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TRAUMA

Eye injuries from fireworks used during celebrations and associated vision loss: the international globe and adnexal trauma epidemiology study (IGATES).

Annette K. Hoskin[1,2] · Rebecca Low[3] · Jan Tjeerd de Faber[4] · Chitaranjan Mishra[5] · Pradeep Susvar[6] · Eli Pradhan[7] · Andres Rousselot[8] · Fasika A. Woreta[9] · Lisa Keay[10,11] · Stephanie L Watson[1] · Rupesh Agrawal[3] · IGATES Fireworks study group

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Abstract

Purpose To report on the factors associated with severe vision loss from fireworks-related ocular trauma during celebrations, including festivals.

Methods Tertiary eye care hospitals in 5 countries and private ophthalmology practices in the Netherlands. Patients included received treatment for fireworks-related ocular trauma during celebrations. Demographic and clinical data for patients affected were analyzed and associations with severe vision loss reported.

Results Of 388 patients, 71 (18.3 %) had severe vision loss (worse than 6/60) at 4-week follow-up due to fireworks-related ocular trauma. Mean age overall was 20.6 years (range 2 to 83 years), and there was a male predominance of 4:1. Clinical factors associated with severe vision loss included penetrating injury (OR 4.874 [95% CI 1.298–18.304; $p = 0.02$]) and lens injury (OR 7.023 [95% CI 2.378–20.736; $p = 0.0004$]). More patients with closed-globe injuries (CGIs) had improved vision after 4 weeks (OR 3.667, 1.096–12.27) compared to those with open-globe injuries (OGI) ($p = 0.035$). Eye protection use was reported by 7 patients, and 39.4% patients < 18 years were unsupervised by an adult at the time of injury.

Conclusions Severe vision loss from fireworks-related ocular trauma occurred during celebrations in a variety of countries and was associated with penetrating and/or lens injury and poor presenting vision. New initiatives are needed to prevent severe vision loss associated with these injuries.

Keywords Fireworks · Ocular trauma · Vision loss

Stephanie L Watson and Rupesh Agrawal are joint senior authors.

✉ Rupesh Agrawal
Rupesh_agrawal@ttsh.com.sg

1 Save Sight Institute, Discipline of Ophthalmology, Sydney Medical School, The University of Sydney, Sydney, New South Wales, Australia

2 Lions Eye Institute, The University of Western Australia, Perth, Australia

3 National Healthcare Group Eye Institute at Tan Tock Seng Hospital, Singapore 308433, Singapore

4 The Rotterdam Eye Hospital, Rotterdam, Netherlands

5 Aravind Eye Hospital, Madurai, India

6 Sankara Nethralaya, Chennai, India

7 Tilganga Institute of Ophthalmology, Kathmandu, Nepal

8 Ophthalmology Department, Universidad del Salvador, Buenos Aires, Argentina

9 Wilmer Eye Institute, Johns Hopkins University School of Medicine, Baltimore, MD, USA

10 School of Optometry and Vision Science, UNSW, Sydney, Australia

11 The George Institute for Global Health, UNSW, Sydney, Australia

Key messages

What is known:

- Fireworks-related eye injuries are significant contributors to vision loss.

New information:

- Severe vision loss from fireworks-related ocular trauma was more likely if there was a penetrating eye injury or injury to the lens
- A patient presenting with poor vision from a fireworks-related eye injury is more likely to have severe vision loss 1 month after the injury
- Fireworks-related eye injuries occur at the time of celebrations in a variety of countries

Introduction

Fireworks associated with celebrations, such as Diwali, Chinese New Year, and New Year's Eve (NYE), are a well-described cause of ocular trauma and preventable vision loss [1–5]. The rate of severe vision loss from fireworks-related ocular trauma has been reported at up to 1 in 6 fireworks injuries, with enucleation rates of 3.9% reported in a worldwide systematic review in 2010 [6]. Males, bystanders, and young children were the groups most affected by fireworks-related ocular trauma. Ocular trauma and the resulting severe vision loss have significant long-term social, economic, psychological, and physical consequences for the patient and the community [7–9]. Up to 90% of ocular trauma is preventable [10], with effective interventions including education, policies, legislation, and the use of eye protection.

Eye injury registries have effectively collected data from a large number of centers [11, 12]. This has facilitated international comparisons and informed the development of global consensus guidelines and/or regional co-ordination of efforts to prevent ocular and adnexal trauma [13]. For example, data from the "European Registration Fireworks Eye Injuries" was used to inform legislation such as the ban on bottle rocket fireworks in Norway in 2007, which was based on a high incidence of vision loss from these fireworks [14]. Legislation requiring a complete ban on the personal use fireworks has been shown to reduce fireworks-related injuries [6]. The International Globe and Adnexal Trauma Epidemiological Study (IGATES) is an ongoing, large multi-center study that has provided a methodology for data collection for ocular trauma. IGATES and the European Fireworks Registry have the potential to provide data on factors associated with severe vision loss to help inform the development of preventive strategies, such as legislation for fireworks-related ocular trauma.

Previous studies have identified the nature and incidence of ocular trauma associated with fireworks for countries including the Netherlands [15], China [3], India [1], Northern Ireland [16], the UK [17], the USA [18, 19], and New Zealand [20]. However, these studies are limited by their relatively small size, limiting their ability to understand severe vision loss from fireworks-related ocular trauma in different countries.

More data is required to understand the factors associated with severe vision loss to help provide targeted strategies to prevent vision loss from fireworks-related injuries. The objective of this study was to report on the factors associated with severe vision loss, from fireworks-related ocular trauma during celebrations, for a large dataset from four countries.

Methods

To capture data from a large number of patients, centers and countries, information from two sources was combined. The IGATES group and The Dutch Ophthalmic Society (Netherlands Oogheelkundig Gezerschap, NOG) have both developed systems for prospective data collection for fireworks-related ocular trauma. Fireworks-related ocular trauma resulting in hospital emergency department or ophthalmic clinic presentations were identified by attending physicians based on the patient or their carers' description of the mechanism of injury for both groups.

