamber tubes.

The role of tube type has been inconsistent in prior studies. Sinha and associates[31] recently published that Baerveldt tubes exhibited a higher rate of corneal decompensation than valved Ahmed tubes (9 eyes vs 0, $P = .001$) in uveitic glaucoma. Conversely, the Ahmed Versus Baerveldt Study found no statistically significant difference in tube complication rate or corneal decompensation rate between the 2 tube types at 5 years, which is consistent with our findings.[29]

The results of Sinha and associates may be partially attributed to the higher rate of tube-cornea touch in Baerveldt tubes, as all 5 patients with tube-cornea touch in the Baerveldt tube group developed corneal decompensation, which accounts for the majority of corneal decompensations in the Baerveldt group. In their study, 2 of the 4 remaining eyes that experienced decompensation underwent tube revision procedures for tube exposure and retraction, and 1 eye experienced an early shallow anterior chamber. In the Ahmed group, there was only 1 eye with tube-cornea touch, and there were no other reported complications in this group. It can thus be hypothesized that their results support the impact of postoperative tube complications, rather than the tube type itself, on corneal decompensation found in our study.

The findings of the Kaplan-Meier survival analysis are significant for a consistent rate of corneal decompensation over the entire study period among the overall GDD population. This would suggest that patients are exposed to a persistent risk of corneal decompensation at any point after surgery beyond just the initial postoperative period. This finding is consistent with studies that found corneal endothelial cell loss is persistent over time following GDD implantation.[14,16,18,32] However, this contrasts with studies that show accelerated corneal endothelial cell loss is transient in patients undergoing either trabeculectomy or phacoemulsification.[33–35] This may be due to the lack of tube-associated risk factors in trabeculectomy

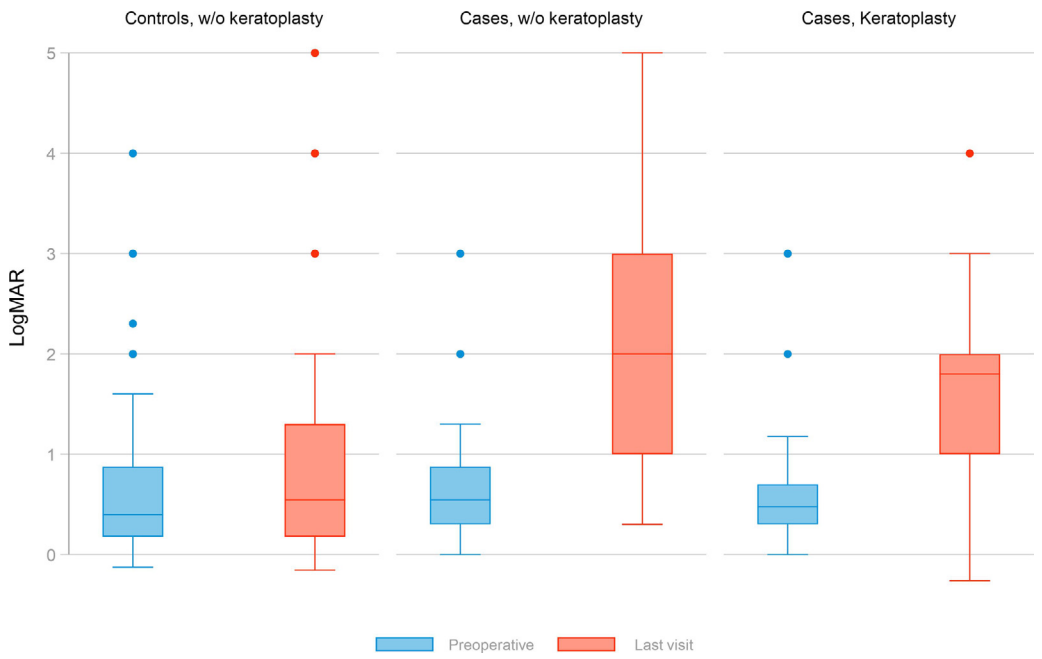

FIGURE 2. Box and whisker plot showing visual outcomes in eyes with and without corneal decompensation or keratoplasty post glaucoma drainage device implantation. The center line denotes the median visual acuity value (50th percentile), whereas the box borders denote the interquartile range (25th and 75th percentiles). The whiskers represent the 5th and 95th percentiles, and dots denote individual outlier values.

such as tube-cornea touch and resultant mechanical corneal trauma.

