Prognosis of Open Globe Injuries at a Tertiary Referral Center: The Modified Florida Ocular Trauma Score

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• PURPOSE: To analyze vision outcomes after open globe injury and propose modifications to the ocular trauma score to offer more specific vision prognoses.
• DESIGN: Validity and reliability analysis.
• METHODS: Patients presenting to the University of Florida with a new open globe injury from October 2015 to January 2021 with subsequent follow-up were included in the study. Demographics, ophthalmic history, trauma details, timeline, imaging, operative findings, and ocular examinations were collected from the medical record. Z tests, χ^2 test, Fisher exact test, receiver operating characteristic curve, and ordinal correlation were used. A weighted logistic model was optimized to predict vision outcomes. Measured outcomes included the best-corrected visual acuity, Ocular Trauma Score category, and performance of vision prognosis scores.
• RESULTS: A total of 162 eyes were identified from chart review. Eighty percent of the Ocular Trauma Score categories were accurate. Only the absence of orbital fractures was associated with a significant weight in the logistic model, which produced more accurate prognoses for 59 patients, and less accurate prognoses for 30 patients compared to the Ocular Trauma Score. Kendall Tau-B was 0.639 for the logistic model and 0.582 for the Ocular Trauma Score.
• CONCLUSIONS: The Ocular Trauma Score accurately estimates vision prognosis after open globe injury. We propose inclusion of orbital fracture status in our Modified Florida Ocular Trauma Score. This addended score is more correlated with final vision outcome and provides more specific prognoses for severe open globe injuries. Prospective, multicenter validation is needed to refine and confirm the use of this new scoring system. (Am J Ophthalmol 2022;244: 152–165. © 2022 Elsevier Inc. All rights reserved.)

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FULL-THICKNESS WOUNDS THROUGH THE CORNEA OR sclera are called open globe injuries (OGIs) according to the widely accepted Birmingham Eye Trauma Terminology (BETT) devised by Kuhn and associates.[1,2] OGIs are typically traumatic, but nontraumatic injuries are also possible.[3-5] These injuries and their sequelae are major causes of vision impairment and ocular morbidity worldwide, estimated by Négrel and associates in 1998 at an global annual incidence of 3.5 per 100 000 persons.[6] Vision-limiting sequelae include traumatic cataract, corneal scarring, retinal detachment, endophthalmitis, and phthisis.[7,8]

Severe sequelae such as endophthalmitis may eventually require evisceration or enucleation resulting in no vision potential.[9] In a large cohort of 48 563 OGI patients in the United States from 2003 to 2013, Ojuok and associates found that enucleation was performed in 6.2% of all OGIs.[10] Despite potential for devastating complications, most patients have an improvement in visual acuity following treatment.[11-13] Several studies in multiple countries demonstrate a vision outcome of 20/40 or better in more than 30% of eyes following OGI.[14-18]

The wide range of vision outcome reveals that not all OGIs are created equal, influenced by several factors including initial visual acuity, injury mechanism, wound extent, wound size, presence of relative afferent pupillary defect (RAPD), concomitant adnexal injury, and associated sequelae.[19-25] Studies consistently demonstrate that the strongest predictors are poor initial visual acuity, ruptured globe, posterior wound, RAPD, retinal detachment, and endophthalmitis.[15,16,26-28]

The Ocular Trauma Score (OTS) was the first and most widely used prognostic model, created by Kuhn and associates in 2002 using standardized nomenclature derived from the BETT.[29,30] The OTS calculates a numerical score based on initial visual acuity, RAPD, globe rupture, globe perforation, endophthalmitis, and retinal detachment. It then stratifies injuries into 5 categories correlating with a probability distribution of visual outcomes after ocular trauma, including OGI. Since its inception and adoption, the OTS has been shown to provide reliable prognostic information for OGIs across a variety of demographic groups.[26,31-36]

Despite its simplicity and utility, the OTS has been criticized for its retrospective design, statistical methods, and

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narrow scope. In 2008, Schmidt and associates[37] created an alternative prognostic model, the Classification and Regression Tree (CART), to predict vision outcomes after OGI using a prospectively validated data-driven approach in 51 patients, which showed an 85.7% sensitivity for no-vision outcomes and a 91.9% specificity for vision survival. A retrospective comparison of the OTS and CART in 100 patients, however, revealed that the OTS was slightly more accurate.[14] The OTS also includes only 6 parameters, excluding factors such as adnexal injury and visual acuity in preverbal children. Therefore, broader classification systems like the Pediatric Ocular Trauma Score (POTS) were devised.[38,39] Considering these limitations, we therefore conducted a retrospective review of OGI patients at our institution and propose modifications to the OTS.

METHODS

This retrospective study was conducted at the University of Florida (UF) Shands teaching hospital and approved under UF IRB 202200727, exempt from individual consent requirements. Patients were identified by querying the UF Health Integrated Data Repository (IDR), a large-scale database of electronic medical records across UF hospitals and clinics supported by the UF Clinical and Translational Science Institute.

The cohort included UF patients of all ages who presented with a new OGI from October 2015 to January 2021 and subsequently returned to UF for ophthalmologic follow-up, as determined by *International Classification of Diseases, Tenth Revision*, codes. The timing of OGI events was determined by review of surgeon, emergency department, and paramedic notes. Time to treatment was defined as hours between initial injury to start of primary repair or first ophthalmology evaluation if no surgery was indicated.

Final best-corrected visual acuity (BCVA) was determined at the first patient encounter after 6 months (180 days) following OGI or at the last patient encounter prior to 6 months if visual acuity had been stable for 2 encounters and no more follow-up was indicated. Patients who were deceased before completing ophthalmic treatment, lost to follow-up, had left against medical advice, or were found to have no OGI were excluded. Patients were considered lost to follow-up if they could perceive light in the injured eye and missed all encounters after initial evaluation.

Individual chart review was conducted for each patient in compliance with the Health Insurance Portability and Accountability Act. Recorded data included patient demographics, insurance status, ophthalmic history, mode and agent of trauma, timeline from injury to follow-up, imaging diagnoses, operative findings, and ophthalmic examinations from the initial and final encounter. For bilateral OGIs, one eye was randomly chosen for analysis by coinflip (ie, heads = OD, tails = OS) to reduce bias from double-counting paired eyes in our cohort. BCVA was recorded as Snellen chart equivalents and categorized into grades 1 (≥20/40) to 5 (no light perception [NLP]). For pediatric patients unable to test visual acuity by chart, no blink to light (NBTL), blink to light (BTL), and central-steady-maintained (CSM) were coded as grades 5, 3, and 1, respectively. Eviscerated or enucleated eyes were considered NLP.

Ophthalmic surgical history included any full-thickness surgeries such as cataract extraction and corneal transplant. OGIs were classified according to the BETTS terminology and visual outcome prognosis was determined using the OTS. Penetrating injuries refer entry wounds without an exit wound, while perforating injuries refer pairs of entry and exit wounds caused by a single trauma. Rupture injuries refer to breaks in the globe caused by high momentary intraocular pressure from blunt trauma.

Data entry and statistical analyses were completed using SPSS, version 28, and Microsoft Excel 2016. *Z* tests of proportion were used to compare final BCVA distributions between the UF cohort and the reference OTS cohort. McNemar χ^2 test and Monte Carlo simulations of Fisher exact test was used to test for associations between final BCVA and patient variables. Significantly associated variables were included in a weighted scoring model. OTS categories, arbitrary score units (ASU), and score ranges were used for the scoring model. The nonlinear generalized reduced gradient method[40] in the Excel Solver add-in was used to solve for variable weights by minimizing sum of residuals between predicted final BCVA grade and actual final BCVA grade for each patient. Variables with low weights (<5 ASU) or negligible impact (<5 net residuals) were removed from the final model,[41] termed the Modified Florida Ocular Trauma Score (MFOTS).