Members of the Asia Pacific Ophthalmic Trauma Society (APOTS), which includes ophthalmologists with a specific interest in ocular trauma from the Asia-Pacific and a number of other countries, including the USA and Argentina, were invited to volunteer to participate in the study. A total of 12 tertiary eye care centers agreed to participate, from 98 centres approached, with each given a unique set of login details to enter patient data. Members of the NOG included 598 active ophthalmologists across the Netherlands from eye clinics and hospitals, who used the European Registration Fireworks form. Data from 12 tertiary eye care centers including 8 from India, 2 from Nepal, and 2 from Argentina were collected using the IGATES Fireworks online form (Appendix 1). The tertiary eye care centers comprised 3 government and 9 private institutions (Appendix 2). Participating centers were asked to fill in the form for all patients meeting the inclusion criteria specified below, with the treating ophthalmologist responsible for data entry. This study was conducted in accordance with the tenets of the Declaration of Helsinki. Ethics approval for the study was obtained from the NOG for the Netherlands study and from the relevant local or regional institutional ethics committee for each of the IGATES centres (see IGATES Fireworks study participants).

IGATES Fireworks data collection

A subset of IGATES—IGATES Fireworks—was developed to collect data on the circumstances and outcomes from fireworks-related eye and adnexal injuries. IGATES Fireworks provided a Web-based "smart form" on a secure encrypted platform with definitions for each category [21].

All patients meeting the inclusion criteria were given a unique code, with identifiers including date of birth and name omitted for patient anonymity. Data collected at presentation and at follow-up (between 3 and 5 weeks) included patient demographics, information about the circumstances including the type of fireworks and any precautions such as eye protection and supervision, the type of injury, treatment received, and visual outcomes. Clinical images where available were uploaded (Appendix 1). Data collection was not mandatory for the participating centers but clinicians were encouraged to include data for all cases that meet the criteria on the registry.

Inclusion and exclusion criteria

Patients with the following clinical features were included:

(a) Open-/closed-globe injury, and/or
(b) Adnexal/orbital involvement, and/or
(c) Intraocular/intraorbital foreign body
(d) Chemical/thermal injury to the eye or adnexa

Patients presenting for management of long-term sequela of fireworks injuries, such as traumatic cataract, were excluded.

NOG data collection

Nederlands Oogheelkundig Gezerschap (NOG) collected data for patients treated in the Netherlands for eye or adnexal fireworks-related injury the 4 days before and 4 days after NYE since 2008.This data has been reported in the literature [22]. All ophthalmologists in the Netherlands were asked to fill in the form for all patients meeting the inclusion criteria during the specified period, and share it with NOG who collated the data. *The European Registration Fireworks Eye Injuries* form was used for data collection. Variables collected included patient date of birth and gender, incident details, type of injury and treatment (Appendix 2).

Definitions

Vision loss was defined in line with World Health Organization (WHO) with mild vision impairment as best corrected visual acuity (BCVA) worse than 6/12, moderate vision impairment as worse than 6/18, severe visual impairment as worse than 6/60, and blindness as worse than 3/60. Patients defined as having "severe vision loss" in this study were those with severe visual impairment or blindness, that is vision 6/60 or worse at 4-week follow-up. [23]

Data analysis

The demographic and clinical data were summarized, and the distribution of patients across centers tested for homogeneity using Pearson's Chi-square test for categorical data and Student's *t*-test for continuous data. The statistical significance of factors associated with severe vision loss was assessed using Marginal homogeneity test [24].

The effect of demographic parameters like age, gender, setting, location, and clinical parameters, i.e., grade of corneal burn, presence of penetrating, or lens injury on vision status, i.e., severe vision loss or not, at the time of presentation, was determined using multiple logistic regression. The association of demographic and clinical parameters on VA at presentation was assessed through bivariate and multiple logistic regression analysis.

Vision change was regarded as a dichotomous outcome (improvement or no improvement/deterioration) and modelled against the baseline status of clinical parameters using binary logistic regression. All the analyses were performed using SPSS version 20.0 (IBM Corp, Armonk, USA), and the statistical significance was tested at 5% level.

Results

From APOTS, twelve members volunteered to participate in the study and from NOG 96% of members participated in the survey. The participating ophthalmologists completed the form for all patients meeting the inclusion criteria over the study period.

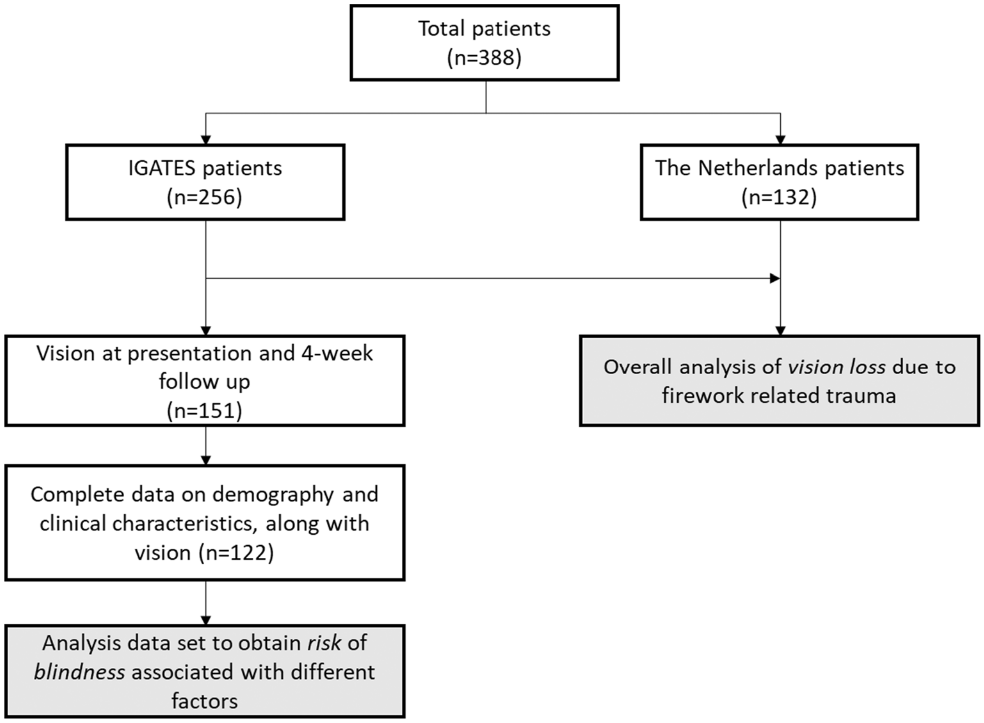

Fig. 1 Sample data distribution for the study

A total of 388 patients from the IGATES and NOG databases met the inclusion criteria, including patients from the Netherlands (n = 132), India (215), Argentina (44), and Nepal (18). Vision at presentation was available for 229 patients and at 4-week follow-up for 151 patients, with complete data on clinical parameters available for 122 patients (Fig. 1).

