



# Analysis of ocular injury 1-year outcome in survivors of Beirut Port ammonium nitrate blast

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## Abstract

**Purpose** Ascertain the 1-year outcome of patients who sustained open eye injuries from the Beirut Port ammonium nitrate (AN) explosion, one of the most powerful non-nuclear explosions in history.

**Methods** Retrospective chart review of the operated eyes in 2 major eye hospitals.

**Results** Out of 42 patients with open globe injury that was originally sutured, 29 patients (34 eyes) were followed at the 1-year mark. The initial vision in logMAR (mean  $\pm$  SD) was  $2.93 \pm 0.87$  (hand motion equivalent) and the final vision was  $1.80 \pm 1.47$  (counting finger 2 m equivalent). No light perception (NLP) vision was noted in 12 eyes on presentation and 10 eyes remained so, while 2 eyes reached light perception (LP) vision. Eight eyes had an intraoperative expulsive choroidal hemorrhage (7 NLP and 1 LP both pre- and postoperatively), and 6 of the 8 developed phthisis. All eyes that developed phthisis had NLP preoperatively and postoperatively. Ocular Trauma Score (OTS) correlated inversely with both initial and final vision ( $p < 0.001$ ). Zone of injury inversely correlated with initial vision ( $p = 0.02$ ) and positively with final vision ( $p < 0.001$ ). Final vision was significantly worse in zone 3 vs. zones 1 and 2 ( $3.2 \pm 0.5$  vs.  $0.9 \pm 1.1$ ) ( $p < 0.001$ ) injuries, as was the initial vision ( $3.3 \pm 0.5$  vs.  $2.7 \pm 0.8$ ;  $p = 0.002$ ).

**Conclusion** The OTS, which provides prognostic information for serious ocular trauma, also yields valuable prognostic information for AN-associated ocular injuries. Expulsive choroidal hemorrhage and NLP vision at presentation remain very poor prognostic signs.

## Key messages

- Ocular Trauma Score offers a good prognostic model in ocular trauma in general.
- In one of the biggest non-nuclear ammonium nitrate blast in Beirut Port, NLP initial vision and intraoperative expulsive choroidal hemorrhage were the most ominous prognostic variables
- Ocular Trauma Score correlated inversely with initial and final vision in Beirut Port blast
- Ocular trauma score yielded valuable prognostic information for ammonium nitrate-associated ocular injuries.

**Keywords** Ammonium nitrate explosion · Beirut port explosion · Pars plana vitrectomy · Trauma · Retinal detachment · Expulsive choroidal hemorrhage · Ocular Trauma Score · Zone of injury · Intraocular foreign body · Ocular laceration · Ocular rupture

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## Introduction

A consignment of an estimated 2750 tons of discretely and unsafely stored ammonium nitrate (AN) ( $\text{NH}_4\text{NO}_3$ ) in the warehouse facility of the port of Beirut exploded at 6:05 pm

on August 4, 2020, destroying a large part of the capital of Lebanon, killing 218, wounding some 14,000 people [1], and leaving around 300,000 residents homeless [2, 3]. Wounded individuals were rushed to still-functional hospitals (those that did not sustain major structural damage), which in turn became severely overcrowded in 2 h. The blast lofted a white mushroom cloud over the Lebanese capital with two million inhabitants and is considered the most severe anthropological disaster of the decade with a consequent direct and indirect financial and economic loss edging 10 billion US dollars [1–3]. The Beirut Port explosion traumatized the living population after a series of political unrest, COVID-19 outbreak, security challenges, and unprecedented economic collapse, transforming Lebanon from a functioning nation to a failing one. Hunger, poverty, lack of medications, fuel shortage, and continuous electricity outage were accompanied by a vast emigration of medical personnel.

Most of the literature have dealt with the immediate human bodily injuries and economic aftermath of collapsed historic buildings [1–3]. Except for a few reports [4–10], publications on major nuclear or major non-nuclear disasters did not focus on ocular injuries, and those that did tackled only the acute phase. Our aim is to analyze the long-term visual sequelae of the Beirut blast in the two largest eye hospitals, excluding eye-injury patients treated at general hospitals.

## Materials and methods

This was a retrospective case review of patients who were treated for eye injuries within 54 h of the blast. Additionally, we included patients who had suturing of the ocular ruptures and lacerations on the day of the blast in a general hospital and were referred for further management within 54 h of the blast. Exclusion criteria included patients who failed their 1-year follow-up. For this purpose, the databases of the hospitals were searched for the operated-on patients with ocular blast injuries. All applicable institutional regulations concerning the accessing of medical notes for research purposes were observed by obtaining institutional review board (BESH N.4072021 and EEI N.8112020) approval. The study adhered to the Declaration of Helsinki.

Primary corneal and scleral full-thickness wounds were sutured by attending ophthalmologists. The situation did not allow detailed preoperative tests such as B-scan ultrasonography or any radiographic evaluation. Postoperative evaluation included slit-lamp bio-microscopy and indirect ophthalmoscopy in addition to B-mode ultrasonography and SD-OCT.