Goodman and Kruskal's Gamma was used to test for monotonic relationships between final BCVA grade and predictions from the OTS and MFOTS. Nonparametric correlation was calculated between final BCVA grade and predictions from both prognostic models using Kendall Tau-B. Receiver operating characteristic (ROC) curve analysis for OTS and MFOTS prediction of good visual outcomes (BCVA grade 1) and total vision loss (BCVA grade 5) were conducted. Areas under the curve (AUCs) were compared by *Z* test. Monte Carlo simulations of Fisher exact test was used to test for association between final BCVA and orbital fracture type.

RESULTS

The IDR cohort query identified 216 patients with a suspected OGI between October 2015 and January 2021. Within this cohort, 44 patients (21.3%) had no OGI on ophthalmic examination or surgical exploration and were excluded. Eight patients (3.7%) with a confirmed OGI were

TABLE 1. Cohort Demographic Profile

Parameter	Frequency (%)	Male	Female
Age, y			
0-9	15 (9.3)	12	3
10-19	13 (8)	9	4
20-29	29 (17.9)	26	3
30-39	28 (17.3)	24	4
40-49	25 (15.4)	23	2
50-59	19 (11.7)	14	5
60-69	12 (7.4)	10	2
70-79	16 (9.9)	8	8
80-89	4 (2.5)	1	3
90-99	1 (0.6)	1	0
Race/ethnicity			
White, non-Hispanic	111 (68.5)	88	23
African American	34 (21)	24	10
Hispanic	16 (9.9)	15	1
Asian	1 (0.6)	1	0
Insurance			
Medicare or Medicaid	77 (47.5)	55	22
Private	62 (38.3)	53	9
Uninsured	23 (14.2)	20	3
Ocular surgical history			
Yes	28 (17.3)	13	15
No	134 (82.7)	115	19
Glasses or eye protection			
Yes	156 (96.3)	122	34
No	6 (3.7)	6	0
Total	162 (100)	128	34

The UF cohort includes patients with diagnosed open globe injuries between October 2015 and January 2021.

lost to follow-up and excluded. The final study cohort characteristics of 162 patients are displayed in Table 1. There were 4 bilateral injuries and 2 pediatric patients who could not use the Snellen chart. Mean time of final BCVA assessment was 169 days (median = 171, SD = 103.7, minimum = 4, maximum = 580). Mean time to treatment was 30 hours (median = 11.5, minimum = 1, maximum = 984). Ophthalmic injury characteristics and risk factors are given in Table 2.

Most patients in the UF cohort were categorized as OTS categories 1 and 2, which carry the most severe prognosis (Table 3). Eviscerations and enucleations were eventually performed in 5 (3.1%) and 21 (12.9%) UF patients, respectively. Comparisons between the UF cohort vision outcomes and the OTS showed significant differences in 5 of 25 prognosis-outcome pairs. OTS category 1 predictions were more pessimistic than actual outcomes, and category 4 predictions were more optimistic than actual outcomes (Figure 1).

Two-tailed Fisher exact tests found no significant association ($P > .05$) between final BCVA grade and ethnicity, suspected endophthalmitis, insurance status, surgical history, eyewear, injury laterality, or time to treatment. Endophthalmitis was not significantly associated with final BCVA grade but is considered in the OTS and therefore included in subsequent analysis. Contingency tables for significantly associated variables and suspected endophthalmitis are given in Table 4.

The weighted scoring model solved for weights of all significant factors not already included in the OTS. Only the absence of orbital fractures was associated with a significant weight (+19 ASU) in the MFOTS. The MFOTS produced more accurate prognoses for 59 patients and less accurate prognoses for 30 patients than the OTS did. Classification of OGIs by OTS (Figure 2, A) and MFOTS (Figure 2, B) shows that the MFOTS predicted more optimistic visual acuity outcomes than the OTS, and that both prognostic models were associated with final BCVAs. Ordinal correlation results are shown in Table 5. The MFOTS had superior performance for predicting vision loss compared to the OTS (Figure 3, A) but did not have significant differences in performance for predicting good visual outcomes compared to the OTS (Figure 3, B). Fisher exact test found no significant association between orbital fracture type and final visual acuity (Table 7, $P = .239$).

DISCUSSION

The primary aim of this study was to compare OGIs and their vision outcomes within the UF hospital system. Results indicate that patients presenting to UF with OGIs (Table 1) have similar age and sex characteristics to other populations in the United States.[5] A wide range of patient ages from 2 to 92 years old were included, and most patients were male. Cohort ethnicity was representative of the local area, but White and Black patients were overrepresented whereas Hispanics were underrepresented.[42] Patients were more likely to be publicly insured (Medicare and Medicaid) or uninsured as opposed to privately insured.[43]

Many patients had a history of penetrating ocular surgery, which reflects the inclusion of older patients and prevalence of cataract surgery in this cohort. Mechanisms of injury (Table 2) are similar to other reported populations, where most OGIs are penetrating or perforating injuries.[42,44-47] Few patients reported eyewear or eye protection, which may be a result of selection bias because eyewear protects against OGIs. Both the left and right eyes were approximately equally represented in the UF cohort. Most patients were categorized as OTS 1 or 2, which may be a result of referral patterns. UF is an academic institution and treats more severe injuries that outside and community ophthalmologists may not feel comfortable managing.

Despite representative demographics and more severe prognoses, the UF cohort generally had better vision outcomes than predicted by the OTS (Table 3).[29] Significantly more UF patients with OTS category 4 injuries, however,

TABLE 2. Cohort Injury and Risk Factor Profile

Parameter Eye injured[a]	Frequency (%)	Male	Female
Right eye	70 (43.2)	60	10
Left eye	92 (56.8)	68	24
Time to treatment, hr[b]			
≤12	93 (57.4)	70	23
13-24	39 (24.1)	30	9
≥25	30 (18.5)	28	2
Iris involvement			
Yes	117 (72.2)	90	27
No	45 (27.8)	38	7
Injury zone			
I	37 (22.8)	29	8
II	66 (40.7)	49	17
III	59 (36.4)	50	9
Computed tomography findings[c]			
Yes	115 (71)	90	25
No	22 (13.6)	21	1
No imaging	25 (15.4)	17	8
Ultrasonographic findings[c]			
Yes	16 (9.9)	11	5
No	12 (7.4)	8	4
No imaging	134 (82.7)	109	25
Orbital fracture			
Yes	36 (22.2)	26	10
No	126 (77.8)	102	24
IOFB present			
Yes	52 (32.1)	47	5
No	110 (67.9)	81	29
Choroidal hemorrhage			
Yes	35 (21.6)	27	8
No	127 (78.4)	101	26
Injury mechanism			
Penetration	91 (56.2)	76	15
Perforation	19 (11.7)	16	3
Rupture	52 (32.1)	36	16
RAPD present			
Yes	66 (40.7)	47	19
No	96 (59.3)	81	15
Endophthalmitis			
Yes	14 (8.6)	9	5
No	148 (91.4)	119	29
Retinal detachment			
Yes	67 (41.4)	51	16
No	95 (58.6)	77	18
Initial best-corrected visual acuity (grade)			
(5) NLP	37 (22.8)	24	13
(4) HM or LP	67 (41.4)	55	12
(3) 19/200 to 1/200	22 (13.6)	20	2
(2) 20/50 to 20/200	13 (8)	10	3
(1) ≥ 20/40	23 (14.2)	19	4
Total	162 (100)	128	34

HM = hand motion, IOFB = intraocular foreign body, LP = light perception, NLP = no light perception, RAPD = relative afferent pupillary defect. Injury profiles were determined during initial evaluation or during surgical exploration.