Visual outcomes

From 388 patients, 71 (18.3%) patients had severe vision loss after fireworks-related ocular trauma at follow-up (Table 1). The proportion of patients with severe vision loss due to fireworks-related ocular trauma at 4 weeks was highest in India (n = 46, 21.4%), followed by the Netherlands (21, 15.9%), Nepal (3, 16.7%), and Argentina 1 (4.4%).

Table. 1 Comparison of presence and absence of severe vision loss at final presentation (4 weeks) across countries (n = 388)

Country/region	Severe vision loss [number (%)] < 6/60			Total
	Not recorded	No	Yes	
Argentina	22 (95.7)	0 (0.0)	1 (4.4)	23
India	72 (33.5)	97 (45.1)	46 (21.4)	215
Nepal	7 (38.9)	8 (44.4)	3 (16.7)	18
Netherlands	0	111 (84.1)	21 (15.9)	132
Total	101 (26.0)	216 (55.7)	71 (18.3)	388

P value < 0.0001 (significant) obtained using Pearson's chi-square test

For all patients with VA data at presentation and 4-week follow-up, a statistically significant improvement in vision at follow-up was observed (p value < 0.0001). Of patients, 83.5% (126/151) had an improvement in VA at follow-up, suggesting a significant overall improvement in vision after treatment. However, 2 patients who had moderate vision loss at presentation had severe vision loss at follow-up.

Comparing vision at presentation to final visual outcomes, of 15 patients with vision worse than 6/60 at presentation, 10 (66.7%) had an improvement in their vision (Table 2). For 61 patients with vision worse than 3/60 at presentation, 32 (52.5%) had improvement. Of 15 patients with mild vision loss at presentation, 11 (73.3%) had no vision loss at 4 weeks, while of the 47 patients with moderate vision loss at presentation, 15 (31.9%) had no vision loss, and 14 (29.8%) had mild vision loss at 4 weeks. Phthisis bulbi was recorded in 3 patients (3/93, (0.03%).

The analysis revealed that patients with a CGI had a significantly higher likelihood of their vision improving compared to those with an OGI [OR of 3.667; 95% CI 1.096–2.27; p = 0.04] (Table 3). None of the other clinical parameters were associated with a significant effect on the odds of vision improvement.

Demographics and circumstances

None of the circumstances of injury or patient demographics were significantly associated with a patient with final visual outcome of 6/60 or worse. Table 4 shows the demographic profile of patients with a fireworks-related ocular trauma by country. Demographic characteristics were available for 256 patients from India, Argentina, and Nepal from IGATES.

Table. 2 Comparison of BCVA at presentation and after 4 weeks ($n = 151$). Shaded cells highlight cases where there was improvement in vision at 4 weeks compared to presentation

BCVA	At 4 weeks					Total
At presentation	Normal	Mild (< 6/12)	Moderate (< 6/18)	Severe (< 6/60)	Blindness (< 3/60)	
Normal	13	0	0	0	0	13
Mild (< 6/12)	11	4	0	0	0	15
Moderate (< 6/18)	15	14	16	2	0	47
Severe (< 6/60)	3	2	5	5	0	15
Blindness (< 3/60)	3	5	12	12	29	61
Total	45	25	33	19	29	151

HS highly significant

P value < 0.0001 (HS); obtained using marginal homogeneity test

These patients had a mean age at presentation of 20.6 years (range 2 to 83 years), with the lowest mean age reported in Nepal (12.4 ± 11.4 years, 0 to 38 years) and highest in India (21.1 ± 14.8 years, 2 to 63 years). The difference in the mean age across countries was statistically insignificant ($p = 0.0653$).

A male predominance of almost 4:1 was seen for the IGATES cohort. Nepal had the lowest (2.4:1), and India had the highest male/female (M:F) ratio (4.5:1); however, the difference was not significant ($p = 0.3785$). Gender was not associated with an increased risk of blindness at presentation (OR 1.385, 95% CI 0.549,3.495; $p = 0.49$).

When stratified by age, the 15- to 20-year age group had the highest M:F ratio (9:1). A significantly higher number of patients sustained their injury in urban versus rural setting (66%; $p = 0.0013$), and the highest proportion of injuries occurred at home (178, 69.5%).

The type of firework was identified for 95.7% patients and included atom bombs (32, 12.6%), loose crackers (30, 11.8%), sparkling fountain (flower pots) (16, 6.3%), and air bombs (12, 4.7%).

The majority of fireworks-related eye injuries in India and Nepal were recorded during *Diwali* festival ($n = 203$ and 16, respectively), while in Argentina (18), they occurred during NYE celebrations.

Eye protection — including spectacles, goggles, and face shields — were reported to be used in 7 (2.7%) of the IGATES patients and did not differ by setting (p value 0.684). For patients < 18 years ($n = 151$), adult supervision at the time of the firework injury occurred more often in Argentina (10/15), than India (30/122) and Nepal (3/14) (Table 4). This difference in supervision across countries was statistically significant (p value = 0.0001).

More than half (133, 52.2%) of the injuries were to a bystander, including 90 (35.3%) where the firecracker was lit by a relative or friend. The majority (98.4%) of injuries in IGATES patients were unintentional, with 2 injuries of uncertain intent and potentially self-harm.

Presenting vision and clinical features

In total, there were 219 (85%) CGI and 34 (13.2%) OGI (Fig. 2 a and b). Where clinical and demographic data were available in the IGATES cohort ($n = 122$) (Table 3), the nature of injuries were predominantly mechanical (32%) or thermal (25%). In bivariate analysis, CGI had a significantly lower associated risk compared to OGI [OR of 0.102; 95% CI 0.027–0.386; $p = 0.0008$]. Other clinical parameters including corneal injury, corneal burns, sclera injury, and conjunctival injury had associated OR of more than 1.0, although these were not statistically significant (Table 5).