Our findings are consistent with the results of Garmany and associates,[10] who found that the risk of receiving a corneal graft following GDD at 5, 10, and 15 years was 9.4%, 16.8%, and 39.4%, respectively. It is worth noting that their use of keratoplasty as the final outcome measure underestimates the impact of corneal decompensation following GDD, as not all patients with corneal decompensation will undergo keratoplasty. This was true in our study and the TVT study.[7] Our data in particular showed a persistent corneal edema rate that was nearly double that of the keratoplasty rate, highlighting the importance of using persistent corneal edema as a marker for postoperative corneal decompensation rather than keratoplasty alone.

This is especially pertinent in eyes with severe glaucomatous damage, where the indications for a keratoplasty procedure are narrowed because of poor expected visual outcomes. Taken together, available studies suggest that the age of the patient be taken into account when considering the risk to the cornea in GDD implantation, as a young patient with longer life expectancy would likely experience greater cumulative lifetime risk, although older patients would experience a greater risk over a specific period of time (ie, per year of time).

Owing to its retrospective nature and the unstandardized treatment and follow-up of the study subjects, we were unable to use pachymetry as an objective measure of corneal decompensation because of its inconsistent use in our patient population after initial presentation. The diagnosis of corneal edema was made based on subjective determination by the provider on slitlamp examination. We suspect that this might have resulted in cases of mild corneal edema being missed and that the rate of corneal decompensation may in fact be greater.

Another limitation is that an edematous cornea can lead to inaccurate IOP measurements, thus affecting the reliability of our IOP measurements within the case group. Furthermore, because of the historic use of GDD for complicated eyes with refractory cases of glaucoma, many cases had preexisting factors that may have led to corneal decompensation even in the absence of a GDD, making it difficult to determine the relative effect a GDD had on the outcome. The 5-year results of the ongoing, prospective PTVT study will be valuable as the study population will presumably have fewer risk factors for corneal decompensation at baseline.[6]

We are also limited in that our study focused on a single tertiary eye referral center at an academic institution in an urban setting in the United States; thus, results found in this study may not be generalizable to other institutions or countries. The retrospective inclusion of 8 different surgeons also prevents the standardization of surgical method and standardized indications for surgical intervention. Future prospective studies are needed to determine if treatments aimed at reducing postoperative hypotony or the incidence of postoperative GDD complications affecting the cornea, such as through ab interno tube ligation[36] or sulcus/pars plana tube placement, are successful in

limiting corneal decompensation post-GDD, especially in treatment-naïve eyes.

The strengths of this study include the number of variables measured, the length of follow-up, and the specificity with which particular tube complications were identified. Additionally, the inclusion of 8 different surgeons increases the external validity, while the matching used for controls reduces the likelihood that surgical technique influences comparison between groups.

In conclusion, risk factors for corneal decompensation in this study included increased age at the time of GDD implantation, a greater number of prior glaucoma surgeries, history of prior corneal pathology, and postoperative GDD complications. Corneal survival post-GDD decreased linearly over time to 85.1% at 9 years. Corneal decompensation is a common, vision-threatening complication of GDD implantation that warrants further investigation into methods that may reduce this risk, such as sulcus tube placement. Patients with risk factors for corneal decompensation should be counseled preoperatively about the risk of persistent corneal edema and associated vision loss. Furthermore, eyes with postoperative GDD complications such as hypotony or tube-cornea touch may benefit from close monitoring of corneal health via pachymetry or endothelial cell density measurements to guide further management such as tube repositioning, although the use of such interventions to slow corneal decompensation requires further study.

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