[a] Bilateral open globes were found in 4 patients and assigned as right eye (2 patients) or left eye (2 patients) by coinflip.

[b] Surgical intervention was not indicated for all patients.

[c] Imaging was not performed for some patients at the discretion of the attending physician.

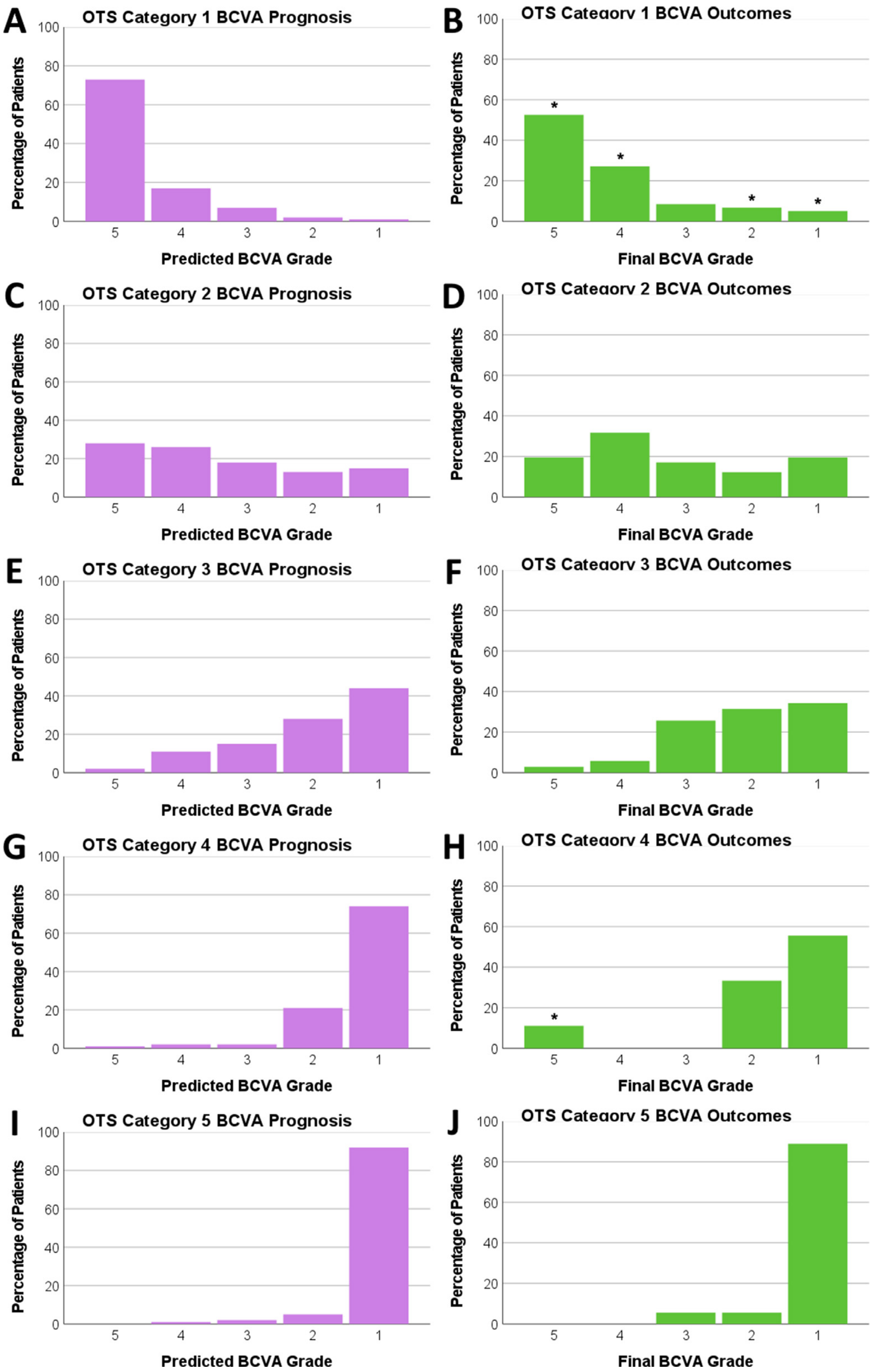

FIGURE 1. Bar graphs of Ocular Trauma Score (OTS) predicted and final best-corrected visual acuity (BCVA) grade distributions. Distributions of final BCVA grade for the OTS reference cohort are displayed on the left, and distributions of final BCVA for the University of Florida (UF) cohort are displayed on the left. Bars marked with an asterisk in (B) and (H) are significantly different from the OTS reference cohort at a 2-tailed 95% CI.

TABLE 3. Comparison of OTS Predicted and Actual Final Visual Acuity.

OTS Category	Final BCVA (Grade)	% OTS Cohort	% UF Cohort	*P* Value
1 (n = 59)	(5) NLP	73	52.5	<.001[a]
	(4) HM or LP	17	27.1	.039[a]
	(3) 19/200 to 1/200	7	8.5	.652
	(2) 20/50 to 20/200	2	6.8	.008[a]
	(1) ≥ 20/40	1	5.1	.002[a]
2 (n = 41)	(5) NLP	28	19.5	.226
	(4) HM or LP	26	31.7	.405
	(3) 19/200 to 1/200	18	17.1	.881
	(2) 20/50 to 20/200	13	12.2	.879
	(1) ≥ 20/40	15	19.5	.420
3 (n = 35)	(5) NLP	2	2.9	.704
	(4) HM or LP	11	5.7	.316
	(3) 19/200 to 1/200	15	25.7	.076
	(2) 20/50 to 20/200	28	31.4	.654
	(1) ≥ 20/40	44	34.3	.248
4 (n = 9)	(5) NLP	1	11.1	.002[a]
	(4) HM or LP	2	0	.669
	(3) 19/200 to 1/200	2	0	.669
	(2) 20/50 to 20/200	21	33.3	.365
	(1) ≥ 20/40	74	55.6	.208
5 (n = 18)	(5) NLP	0	0	>.999
	(4) HM or LP	1	0	.670
	(3) 19/200 to 1/200	2	5.6	.275
	(2) 20/50 to 20/200	5	5.6	.907
	(1) ≥ 20/40	92	88.9	.628

BCVA = best-corrected visual acuity, HM = hand motion, LP = light perception, NLP = no light perception, OTS = Ocular Trauma Score, UF = University of Florida.

Two-sided *Z* tests for proportion were used to determine *P* values.

[a]Significant *P* values at a 95% CI.

had total vision loss of the affected eye. These results are similar to those of other studies evaluating accuracy of the OTS,[31,34,47,48] suggesting that the OTS may overestimate visual outcomes for less severe injuries and underestimate visual outcomes for the most severe injuries. Several factors may explain this difference.

First, previously dire injuries may now be salvaged with advances in technology and treatment, especially in vitreoretinal surgery.[49] Second, UF is an academic institution with ophthalmology on call 24-7 to quickly triage and manage OGIs, which may be unavailable at community hospitals where patients must be transferred, resulting in delayed care. Third, surgeons at UF may be more experienced with ocular trauma repair and better versed at repair techniques.