The presence of a penetrating injury, lens injury, and vitreous injury were associated with a significantly higher risk of blindness at presentation (OR of 16.81 [95% CI 5.451–51.838; $p < 0.0001$], OR of 14.52 [95% CI 5.697–36.997; $p < 0.0001$], OR of 4.855 [95% CI 2.058–11.453; $p = 0.0003$], respectively). Retinal injury, such as macula damage suffered by the patient featured in Fig. 3a, had associated odds of 4.125 [95% CI 1.832–9.287; $p = 0.0006$] toward blindness. Parameters such as adnexal injury, eyelid injury, and orbital injury were associated with a reduced odds of severe vision loss, but this was statistically insignificant.

Significant clinical parameters were included in the multiple logistic regression model. CGI had significantly reduced odds of severe vision loss [OR 0.192; 95% CI 0.04–0.916; $p = 0.04$] after adjustment. The presence of penetrating injury or lens injury continued to be significantly associated with an increased risk of blindness with OR of 4.874 [95% CI 1.298–18.304; $p = 0.02$] and 7.023 [95% CI 2.378–20.736; $p = 0.0004$] respectively in the multivariate model

Surgical procedures

A total of 93 surgeries were performed on 62 patients from the IGATES cohort (average 1, range 0–3). Surgeries included

Table. 3 Effect of different demographic and clinical parameters on BCVA due to fireworks-related ocular trauma at presentation (n = 122)

Characteristics	Levels	Total	BCVA at presentation		OR [95% CI]; *P* value	
			Not Blind	Blind	Crude	Adjusted
Age at time of injury	*0–5*	10	9 (90)	1 (10)	Reference	
	5–10	28	23 (82.1)	5 (17.9)	1.957 [0.2, 19.15];0.56	
	10–15	21	14 (66.7)	7 (33.3)	4.5 [0.471, 42.97];0.19	
	15–20	7	3 (42.9)	4 (57.1)	12 [0.936, 153.885];0.06	
	20–40	37	18 (48.6)	19 (51.4)	9.5 [1.091, 82.725];0.04*	
	> 40	19	12 (63.2)	7 (36.8)	5.25 [0.544, 50.641];0.15	
Gender	*Female*	27	19 (70.4)	8 (29.6)	Reference	
	Male	95	60 (63.2)	35 (36.9)	1.385 [0.549, 3.495];0.49	
Settings of injury	*Rural*	41	26 (63.4)	15 (36.6)	Reference	
	Urban	81	53 (65.4)	28 (34.6)	0.916 [0.418, 2.004];0.83	
Adult supervision	*No*	79	54 (68.4)	25 (31.6)	Reference	
	Yes	30	19 (63.3)	11 (36.7)	1.251 [0.518, 3.018];0.62	
	NA	13	6 (46.1)	7 (53.8)	2.52 [0.767, 8.276];0.13	
Eye protection	*No*	119	78 (65.5)	41 (34.4)	Reference	
	Yes	3	1 (33.3)	2 (66.7)	3.805 [0.335, 43.221];0.28	
Type of iInjury	*Open Globe*	15	3 (20)	12 (80.0)	Reference	Reference
	Closed Globe	107	76 (71.0)	31 (28.9)	0.102 [0.027, .386];0.0008*	0.192 [0.040, 0.916];0.04
Type of object	*Blunt*	107	71 (66.4)	36 (33.6)	Reference	
	Sharp	15	8 (53.3)	7 (46.7)	1.726 [0.58, 5.137];0.33	
Corneal injury	*No*	14	9 (64.3)	5 (35.7)	Reference	
	Yes	108	70 (64.8)	38 (35.2)	0.977 [0.306, 3.124];0.97	
Corneal burns	*None*	26	14 (53.8)	12 (46.1)	Reference	
	Grade 1	61	48 (78.7)	13 (21.3)	0.316 [0.118, 0.846];0.022*	
	Grade 2	21	13 (61.9)	8 (38.1)	0.718 [0.223, 2.315];0.58	
	Grade 3	9	3 (33.3)	6 (66.7)	2.333 [0.478, 11.396];0.29	
	Grade 4	5	1 (20.0)	4 (80.0)	4.667 [0.457, 47.629];0.19	
Scleral injury	*No*	115	76 (66.1)	39 (33.9)	Reference	
	Yes	7	3 (42.9)	4 (57.1)	2.598 [0.554, 12.192];0.23	
Conjunctival injury	*No*	45	32 (71.1)	13 (28.9)	Reference	
	Yes	77	47 (61.0)	30 (38.9)	1.571 [0.713, 3.465];0.26	
Anterior chamber injury	*No*	54	50 (92.6)	4 (7.4)	Reference	Reference
	Yes	68	29 (42.6)	39 (57.3)	16.81 [5.451, 51.83]; < 0.0001*	4.874 [1.298, 18.304];0.02*
Lens injury	*No*	85	70 (82.3)	15 (17.7)	Reference	Reference
	Yes	37	9 (24.3)	28 (75.7)	14.519 [5.697, 36.997]; < 0.0001*	7.023 [2.378, 20.736];0.0004*
Vitreous injury	*No*	90	67 (74.4)	23 (25.6)	Reference	Reference
	Yes	32	12 (37.5)	20 (62.5)	4.855 [2.058, 11.453];0.0003*	2.879 [0.891, 9.319];0.08
Retina injury	*No*	84	63 (75.0)	21 (25.0)	Reference	Reference
	Yes	38	16 (42.1)	22 (57.9)	4.125 [1.832, 9.287];0.0006*	1.427 [0.461, 4.414];0.54
Adnexal injury	*No*	62	36 (58.1)	26 (41.9)	Reference	
	Yes	60	43 (71.7)	17 (28.3)	0.547 [0.257, 1.164];0.12	
Eyelid injury	*No*	63	37 (58.7)	26 (41.3)	Reference	
	Yes	59	42 (71.2)	17 (28.8)	0.576 [0.271, 1.225];0.15	
Facial orbital injury	*No*	109	69 (63.3)	40 (36.7)	Reference	
	Yes	13	10 (76.9)	3 (23.1)	0.518 [0.134, 1.992];0.34	

*Statistically significant

Table. 4 Demographic profile of patients and circumstances associated with fireworks related ocular trauma across different countries (n = 256)