The recorded data included age, gender, laterality, initial visual acuity, and anterior and posterior segment examinations. The type of injury [11, 12] (rupture, penetration,

intraocular foreign body [IOFB], perforation), and the zone of injury (ZOI) (zone 1 (wound limited to cornea), zone 2 (wound of sclera and no more posterior than 5 mm from the limbus), and zone 3 (wound posterior to anterior 5 mm of sclera)) were recorded. The Ocular Trauma Score [11, 12] (OTS) and the ZOI were determined retrospectively by 2 senior surgeons (AMM, AJ) based on the sketch of the injury on admission notes, operative findings, and follow-up notes.

All reports concerning major ammonium nitrate explosions from 1900 to the present were searched for ocular injuries using PubMed or Google Scholar databases using the search term “ammonium nitrate disaster” [13]. The records were screened for estimated weight of the ammonium nitrate, number of fatalities, number of wounded, and ocular injuries especially in regard for open globe trauma.

Statistical analyses were carried using the Mann–Whitney *U* test for small numbers below 30 and the Pearson correlation coefficient. Statistical significance was set at  $p < 0.05$ .

## Results

The two eye hospitals near the blast were Beirut Eye Specialty Hospital (BESH) and Eye and Ear International (EEI). BESH is located 3.9 km (2 miles) from the blast site and had a total of 46 admissions to the emergency room with various ocular injuries; 11 patients with open eye injury were operated there with 10 returning for the 1-year follow-up. EEI is located 11 km (6 miles) from the Beirut Port; it had 31 admissions to the emergency room, all with open eye injury and all were operated on, with 19 patients available for the 1-year follow-up. In all, 29 out of 42 originally operated-on patients constituted the patient population for the current report. Twenty-four patients had unilateral and five had bilateral trauma (Table 1), making the number of eyes included in this study 34. All cases were operated within hours of admission to the emergency room. The surgeons kept operating until late on the night of the blast. Enucleation was not carried out on that night of the blast as all wounds were deemed amenable to suturing.

The mean age was  $44.4 \pm 18.8$  years with a slight male preponderance (17 men and 12 women). The mean initial vision in logMAR (mean  $\pm$  SD) was  $2.93 \pm 0.87$  (hand motion [HM] equivalent) and the final vision was  $1.80 \pm 1.47$  (counting finger [CF] 2 m equivalent) (Table 2). No light perception vision (NLP) was noted in 12 eyes on presentation and 10 eyes maintained so while 2 eyes reached light perception (LP) vision. The visual acuity was unchanged in 11 eyes, improved in 22 (with a mean visual gain of 1.11 logMAR or 11 EDTRS lines), and worsened in 1 eye.

Eight eyes had an intraoperative expulsive choroidal hemorrhage (7 NLP and 1 LP both pre- and postoperatively), and 6 of the 8 developed phthisis (Table 3). Two eyes with

**Table 1** Clinical and ocular trauma characteristics of 29 patients with initial suturing of ocular lacerations and followed for 1 year after the Beirut Blast

Clinical variables	Mean (range) or number
Age	44.4 (15–100)
Gender	
Men	17
Women	12
Laterality	
Unilateral	24
Bilateral	5
Injury type	
Rupture	10
Penetrating	13
Perforating	11
Location of laceration	
Cornea	4
Corneosclera	20
Sclera	4
ZOI	
1	8
2	13
3	13
OTS	63.1 (36–90)
Below 50	11
50–69	7
70 and above	16

phthisis did not have recorded expulsive choroidal hemorrhage. All eyes that developed phthisis had NLP preoperatively and postoperatively. Glass injuries from balconies facing the Beirut Port represented most of the injuries: intraocular foreign bodies were removed in 6 cases and consisted of glass in 5 cases and metal in one case.

OTS (mean ± SD 63.1 ± 13.7) correlated inversely with both initial ( $R = -0.82$ ) and final vision ( $R = -0.68$ )

**Table 2** Visual acuity at presentation and at the 1-year follow-up on 29 patients with sutured ocular lacerations following the Beirut Blast

Vision	Initial	1-year
NLP	12	10
LP	7	2
HM	8	1
20/1600	0	2
20/800	3	2
20/400	3	3
20/200	1	1
20/100	1	2
20/80	0	1
20/50	0	1
20/40	0	2
20/30	0	3
20/20	0	4

**Table 3** Operative findings at presentation and subsequent surgeries on 29 patients with sutured ocular lacerations following the Beirut Blast

Intraoperative findings	
Expulsive choroidal hemorrhage	8
Retinal detachment	6
Traumatic or ruptured cataract	9
Eyelid laceration	9
Number of subsequent surgeries	
0	18
1	11
2	1
3	3
Subsequent surgery	
Pars plana vitrectomy	7
Evisceration	2
Intraocular lens implantation	
Primary	6
Secondary	3
Silicone oil removal	2
Penetrating keratoplasty	3
Phacoemulsification	2
Lenectomy	1