Overall, 20 of the 25 combinations of final BCVA and OTS category were not significantly different from the OTS distribution. Validation studies report a similar predictive accuracy of around 80%.[50] Discrepancies between visual outcomes and prognoses for this study may be therefore expected from appropriate OTS interpretation.

Several factors known to affect BCVA outcome were identified in the UF cohort (Table 4), including injury mechanism, presence of RAPD, iris involvement, injury zone, intraocular foreign bodies, orbital fractures, retinal detachments, and choroidal hemorrhage.[15,16,23,26,27] OGIs visible on computed tomography and ultrasonography were also associated with worse BCVA outcomes. This finding may reflect that more severe injuries with greater anatomical distortion are more readily apparent on imaging, which may have implications for surgical outcomes.[51] Wound size was not measured for many patients in this cohort, but larger wounds have been correlated with worse BCVA outcomes despite its exclusion from this analysis.[15]

Endophthalmitis and time to treatment, however, were not significantly associated with BCVA outcome, contrary to some previous studies.[52] The UF cohort had 14 cases of suspected endophthalmitis, all of which were immediately treated with systemic and, in some cases, intravitreal antibiotics. This small sample size may lack power to detect

TABLE 4. Significant Comparisons of Final BCVA Grade With Injury Characteristics and Risk Factors

Parameter	Final BCVA Grade, n (%)	*P* Value				
	5	4	3	2	1	
Sex[a]						
Male	27 (21.1)	23 (18)	21 (16.4)	21 (16.4)	36 (28.1)	.048-.050
Female	14 (41.2)	8 (23.5)	1 (2.9)	3 (8.8)	8 (23.5)	
Iris involvement[a]						
Yes	36 (30.8)	27 (23.1)	14 (12)	14 (12)	26 (22.2)	<.001
No	5 (11.1)	4 (8.9)	8 (17.8)	10 (22.2)	18 (40)	
Injury zone[a]						
I	3 (8.1)	5 (13.5)	4 (10.8)	10 (27)	15 (40.5)	<.001
II	9 (13.6)	15 (22.7)	11 (16.7)	8 (12.1)	23 (34.8)	
III	29 (49.2)	11 (18.6)	7 (11.9)	6 (10.2)	6 (10.2)	
CT findings[a]						
Yes	37 (32.2)	28 (24.3)	16 (13.9)	13 (11.3)	21 (18.3)	<.001
No	1 (4.5)	1 (4.5)	3 (13.6)	3 (13.6)	14 (63.6)	
US findings[a]						
Yes	5 (31.3)	5 (31.3)	3 (18.8)	1 (6.3)	2 (12.5)	.086-.088
No	1 (8.3)	1 (8.3)	2 (16.7)	1 (8.3)	7 (58.3)	
Orbital fracture[a]						
Yes	25 (69.4)	8 (22.2)	2 (5.6)	1 (2.8)	0 (0)	<.001
No	16 (12.7)	23 (18.3)	20 (15.9)	23 (18.3)	44 (34.9)	
IOFB present[a]						
Yes	11 (21.2)	6 (11.5)	8 (15.4)	11 (21.2)	16 (30.8)	<.001
No	30 (27.3)	25 (22.7)	14 (12.7)	13 (11.8)	28 (25.5)	
Choroidal hemorrhage[a]						
Yes	20 (57.1)	6 (17.1)	3 (8.6)	3 (8.6)	3 (8.6)	<.001
No	21 (16.5)	25 (19.7)	19 (15)	21 (16.5)	41 (32.3)	
Mechanism[a]						
Penetration	11 (12.1)	13 (14.3)	14 (15.4)	17 (18.7)	36 (39.6)	<.001
Perforation	11 (57.9)	2 (10.5)	3 (15.8)	0 (0)	3 (15.8)	
Rupture	19 (36.5)	16 (30.8)	5 (9.6)	7 (13.5)	5 (9.6)	
RAPD[a]						
Yes	33 (50)	19 (28.8)	4 (6.1)	5 (7.6)	5 (7.6)	<.001
No	8 (8.3)	12 (12.5)	18 (18.8)	19 (19.8)	39 (40.6)	
Endophthalmitis[a,b]						
Yes	4 (28.6)	2 (14.3)	2 (14.3)	0 (0)	6 (42.9)	.422-.426
No	37 (25)	29 (19.6)	20 (13.5)	24 (16.2)	38 (25.7)	
Retinal detachment[a]						
Yes	26 (38.8)	18 (26.9)	9 (13.4)	8 (11.9)	6 (9)	<.001
No	15 (15.8)	13 (13.7)	13 (13.7)	16 (16.8)	38 (40)	
Initial BCVA grade[c]						
5	28 (75.7)	8 (21.6)	1 (2.7)	0 (0)	0 (0)	<.001
4	10 (14.9)	19 (28.4)	17 (25.4)	11 (16.4)	10 (14.9)	
3	1 (4.5)	3 (13.6)	2 (9.1)	6 (27.3)	10 (45.5)	
2	0 (0)	1 (7.7)	1 (7.7)	6 (46.2)	5 (38.5)	
1	2 (8.7)	0 (0)	1 (4.3)	1 (4.3)	19 (82.6)	
Total	41 (25.3)	31 (19.1)	22 (13.6)	24 (14.8)	44 (27.2)	—

BCVA = best-corrected visual acuity, CT = computed tomography, IOFB = intraocular foreign body, RAPD = relative afferent pupillary defect, US = ultrasonography.

Factors significantly associated at a 2-tailed confidence level of 95% are displayed. Age category, ethnicity, insurance status, surgical history, eyewear, laterality, and time to treatment were not significantly associated.

[a] Fisher exact tests were used to estimate *P* values by the Monte Carlo method.

[b] Endophthalmitis was not significantly associated with final BCVA grade but is used for OTS calculation and was therefore included in the table.

[c] McNemar χ^2 test for paired comparisons was used to determine the *P* value.

TABLE 5. The Modified Florida Ocular Trauma Score

Calculating OTS/MFOTS	Preoperative Features	Points				
1. Calculate the OTS sum of points as determined by the preoperative visual acuity and associated ocular injuries. Only include 1 BCVA category.	BCVA = NLP	+60				
	BCVA = LP or HM	+70				
	BCVA = 1/200 to 19/200	+80				
	BCVA = 20/200 to 20/50	+90				
	BCVA ≥ 20/40	+100				
	Globe rupture	–23				
	Endophthalmitis	–17				
	Perforating injury	–14				
	Retinal detachment	–11				
	RAPD present	–10				
2. Calculate the MFOTS sum of points by adjusting for orbital fracture or lack thereof.	Orbital fractures *absent*	+19				
3. Determine the OTS or MFOTS based on the sum of points calculated from preoperative features.	Sum of Points	OTS/MFOTS Category				
	0-44	1				
	45-65	2				
	66-80	3				
	81-91	4				
	92-100	5				
4. Estimate probability of final vision acuities based on the OTS.	OTS Category	NLP,				
%	LP or HM,					
%	1/200 to 19/200,					
%	20/200 to 20/50,					
%	≥20/40,					
%						
	1	73	17	7	2	1
	2	28	26	18	13	15
	3	2	11	15	28	44
	4	1	2	2	21	74
	5	0	1	2	5	92
5. Estimate probability of final vision acuities based on the MFOTS. This distribution is only applicable for the MFOTS, and not for the OTS	MFOTS Category	NLP,				
%	LP or HM,					
%	1/200 to 19/200,					
%	20/200 to 20/50,					
%	≥20/40,					
%						
	1	71.05	18.42	5.26	2.63	2.63
	2	27.27	42.42	12.12	9.09	9.09
	3	11.11	29.63	25.93	18.52	14.81
	4	3.7	7.41	25.93	25.93	37.04
	5	2.7	0	5.41	21.62	70.27

BCVA = best-corrected visual acuity, HM = hand motion, LP = light perception, MFOTS = Modified Florida Ocular Trauma Score, NLP = no light perception, OTS = Ocular Trauma Score, RAPD = relative afferent pupillary defect.