Levels	IGATES cohort			Total	*P* value
	Argentina	India	Nepal		
No. (%)	23 (8.98)	215 (81.13)	18 (7.03)	256 (100)	-
Type of hospital (public/private)	Public	Private	Private	-	-
Age (in years)					
Mean ± SD	20.09 ± 19.41	21.06 ± 14.79	12.39 ± 11.35	-	0.0653 (NS)[¥]
Median	14.00	15.00	9.00	-	
Minimum	2.00	2.00	3.00	-	
Maximum	83.00	63.00	38.00	-	
Gender					
Male	17 (73.91)	176 (81.86)	12 (66.67)	205 (80.08)	0.3785 (NS)[‡]
Female	6 (26.09)	39 (18.14)	5 (27.78)	50 (19.53)	
Blank	0	0	1 (5.56)	1 (0.39)	
Settings					
Rural	0	74 (34.42)	8 (44.44)	82 (32.03)	0.0013 (S)[‡]
Urban	23 (100)	137 (63.72)	9 (50)	169 (66.02)	
Blank	0	4 (1.86)	1 (5.56)	5 (1.95)	
Location					
Home	17 (73.91)	151 (70.23)	10 (55.56)	178 (69.53)	0.1010 (NS)[‡]
Public area	0	47 (21.86)	5 (27.78)	52 (20.31)	
Relative's/friend's home	6 (26.09)	15 (6.98)	2 (11.11)	23 (8.98)	
Road	0	1 (0.47)	0	1 (0.39)	
Blank	0	1 (0.47)	1 (5.56)	2 (0.78)	
Festival type					
*Diwali**	NA	203 (94.4)	16 (88.9)	219 (85.55)	-
New Year's Day/Eve	18 (78.3)	0	0	18 (7.03)	
Christmas	5 (21.7)	1 (0.5)	0	6 (2.34)	
Family celebration	0	5 (2.3)	0	5 (1.95)	
Birthday celebration	0	3 (1.4)	0	3 (1.17)	
Marriage ceremony	0	0	1 (5.6)	1 (0.39)	
Blank	0	3 (0.5)	1 (5.6)	4 (1.56)	
Supervision (for ≤ 18 years)					
Yes	10 (43.48)	30 (13.95)	3 (16.67)	43 (16.80)	0.0015 (S)[‡]
No	5 (21.74)	92 (42.79)	11 (61.11)	108 (42.19)	
*Not applicable^*	8 (34.78)	91 (42.33)	3 (16.67)	102 (39.84)	
Blank	0	2 (0.93)	1 (5.56)	3 (1.17)	
Eyeprotection					
Yes	0	7 (2.7)	0	7 (2.73)	0.7184 (NS)[‡]
No	23 (100)	207 (97.3)	17 (94.4)	247 (96.48)	
Blank	-	1 (0.5)	1 (5.6)	2 (0.78)	

S significant, *NS* nonsignificant

^*Supervision, "not applicable"—refers to patients not included in the analysis as they were adults and therefore supervision was not considered*

[¥] Obtained using one-way analysis of variance

[‡] Obtained using Pearson's chi-square test

[†] Obtained using Fisher's exact test

*Festival of lights

corneal, scleral, or conjunctival repairs (21/93, 22.6%) and cataract surgery (18/93, 19.4%). Removal of gunpowder residue was also conducted for one patient (see Fig. 3b).

Discussion

Severe vision loss at 4-week follow-up due to fireworks-related ocular trauma was recorded for 18.3% patients, with the highest rate of severe vision loss in our cohort recorded in India (21.4%). Severe vision loss from fireworks-related ocular trauma during celebrations was found to be associated with a range of factors including worse presenting BCVA, an OGI penetrating injury or lens injury. No association was identified with severe visual loss and reported use of eye protection nor supervision of patients < 18 years old by adults.

The proportion of patients with severe vision loss was dissimilar to prior studies. Full visual recovery following fireworks-related eye injury in 61.5% patients has been reported in the Netherlands [15] and vision of 6/18 or better in 77.5% of children in India [1]. A

Table. 5 Odds of visual improvement associated with different clinical characteristics at 4 weeks after treatment using binary logistic regression (n = 120)

Characteristics	Levels	Total	BCVA (after 4 weeks)		OR [95% CI]; *P* value
			No improvement‡ (n = 58)	Improvement (n = 64)	
Type of injury	*Open globe*	15	11 (73.3)	4 (26.7)	Reference
	Closed globe	105	45 (42.9)	60 (57.1)	3.667 (1.096–12.27);0.04*
Type of object	*Blunt*	105	49 (46.7)	56 (53.3)	Reference
	Sharp	15	7 (46.7)	8 (53.3)	1.000 (0.338–2.958);0.99
Corneal injury	*No*	14	7 (50.0)	7 (50.0)	Reference
	Yes	106	49 (46.3)	57 (53.7)	1.163 (0.381–3.548);0.79
Corneal burns	*None*	24	13 (54.2)	11 (45.8)	Reference
	Grade 1	61	28 (45.9)	33 (54.1)	1.393 (0.54–3.594);0.49
	Grade 2	21	7 (33.3)	14 (66.7)	2.364 (0.704–7.939);0.16
	Grade 3	9	5 (55.6)	4 (44.4)	0.945 (0.203–4.413);0.94
	Grade 4	5	3 (60.0)	2 (40.0)	0.788 (0.111–5.6);0.81
Scleral injury	*No*	113	52 (46.0)	61 (53.9)	Reference
	Yes	7	4 (57.1)	3 (42.9)	0.639 (0.137–2.988);0.57
Conjunctival injury	*No*	45	21 (46.7)	24 (53.3)	Reference
	Yes	75	35 (46.7)	40 (53.3)	1.000 (0.477–2.098);0.99
Anterior chamber injury	*No*	54	25 (46.3)	29 (53.7)	Reference
	Yes	66	31 (46.9)	35 (53.1)	0.973 (0.473–2.002);0.94
Lens injury	*No*	83	37 (44.6)	46 (55.4)	Reference
	Yes	37	19 (51.3)	18 (48.7)	0.762 (0.351–1.656);0.49
Vitreous injury	*No*	90	38 (42.2)	52 (57.8)	Reference
	Yes	30	18 (60.0)	12 (40.0)	0.487 (0.21–1.13);0.09
Retina injury	*No*	84	37 (44.1)	47 (55.9)	Reference
	Yes	36	19 (52.8)	17 (47.2)	0.704 (0.322–1.542);0.38
Adnexal injury	*No*	62	30 (48.4)	32 (51.6)	Reference
	Yes	58	26 (44.8)	32 (55.2)	1.154 (0.563–2.366);0.69
Eyelid injury	*No*	63	31 (49.2)	32 (50.8)	Reference
	Yes	57	25 (43.9)	32 (56.1)	1.24 (0.604–2.546);0.56
Presence of facial orbital injury	*No*	107	51 (47.7)	56 (52.3)	Reference
	Yes	13	5 (38.5)	8 (61.5)	1.457 (0.448–4.742);0.53
Facial orbital injury	*No*	119	56 (47.1)	63 (52.9)	-
	Yes	1	0 (0)	1 (100)	