The MFOTS is adapted from the Ocular Trauma Score based created by Kuhn and associates in 2002. The leftmost column describes steps involved in estimating vision potential. The MFOTS stratifies injuries into 5 categories correlating with a probability distribution of likely visual outcomes after open globe injury.

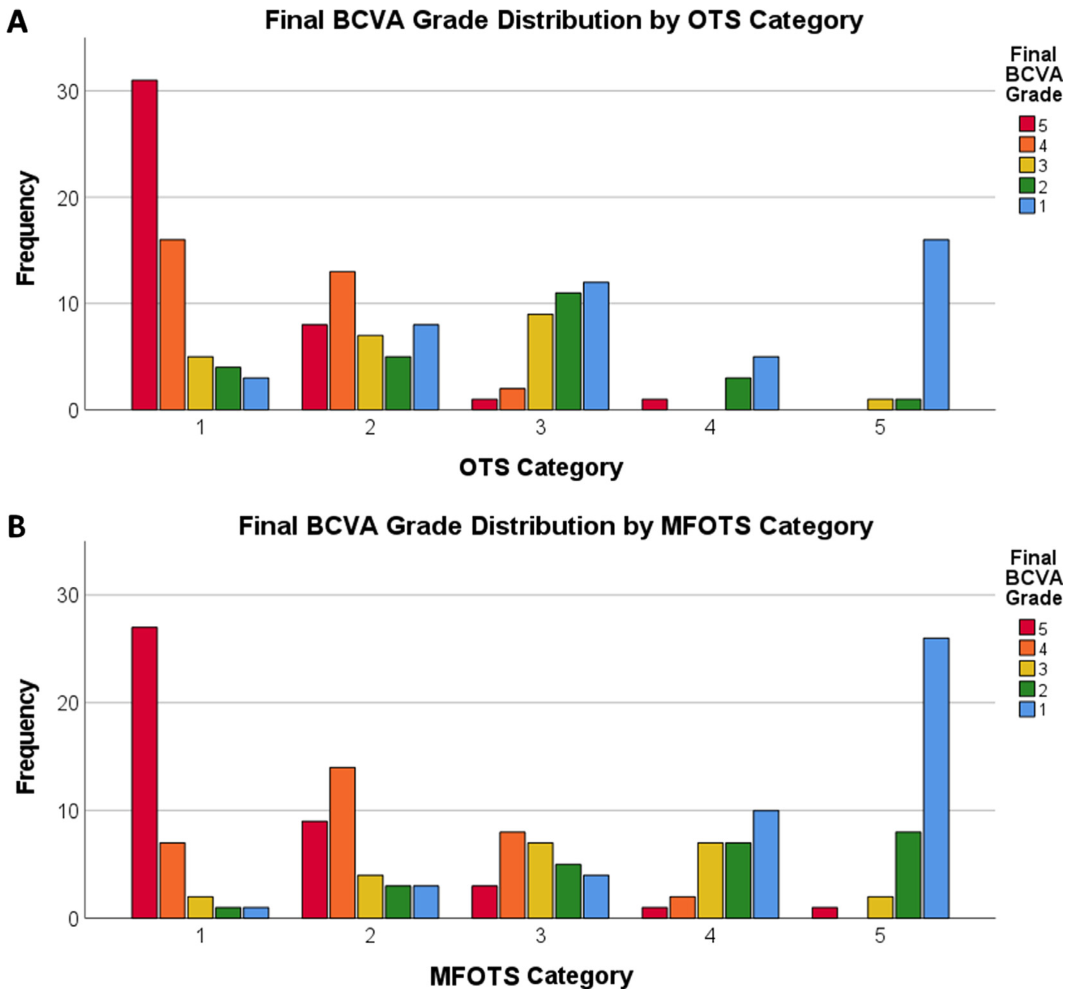

FIGURE 2. Bar graph of final best-corrected visual acuity (BCVA) grade distributed by Ocular Trauma Score (OTS) and Modified Florida Ocular Trauma Score (MFOTS). BCVA grades are displayed in colors and clustered by OTS and MFOTS categories. Red bars indicate the worst vision outcomes, and blue bars indicate the best vision outcomes.

associations with BCVA, or it may reflect the efficacy of improved antibiotic treatment of endophthalmitis.[8]

Whereas some studies showed evidence that final visual outcome is affected by time to treatment,[53] other studies have also concluded that the time to treatment may not considerably affect vision outcomes for most patients.[54] Times to treatment were also less precise for longer intervals beyond 1 week, sometimes to the closest day or week. Therefore, high-resolution comparisons that may have identified worse outcomes for very long times to treatment could not be performed with high statistical accuracy.

The secondary aim of this study was to propose improvements to the OTS, if any were possible. Although vision outcomes can be uncertain for months after OGI, patients benefit from information regarding their projected vision recovery or lack thereof.[7] These benefits may include anxiety relief and better-informed decision making. Ambiguous, overly optimistic, and overly pessimistic prognoses are not effective or useful information to patients, who may be better served with objective and specific prognoses.[55] Practical aspects should also be taken into consideration, as OGIs are ocular emergencies and require a straightforward model using easily accessible information.

Early identification of poor prognosis may aid in the decision to proceed with timely enucleation or evisceration to minimize risk of sympathetic ophthalmia. The OTS has remained the gold standard for OGI prognoses because of its ease of use and general accuracy, but its prognoses are somewhat biased, and its statistical methods are not documented.[14,37,48] In addition, OTS categories 2-4 give ambiguous prognoses. For example, OTS category 3 is more likely to result in the best visual acuity grade than moderate grades (Figure 1, E), and OTS category 2 is not predictive of any specific final BCVA grade (Figure 1, C).

With these scoring characteristics in mind, we created the MFOTS (Table 5) as a simple and accessible modification to the OTS that improves prognostic accuracy, especially for OTS category 1 injuries. Its statistical methods are

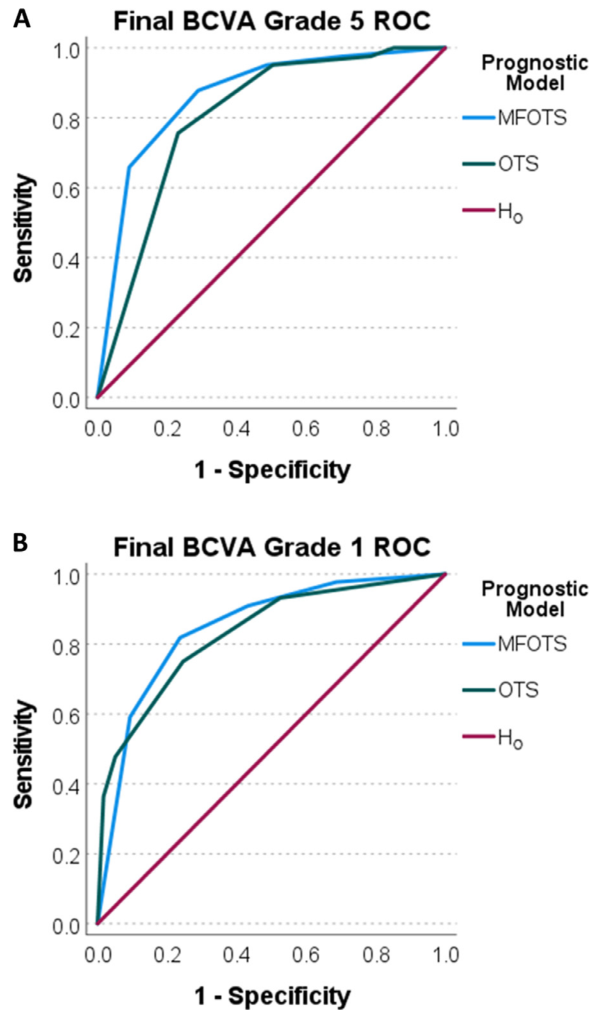

FIGURE 3. Receiver operating characteristic (ROC) curves of best-corrected visual acuity (BCVA) grade 5 and 1 by Ocular Trauma Score (OTS) and Modified Florida Ocular Trauma Score (MFOTS). ROC curves for MFOTS and OTS are displayed in blue and green, respectively. A red line with area under the curve (AUC) = 0.5 representing the null hypothesis (H_0) is displayed in both graphs. A. MFOTS (AUC = 0.865) outperforms OTS (AUC = 0.805) for BCVA grade 5 prognoses ($Z = 3.636$, $P < .001$). B. MFOTS (AUC = 0.847) and OTS (AUC = 0.831) have similar performance for BCVA grade 1 prognoses ($Z = 1.060$, $P = .289$).

also well documented and accessible for future validation or modification.[56] Predictions were optimized by assigning positive or negative weighted scores to associated factors in Table 4, but several with low impact and negligible weights were excluded from the MFOTS by model regularization.[41]

Exclusion of known associated factors may be explained by signal redundancy, wherein one factor may be excluded if another more impactful factor provided similar information.[57] For example, zone III and retinal detachment both indicate posterior globe injury, but retinal detachment is more indicative of vision loss. Other examples, age and sex, were also significantly associated with final BCVA, but are confounded with more definitive factors such as injury mechanism and subsequently excluded from the MFOTS.[58]

The weights used in the original OTS were also retained instead of recalculated, since the OTS had a substantial sample size and has been proven to be an overall accurate model. Within this cohort, perforations appeared to be more associated with poor prognosis than rupture (Table 4), but the OTS (Table 5) gives more weight to globe ruptures (–23 ASU) than to perforations (–14 ASU). This apparent discrepancy may be caused by redundant associations with other considered parameters such as retinal detachments. Ruptures are often anterior, such as in ruptured corneal grafts, or at rectus muscle insertions, where the sclera is thin. Perforations, however, often create exit wounds in the posterior pole where vision is difficult to rescue. As a result, our model and the OTS may have attributed the poor vision outcome to corresponding retinal injury instead of the perforation itself Table 6.

These results also may be compatible with the OTS weights, because results of Fisher exact tests (Table 4) only detect presence of association, not strength of association or effect size. The OTS weights for endophthalmitis are similarly high (–17 ASU) but was not shown to affect outcomes in this cohort (Table 4), which may be a result of high rates of topical, systemic, and intravitreal antibiotic use for most OGIs at UF.

Although the MFOTS was more accurate overall than the OTS and increased prognostic accuracy in 59 patients, it decreased prognosis accuracy in 30 patients. This is an expected result of appropriate model optimization for real-world data, as decreasing total error may increase error for individual outliers. Excessive interpolation to reduce error for all outliers may incorporate statistical noise and result in poor extrapolation and model generalizability.[59] In the setting of this cohort, superior MFOTS performance for all patients may be achieved by including all factor weights regardless of impact but would risk model overfitting.[41] Such a model may be poorly generalizable for individuals outside this sample and be cumbersome for clinical use.

These model design choices aim to balance prognostic performance within the cohort and generalizability for all OGIs. Therefore, decreased accuracy for some patients is an expected tradeoff for more general accuracy. Similarly, recalculating the weights for initial BCVA, RAPD, perforation, rupture, endophthalmitis, and retinal detachment may improve the performance of the MFOTS for the UF cohort but not for all OGIs. The OTS parameters derive from a larger sample size than the MFOTS and were thus retained to improve MFOTS generalizability.

Comparing the OTS and MFOTS, both prognostic models have a monotonic relationship with better BCVA outcomes (ie, as one increases, so does the other). The MFOTS, however, has a slightly higher correlation with final BCVA than does the OTS. ROC analysis comparing the OTS and MFOTS also shows that the MFOTS has su-

TABLE 6. Comparison of OTS and MFOTS Prognostic Performance

Scoring System	Statistic	Value	Error[a]	*P* Value
OTS	Gamma	0.723	0.050	<.001
	Kendall Tau-B	0.582	0.045	<.001
	BCVA grade 1 AUC[b]	0.831	0.036	<.001
	BCVA grade 5 AUC[b]	0.805	0.033	<.001
MFOTS	Gamma	0.759	0.044	<.001
	Kendall Tau-B	0.639	0.042	<.001
	BCVA grade 1 AUC[b]	0.847	0.033	<.001
	BCVA grade 5 AUC[b]	0.865	0.032	<.001

AUC = area under the curve, MFOTS = Modified Florida Ocular Trauma Score, OTS = Ocular Trauma Score.

[a] Asymptotic standard error was estimated in SPSS.

[b] Areas under the curve were compared to a null hypothesis of 0.500.

TABLE 7. Contingency Table of Orbital Fracture Type and Final BCVA Grade

Final BCVA Grade	Orbital Fracture Type				
	Floor, n (%)	Lateral, n (%)	Medial, n (%)	Roof, n (%)	All Fractures
5	3 (18.8)	1 (6.3)	9 (56.3)	3 (18.8)	16
4	4 (50)	1 (12.5)	3 (37.5)	0 (0)	8
3	0 (0)	2 (40)	3 (60)	0 (0)	5
2	0 (0)	1 (33.3)	1 (33.3)	1 (33.3)	3
1	2 (50)	0 (0)	1 (25)	1 (25)	4
Total	9 (25)	5 (13.9)	17 (47.2)	5 (13.9)	36

BCVA = best-corrected visual acuity.

Fisher exact tests were used to estimate *P* values by the Monte Carlo method. No significant association was found ($P = .239$).

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perior performance when identifying total vision loss, although its performance when identifying good visual outcomes (BCVA grade 5) is not significantly different from the OTS.

Distributions of vision outcomes within the MFOTS categories are centered closer to their predicted BCVA than for the OTS, which has the potential to offer patients a more specific prognosis (Figure 2). This aspect may be a consequence of the difference in model design, as the OTS is intended to produce distributions of BCVA for each prognosis category, whereas the MFOTS also attempts to match prognosis and BCVA outcomes in a 1:1 fashion.

The superior performance of the MFOTS is attributed entirely to the inclusion of orbital fractures, a unique proxy for impact force and energy.[60] Orbital fractures can also complicate open globe surgery and may subsequently be associated with poor anatomical outcomes after primary repair.[61] As a result, the MFOTS provides increased prognostic accuracy for the most severe injuries (Figure 3, A), but not for less severe injuries with favorable prognoses (Figure 3, B). The OTS may already be highly optimized for less severe injuries, and inclusion of orbital fracture in the MFOTS is not expected to improve prognostic accuracy in these patients who are unlikely to have orbital fractures. In essence, association of a positive weight with absence of orbital fracture (Table 5) screens out low-impact OGIs from the poorest prognosis categories predicted by the OTS.