Includes patients with same vision status before and after treatment as well as vision deterioration after treatment

*Statistically significant

‡ Two cases were loss to follow-up

lower rate of full visual recovery in our study may be related to delays in treatment, with children more represented in our study. Children may not report injuries for fear of repercussions, but no evidence is available to support this conclusion. Further, our follow-up period was shorter than other studies, averaging 6 to 26 weeks; there may be further improvement after 4-week follow-up. It may also be that the clinicians in our study were more inclined to record severe cases of ocular trauma in the registries.

Gender has been previously identified as a risk factor for fireworks-related ocular injury, with a male preponderance of 6.8:1 to 8.7:1 [15, 25]. Our study, however, found a lower rate of male preponderance, 4.1:1. The lower rate of males injured may relate to participation in celebrations being family-related and more likely to be gender balanced. The average age of patients from India, Argentina, and Nepal was 20.6 years, which is similar to previous studies where average age reported was 22 [15] to 25 years [3]. In our cohort, 15- to

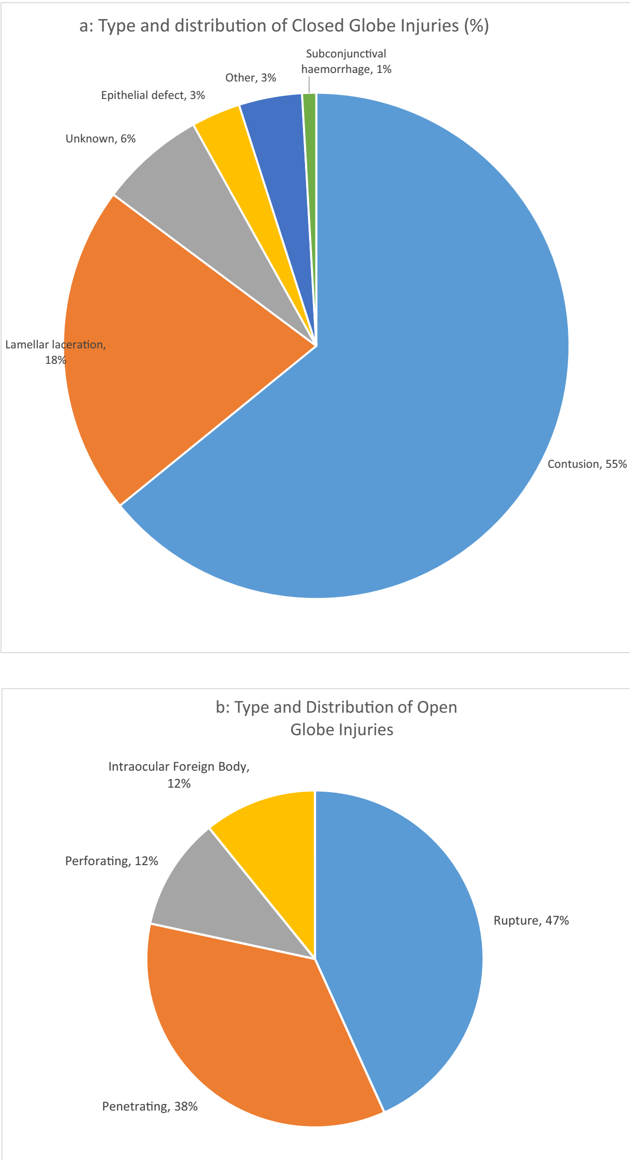

Fig. 2 **a** Type and distribution of closed globe injuries (%). **b** Type and distribution of open-globe injuries

20-year-olds were more likely to present with vision < 6/60 but age was not significantly associated with the final visual outcome.

Prevention measures, including education about the hazards associated with fireworks, use of eye protection and legislation have been used with the aim of reducing fireworks- related ocular trauma. Programs in the Netherlands have promoted the use of eye protection whilst using fireworks, with eye protection provided during peak fireworks use periods [15] resulting in a reduction in eye injuries [22]. However, eye protection use was not commonly reported in this study and it is possible that that those wearing eye protection were not injured therefore our dataset maybe biased. Low numbers of patients reporting use of eye protection may have been related to many injuries occurring at home or during leisure, where awareness and access to eye protection is limited. The low rate of use could also be as the history of eye protection was not taken and/or recorded in the medical records by the clinician. More data needs to be gathered to fully understand the influence of preventive measures on incidence of eye injuries from fireworks.

In patients aged 18 years and under, a low number of presentations were associated with adult supervision (17.8%). This finding is in contrast to previous studies that have reported higher numbers of fireworks-related ocular trauma in children [3] despite the presence supervision in more than 50% of cases [26]. Further studies are needed to establish the effect of adult supervision on reducing fireworks-related injury in children. This could become an important message in public awareness campaigns to reduce fireworks-related ocular injury in children.

Fireworks-related ocular traumas are rarely associated with public fireworks displays [17], rather are more commonly seen in and around either the home or at a friend or relatives place. In our study, more than three quarters of the injuries occurred in the patient's or a relative's home. Legislation to reduce or prevent the private sale and use of fireworks has reduced the rates of fireworks-related ocular traumas in many countries and regions, including Australia and the USA [6]. In the Netherlands, consumer fireworks (category 1, 2, and 3) are allowed to be sold 3 working days before NYE to persons older than 16 years for use from December 31, 6.00 PM, to January 1, 2.00 AM. Roman candles, little bottle rockets and launching tubes for rockets are banned in the Netherlands. In India, where concerns include pollution and noise, a ban on fireworks use outside of 8 pm and 10 pm during Diwali and 11.45 pm and 12.15 am during Christmas and NYE was called by the Supreme Court in 2018 [27]. In the state of Tamil Nadu, India, fireworks are restricted for use 6 am to 7 am and 7 pm to 8 pm during Diwali. Australia has almost entirely eliminated personal use of fireworks, except for in the Northern Territory where sale and use is legal for a limited period around Territory Day [28]. What is clear from the Australian example is that any relaxation of fireworks legislation relating to private use even for a short period of time results in injuries including to the eyes with resulting vision loss [28].