Previous studies have shown that roof-involving orbital fractures may be associated with ocular injury incidence and severity,[62] but stratification of orbital fractures did not show an association with final BCVA (Table 7). Although roof-involving fractures may be associated with ocular injury, the inverse is not necessarily true, and OGIs may not be more associated with roof-involving fractures than other orbital fractures. Finite element analysis has even suggested that medial or floor fractures are more suggestive of direct ocular injury, as opposed to lateral wall and roof fractures that may be suggestive of primary orbital fracture and secondary ocular injury.[63]

In conclusion, the aims of this study were to compare OGI outcomes at UF to the OTS and to propose improvements to the OTS. Patients treated for OGIs at UF hospitals were representative of patients with OGIs in the United

States, and their vision outcomes were generally well estimated by the OTS. Some severe OGIs had better prognoses than predicted by the OTS, but validation studies from other trauma centers have demonstrated similar prognostic error using the OTS. Given that OGIs and their outcomes at UF are comparable with those at other trauma centers,[31,34,47,48] the MFOTS was derived from this cohort to improve on the OTS with generalizability and statistical parsimony in mind. The MFOTS improved prognostic accuracy for more severe OGIs by identifying better vision outcomes in some patients without orbital fractures. Clinicians should therefore be more hesitant to enucleate or eviscerate severe open globes in the absence of orbital fracture, as prognoses are more optimistic than previously thought according to the OTS. Another advantage of the MFOTS over the OTS is a slightly greater monotonic relationship between prognosis and outcome, although the OTS was not explicitly designed for this purpose.

Therefore, we tentatively propose the use of the MFOTS in addendum to the OTS for providing patients with a more specific prognosis. Interpretation of this study should consider its limited prognostic value due to its retrospective design, smaller sample size, and its origin in a single tertiary trauma center. Prospective studies at UF and other sites are needed to validate the accuracy of the MFOTS, which may soon be possible with large ocular trauma databases such as International Globe and Adnexal Trauma Epidemiology Study (IGATES).[64] As treatments for OGI improve, it may be necessary to reassess and recalculate parameter weights for both the OTS and MFOTS to provide patients with accurate prognoses that consider current best practices.

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REFERENCES

1. Kuhn F, Morris R, Witherspoon CD. Birmingham Eye Trauma Terminology (BETT): terminology and classification of mechanical eye injuries. *Ophthalmol Clin North Am*. 2002;15(2):139–143 v.
2. Kuhn F, Morris R, Witherspoon CD, Heimann K, Jeffers JB, Treister G. A standardized classification of ocular trauma. *Ophthalmology*. 1996;103(2):240–243.
3. Gross AW, Fan JZ, Pfeiffer ML, Chuang AZ, Richani K, Crowell EL. Non-traumatic open globe injuries: presenting characteristics and visual outcomes. *Eye (Lond)*.Published online December 2, 2021. doi: 10.1038/s41433-021-01869-4
4. May DR, Kuhn FP, Morris RE, et al. The epidemiology of serious eye injuries from the United States Eye Injury Registry. *Graefes Arch Clin Exp Ophthalmol*. 2000;238(2):153–157.
5. Mir TA, Canner JK, Zafar S, Srikumaran D, Friedman DS, Woreta FA. Characteristics of open globe injuries in the United States from 2006 to 2014. *JAMA Ophthalmol*. 2020;138(3):268–275.
6. Négrel A-D, Thylefors B. The global impact of eye injuries. *Ophthalmic Epidemiol*. 1998;5(3):143–169.
7. Thakker MM, Ray S. Vision-limiting complications in open–globe injuries. *Can J Ophthalmol*. 2006;41(1):86–92.
8. Ahmed Y, Schimel AM, Pathengay A, Colyer MH, Flynn HW. Endophthalmitis following open-globe injuries. *Eye*. 2012;26(2):212–217.
9. Savar A, Andreoli MT, Kloek CE, Andreoli CM. Enucleation for open globe injury. *Am J Ophthalmol*. 2009;147(4):595–600 e591.
10. Ojuok E, Uppuluri A, Langer PD, Zarbin MA, Thangamathesvaran L, Bhagat N. Predictive factors of enucleation after open globe injuries. *Graefes Arch Clin Exp Ophthalmol*. 2021;259(1):247–255.
11. Mayer CS, Reznicek L, Baur ID, Khoramnia R. Open globe injuries: classifications and prognostic factors for functional outcome. *Diagnostics*. 2021;11(10):1851.
12. Scanzera AC, Dunbar G, Shah V, Cortina MS, Leiderman YI, Shorter E. Visual rehabilitation with contact lenses following open globe trauma. *Eye Contact Lens*. 2021;47(5):288–291.
13. Pimolrat W, Choovuthayakorn J, Watanachai N, et al. Predictive factors of open globe injury in patients requiring vitrectomy. *Injury*. 2014;45(1):212–216.
14. Man CYW, Steel D. Visual outcome after open globe injury: a comparison of two prognostic models—the Ocular Trauma Score and the Classification and Regression Tree. *Eye*. 2010;24(1):84–89.
15. Rofail M, Lee GA, O'Rourke P. Prognostic indicators for open globe injury. *Clin Exp Ophthalmol*. 2006;34(8):783–786.
16. Agrawal R, Rao G, Naigaonkar R, Ou X, Desai S. Prognostic factors for vision outcome after surgical repair of open globe injuries. *Indian J Ophthalmol*. 2011;59(6):465–470.
17. Kim JH, Yang SJ, Kim DS, Kim JG, Yoon YH. Fourteen-year review of open globe injuries in an urban Korean population. *J Trauma*. 2007;62(3):746–749.
18. Vingopoulos F, Wang Y, Grob S, et al. Open-globe injury with intraocular foreign body. *J Vitreoretin Dis*. 2020;5(4):288–294.
19. Pieramici DJ, MacCumber MW, Humayun MU, Marsh MJ, de Jr Juan E. Open-globe injury: update on types of injuries and visual results. *Ophthalmology*. 1996;103(11):1798–1803.
20. Rahman I, Maino A, Devadason D, Leatherbarrow B. Open globe injuries: factors predictive of poor outcome. *Eye*. 2006;20(12):1336–1341.