Argentina's legislation varies by territory, and in Buenos Aires where most of our data was collected, penalties include fines and arrest for manufacture, transport, storage, and/or sale of pyrotechnic devices without proper authorization. Efforts to ban all fireworks in Argentina, especially in the greater urban area surrounding the capital, were resisted by pyrotechnic manufacturers on the basis that the ban was unconstitutional (Suprema Corte de Justicia Provincia de Buenos Aires) [29]. Our data have shown that fireworks-related ocular trauma still occurred during festival times despite legislation in these countries.

Categorization of fireworks, whilst not harmonized internationally, is generally based on the level of hazard and noise. In Europe, fireworks are classified into four categories based on the danger to the user. Categories range from F1, which pose

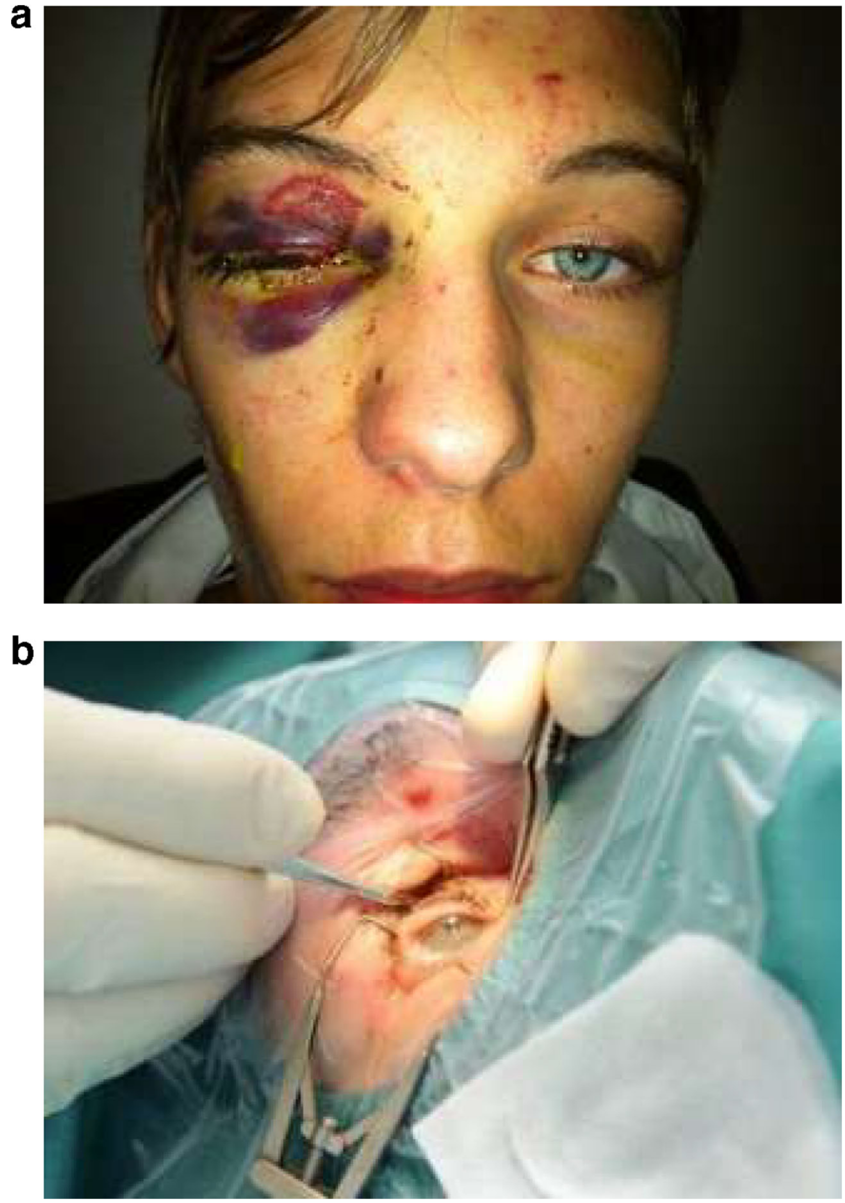

Fig. 3 **a** Right eye contusion and blunt ocular trauma with macular damage after being hit by Roman Candle firework. Final VA 20/200. **b** Surgical removal of gunpowder (as a result of fireworks exposure) from conjunctival fornix under general anaesthesia to prevent chemical injury of a right eye. Final visual outcome 20/200. Images provided by Jan de Faber. Figure 3 a appeared on the front page of *NRC Handelsblad*, the daily evening newspaper published in the Netherlands by NRC Media, on the 30th of December 2013 with patient consent obtained

very little danger, e.g., sparklers, to F4 which pose grave danger and are intended for use by professionals with specialized knowledge. This system could help purchasers of fireworks for personal use assess the risk. Not enough information was available in our data set to determine the classification of fireworks.

In addition to legislating and restricting the sale and personal use of fireworks, alternatives, e.g., drones for lighting displays and support for professional fireworks, should be encouraged. Several organizations including the World Health Organization, National Fire Protection Association and American Academy of Pediatrics, International Fire Marshalls Association have supported bans on fireworks for private use. Despite a complete ban on fireworks they are illegally imported into Nepal resulting in ocular trauma. Banning specific products related to a higher incidence of ocular trauma has been successfully implemented in some countries, e.g., bottle rockets are banned in Norway and the Netherlands.

Limitations

With no active follow-up conducted, a large proportion (37.8%, $n = 99/256$) of patients did not present after initial treatment and were lost to follow-up. Further, visual potential information was missing for 85 patients (33.2%) from the baseline visit and VA at follow-up missing for 107 (41.8%) patients. Further, follow-up was relatively short at an average of 4 weeks, whereas further vision improvement may occur after this time. Information regarding the circumstances of injuries relies on self-reported data from patients and their carers, which may have introduced reporting or selection bias.