21. Sternberg Jr P, de Juan Jr E, Michels RG, Auer C. Multivariate analysis of prognostic factors in penetrating ocular injuries. *Am J Ophthalmol*. 1984;98(4):467–472.
22. Hatton MP, Thakker MM, Ray S. Orbital and adnexal trauma associated with open-globe injuries. *Ophthalmic Plast Reconstr Surg*. 2002;18(6):458–461.
23. Barr CC. Prognostic factors in corneoscleral lacerations. *Arch Ophthalmol*. 1983;101(6):919–924.
24. Martin DF, Meredith TA, Topping TM, Sternberg P, Kaplan HJ. Perforating (through-and-through) injuries of the globe: surgical results with vitrectomy. *Arch Ophthalmol*. 1991;109(7):951–956.
25. de Juan Jr E, Sternberg Jr P, Michels RG. Penetrating ocular injuries: types of injuries and visual results. *Ophthalmology*. 1983;90(11):1318–1322.
26. Guven S, Durukan AH, Erdurman C, Kucukevcilioglu M. Prognostic factors for open-globe injuries: variables for poor visual outcome. *Eye*. 2019;33(3):392–397.
27. Al-Mezaine HS, Osman EA, Kangave D, Abu El-Asrar AM. Prognostic factors after repair of open globe injuries. *J Trauma*. 2010;69(4):943–947.
28. Farr AK, Hairston RJ, Humayun MU, et al. Open globe injuries in children: a retrospective analysis. *J Pediatr Ophthalmol Strabismus*. 2001;38(2):72–77.
29. Kuhn F, Maisiak R, Mann L, Mester V, Morris R, Witherspoon CD. The Ocular Trauma Score (OTS). *Ophthalmol Clin North Am*. 2002;15(2):163–165 vi.
30. Pieramici DJ, Sternberg Jr P, Aaberg Sr TM, et al. A system for classifying mechanical injuries of the eye (globe). The Ocular Trauma Classification Group. *Am J Ophthalmol*. 1997;123(6):820–831.
31. Unver YB, Kapran Z, Acar N, Altan T. Ocular trauma score in open-globe injuries. *J Trauma*. 2009;66(4):1030–1032.
32. Kuhn F, Morris R, Mester V, Witherspoon CD, Mann L, Kuhn F. Predicting the severity of an eye injury: the Ocular Trauma Score (OTS). *Ocular Traumatology*. Berlin Heidelberg: Springer; 2008:17–22.
33. Pieramici DJ, KG Au Eong, Sternberg Jr P, Marsh MJ. The prognostic significance of a system for classifying mechanical injuries of the eye (globe) in open-globe injuries. *J Trauma*. 2003;54(4):750–754.
34. Uysal Y, Mutlu FM, Sobaci G. Ocular Trauma Score in childhood open-globe injuries. *J Trauma*. 2008;65(6):1284–1286.
35. Sobaci G, Mutlu FM, Bayer A, Karagül S, Yildirim E. Deadly weapon–related open-globe injuries: outcome assessment by the Ocular Trauma Classification System. *Am J Ophthalmol*. 2000;129(1):47–53.
36. Schörkhuber MM, Wackernagel W, Riedl R, Schneider MR, Wedrich A. Ocular trauma scores in paediatric open globe injuries. *Br J Ophthalmol*. 2014;98(5):664–668.
37. Schmidt GW, Broman AT, Hindman HB, Grant MP. Vision survival after open globe injury predicted by classification and regression tree analysis. *Ophthalmology*. 2008;115(1):202–209.
38. Shukla B, Agrawal R, Shukla D, Seen S. Systematic analysis of ocular trauma by a new proposed ocular trauma classification. *Indian J Ophthalmol*. 2017;65(8):719–722.
39. Acar U, Tok OY, Acar DE, Burcu A, Ornek F. A new ocular trauma score in pediatric penetrating eye injuries. *Eye*. 2011;25(3):370–374.
40. Lasdon LS, Fox RL, Ratner MW. Nonlinear optimization using the generalized reduced gradient method. *Rev Franç D'automat Inform Rech Opér Rech Opér*. 1974;8(V3):73–103.
41. Ying X. An overview of overfitting and its solutions. *J Phys Conf Ser*. 2019;1168(2).
42. Ojuok E, Uppuluri A, Langer PD, Zarbin MA, Thangamathesvaran L, Bhagat N. Demographic trends of open globe injuries in a large inpatient sample. *Eye*. 2021;35(8):2270–2276.
43. Keisler-Starkey K, Bunch LN. Health insurance coverage in the United States: 2020. United States Census Bureau; 2021.
44. Blanch RJ, Bindra MS, Jacks AS, Scott RAH. Ophthalmic injuries in British Armed Forces in Iraq and Afghanistan. *Eye*. 2011;25(2):218–223.
45. Meng Y, Yan H. Prognostic factors for open globe injuries and correlation of Ocular Trauma Score in Tianjin, China. *J Ophthalmol*. 2015;2015 345764-345764.
46. Court JH, Lu LM, Wang N, McGhee CNJ. Visual and ocular morbidity in severe open-globe injuries presenting to a regional eye centre in New Zealand. *Clin Exp Ophthalmol*. 2019;47(4):469–477.
47. Ustaoglu M, Karapapak M, Tiryaki S, et al. Demographic characteristics and visual outcomes of open globe injuries in a tertiary hospital in Istanbul, Turkey. *Eur J Trauma Emerg Surg*. 2020;46(3):549–556.
48. Shrestha SM, Anthony CL, Justin GA, et al. Factors affecting final functional outcomes in open-globe injuries and use of ocular trauma score as a predictive tool in Nepalese population. *BMC Ophthalmol*. 2021;21(1):69.
49. Lai FHP, Wong EWN, Lam WC, et al. Endoscopic vitreoretinal surgery: review of current applications and future trends. *Surv Ophthalmol*. 2021;66(2):198–212.
50. Scott R. The Ocular Trauma Score. *Community Eye Health*. 2015;28(91):44–45.
51. Sung EK, Nadgir RN, Fujita A, et al. Injuries of the globe: what can the radiologist offer? *Radiographics*. 2014;34(3):764–776.
52. Lieb DF, Scott IU, Flynn HW, Miller D, Feuer WJ. Open globe injuries with positive intraocular cultures: factors influencing final visual acuity outcomes. *Ophthalmology*. 2003;110(8):1560–1566.
53. Blanch RJ, Bishop J, Javidi H, Murray PI. Effect of time to primary repair on final visual outcome after open globe injury. *Br J Ophthalmol*. 2019;103(10):1491–1494.
54. Hernández DM, Gómez VL. [Ocular Trauma Score comparison with open globe receiving early or late care attention]. Article in Spanish. *Cir Cir*. 2015;83(1):9–14.
55. Justin GA, Rapuano CJ, Pelton RW, Auran JD. Ocular futility: how to approach end-of-sight care. *Ophthalmology*. 2019;126(9):1209–1211.
56. Weinreb NJ, Cappellini MD, Cox TM, et al. A validated disease severity scoring system for adults with type 1 Gaucher disease. *Genet Med*. 2010;12(1):44–51.
57. Gutknecht AJ, Wibral M, Makkeh A. Bits and pieces: understanding information decomposition from part-whole relationships and formal logic. *Proc Math Phys Eng Sci*. 2021;477(2251):20210110.
58. Koo L, Kapadia MK, Singh RP, Sheridan R, Hatton MP. Gender differences in etiology and outcome of open globe injuries. *J Trauma*. 2005;59(1):175–178.

59. Forster MR. Key concepts in model selection: performance and generalizability. *J Math Psychol*. 2000;44(1):205–231.
60. Gilliland GD, Gilliland G, Fincher T, Harrington J, Gilliland JM. Assessment of biomechanics of orbital fracture: a study in goats and implications for oculoplastic surgery in humans. *Am J Ophthalmol*. 2005;140(5):868–876 e862.
61. Vaca EE, Mundinger GS, Kelamis JA, et al. Facial fractures with concomitant open globe injury: mechanisms and fracture patterns associated with blindness. *Plast Reconstr Surg*. 2013;131(6):1317–1328.
62. Santamaria J, Mehta A, Reed D, Blegen H, Bishop B, Davies B. Orbital roof fractures as an indicator for concomitant ocular injury. *Graefes Arch Clin Exp Ophthalmol*. 2019;257(11):2541–2545.
63. Darwich A, Attieh A, Khalil A, Szávai S, Nazha H. Biomechanical assessment of orbital fractures using patient-specific models and clinical matching. *J Stomatol Oral Maxillofac Surg*. 2021;122(4):e51–e57.
64. Ng SMS, Low R, Hoskin AK, et al. The application of clinical registries in ophthalmic trauma—the International Globe and Adnexal Trauma Epidemiology Study (IGATES). *Graefes Arch Clin Exp Ophthalmol*. 2021:1–13.