As patients with severe clinical presentations are more likely to present and return for further follow-up, this may have also resulted in reporting bias, leading to an over representation of severe injuries. Information bias could have arisen with potential differences in data collection methods; this was likely reduced as ophthalmologists recorded and entered the data. Nonetheless, as data entry into the registry was not mandatory there may have been a bias toward reporting more severe cases. Data not missing at random is likely to include the presence or absence of safety measures (such as use of eye protection which was not recorded for 2 patients) and presenting VA, where VA could not be measured, e.g., in very young patients, both of which should be incorporated into our conclusions.

Our data was collected around the time of the festivals, which varied between the IGATES study and the NOG data. For example, the NOG data included patients within the period 4 days before or after NYE with the assumption that the use of fireworks during this period was associated with NYE celebrations. The geographic locations associated with our data collected are vastly different, which could have led to a potential bias in access to healthcare, legislation, and enforcement. Any reported difference in prevention measures may have been biased by a difference in access to eye protection in each of the countries.

Conclusion

Fireworks-related ocular and adnexal trauma associated with celebrations in a variety of countries can lead to severe vision loss, with factors including penetrating injury and lens injury increasing the risk. Countries should adopt prevention measures, including education, on the risks associated with the use of fireworks, improved supervision of children and legislation to limit their use.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00417-021-05284-z.

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IGATES Fireworks study group

Annette Hoskin[1,2], Rebecca Low[3], Jan Tjeerd de Faber[4], Chitaranjan Mishra[5], Kim Ramasamy[5], Dhipak A. Balasubramanian[5], Parveen Sen[6], Pradeep Susvar[6], Amulya Das[6], Rajiv Raman[6], Chaitra Jayadev[7], Kushagra Jain[7], Andres Rousselot[8], Martina Larroude[9], Fernando Jorge Scattini [9], Patricia Atenor[10] , Diana Salz[10], Eli Pradhan[11], Dr Ben Limbu[11], Dr Hom Gurung[11], Dr Anadi Khatri[12], Mehul Shah[13], Shakeen Singh[14], Anureet Kaur[14], Anurag Mittal[15], A. K Grover[15], Rekha Khandelwal[16], S Natarajan[17], Dr Akshay Nair[17], Dinesh Visva Gunasekeran[3], Fasika Woreta[18], Lisa Keay[19, 20], Stephanie L Watson[1], Rupesh Agrawal[3]

[1]The University of Sydney, Save Sight Institute, Discipline of Ophthalmology, Sydney Medical School, Sydney, New South Wales, Australia

[2]Lions Eye Institute, The University of Western Australia, Perth. Australia

[3]National Healthcare Group Eye Institute at Tan Tock Seng Hospital, Singapore

[4]The Rotterdam Eye Hospital, Rotterdam, Netherlands

[5]Aravind Eye Hospital, Madurai, India

[6]Sankara Nethralaya, Chennai, India

[7]Narayana Nethralaya Eye Institute, Bangalore, India

[8]Universidad del Salvador, Ophthalmology Department, Buenos Aires, Argentina

[9]Hospital Oftalmológico Dr PEDRO Lagleyze, Buenos Aires, Argentina

[10]Hospital Oftalmológico Santa Lucía, Buenos Aires, Argentina

[11]Tilganga Institute of Ophthalmology, Nepal

[12]Birat Eye Hospital, Biratnagar, Nepal

[13]Drashti Netralaya, Dahod, India

[14]Shakeen Singh Eye Hospital, Amritsa, India

[15]Sir Ganga Ram Hospital, New Delhi, India

[16]NKP Save Institute of Medical Sciences, Nagpur, India

[17]Aditya Jyot Eye Hospital, Mumbai, India

[18]Wilmer Eye Institute, Johns Hopkins University School of Medicine, Maryland, USA

[19]University of New South Wales, Sydney, Australia

[20]The George Institute, Sydney, Australia

Author contribution Rupesh Agrawal and Annette Hoskin made contributions to the study conception or design. Material preparation and data analysis were performed by Rupesh Agrawal, Annette Hoskin, Rebecca Low, Fasika Woreta, Jan Tjeerd de Faber, Lisa Keay and Stephanie Watson. Data was collected by Jan Tjeerd de Faber, Chitaranjan Mishra, Pradeep Susvar, Eli Pradhan, Andres Rousselot, and Fasika Woreta. The first draft of the manuscript was written by Annette Hoskin, and all authors commented on previous versions of the manuscript and approved the final version of the manuscript.

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Data availability The full data set was only available to the core research team, through a unique individual password.

Code availability Secure encrypted platform was programmed in Amazon Cognito® by D.V.G and R.A and maintained and stored on servers at the Tan Tock Seng Hospital, Singapore.

Declarations

Ethics approval Ethics Committee approval was obtained by each center's Human Research Ethics Committee or equivalent (see below).

Ethics approval for IGATES Fireworks participating centers

Center name	Country	State/city	Ethics approval	Funding
Netherlands	Netherlands	-	Nederland's Oogheelkundig	None

			Gezelschap (NOG)	
Aravind Eye Hospital, Madurai, India	India	Madurai	Institutional Ethics Committee	None
Sankara Netralaya, Chennai, India	India	Tamil Nadu	Institutional Review Board	None
Narayana Netralaya	India	Netralaya	Naranyana Nethralaya Ethcis Committee	None
Tilganga Institute of Ophthalmology	Nepal	Kathmandu	Institutional Review Committee	None
Hospital Oftalmológico Dr PEDRO Lagleyze	Argentina	Buenos Aires	Research Ethics Committee	None
Drashti Netralaya	India	Gujarat	Hospital Ethics Committee	None
Hospital Oftalmológico Santa Lucía	Argentina	Buenos Aires	Research Ethics Committee	None
Shakeen Singh Eye Hospital	India	Punjab	Institutional Ethics Committee	None
Sir Ganga Ram Hospital	India	New Delhi	Institutional Ethics Committee	None
NKP Save Institute of Medical Sciences	India	Maharashtra	Institutional Ethics Committee	None
Aditya Jyot Eye Hospital,	India	Mumbai, Maharashtra	Ethic Committee	None
Kakarvitta Eye Care Centre PVT. LTD	Nepal	Jhapa	Human Research Ethics Committee & Institutional Review Committee	None

Consent to participate Not applicable, all information is anonymized and the submission does not include images that may identify the person.

Consent for publication Not applicable, all information is anonymized and the submission does not include images that may identify the person.

Conflict of interest The authors declare no competing interests.

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