( $p < 0.001$ ) (Table 4). ZOI inversely correlated with initial vision ( $R = -0.40$ ;  $p = 0.02$ ) and positively with final vision ( $R = 0.75$ ;  $p < 0.001$ ). Visual gain correlated inversely with ZOI ( $R = -0.63$ ;  $p < 0.001$ ) and final vision ( $R = -0.81$ ;  $p < 0.001$ ). Final vision was significantly worse in zone 3 (logMAR  $3.2 \pm 0.5$ ) vs. zones 1 and 2 (logMAR  $0.9 \pm 1.1$ ) ( $z$ -score =  $-4.2$ ;  $p < 0.001$ ) injuries, as was the initial vision ( $3.3 \pm 0.5$  vs.  $2.7 \pm 0.8$ ;  $z$ -score =  $-3.1$ ;  $p = 0.002$ ). The eyes with retinal detachment had worse final vision than the eyes without retinal detachment ( $2.5 \pm 0.9$  vs.  $1.7 \pm 2.3$ ;  $z$ -score =  $-1.1$ ;  $p = 0.3$ ), but this was statistically not significant.

Ammonium nitrate (AN) is a detonable substance which has led to 16 major disasters from 1916 until the present day (Table 5). The combined total estimated weight of the exploding AN was 24,493 (mean 1750) tons. The number of deaths was 2443 (mean 152), the casualties 28,090 (mean 1873), and the ocular injuries 229 (mean 38, Table 5).

### Discussion

The current 1-year postinjury report demonstrates the blinding sequelae of AN explosions (especially in the eyes with NLP or expulsive choroidal hemorrhage), and the recovery of vision in other patients (especially in the eyes with HM or better initial vision). The range of treatment included corneal transplant, intraocular lens implantation (primarily

**Table 4** Estimated probability of follow-up visual acuity category at 12-month (parentheses) vs. current findings in 29 patients with sutured ocular lacerations following the Beirut Blast (*ZOI*, zone of injury; *ECH*, expulsive choroidal hemorrhage)

Raw score sum	OTS score	NLP	LP-HM	1/200–19/200	20/200–20/50	≥ 20/40	zoi1,2,3	ECH
0–44	<b>1</b>	0 ( <b>73%</b> )	0 ( <b>17%</b> )	1 (100%) ( <b>7%</b> )	0 ( <b>2%</b> )	0 ( <b>1%</b> )	1 zoi3	0
45–65	<b>2</b>	10 (59%) ( <b>28%</b> )	2 (17%) ( <b>26%</b> )	3 (18%) ( <b>18%</b> )	0 ( <b>13%</b> )	2 (12%) ( <b>15%</b> )	2 zoi1 4 zoi2 11 zoi3	9
66–80	<b>3</b>	0 ( <b>2%</b> )	1 (7%) ( <b>11%</b> )	3 (21%) ( <b>15%</b> )	4 (29%) ( <b>28%</b> )	6 (43%) ( <b>44%</b> )	6 zoi1 7 zoi2 1 zoi3	0
81–91	4	0 ( <b>1%</b> )	0 ( <b>2%</b> )	0 ( <b>2%</b> )	0 ( <b>21%</b> )	2 (100%) ( <b>74%</b> )	2 zoi2	0
92–100	5	0 ( <b>0%</b> )	0 ( <b>1%</b> )	0 ( <b>2%</b> )	0 ( <b>5%</b> )	0 ( <b>92%</b> )	0	0
Total		10	3	7	4	10	8 zoi1 13 zoi2 13 zoi3	9

The values between brackets in bold represent the estimated probability

or secondarily), and the full spectrum of vitreoretinal surgery. Most people's eyes were injured by glass shrapnel and debris. Two previous reports on the Beirut blast mentioned

in great detail the large number of difficulties during the acute management of suturing the ocular wounds in a major general hospital (American University of Beirut; 6 cases)

**Table 5** A historical record of ammonium nitrate explosions in chronological order (*NA*, not assessed)

Year	City, country	Estimated weight in tons	Fatalities	Wounded	Open eye	Remarks
2.4.1916	Faversham, Kent, UK	700	115	115	NA	
21.9.1921	BASF Plant, Oppau, Germany	4500	561	1952	Several cases of ocular injuries	7500 homeless; 1.7 million USD material damages
1.3.1924	Nixon Nitration Works, Edison, New Jersey, USA	3800	150	150	NA	Destruction of 40 buildings, and the industrial town of Nix demolition
29.4.1942	Factory in Tessenderlo, Belgium	150	189	900	NA	
16.4.1947	Port of Texas City, Texas, USA	2300	581	3600	38 open eyes	100 million USD material damage
28.7.1947	Ship in port Brest, France	3300	29	NA	NA	Port of Brest severely damaged
7.8.1959	Gerretsen Building Supply Company, Roseburg, Oregon, USA	4.5	14	25	NA	
5.8.1993	Shenzhen, China	91	15	141	NA	
13.12.1994	Port Neal fertilizer plant, Iowa, USA	5700	4	18	NA	Evacuation of 1700 residents
19.4.1995	Oklahoma City, USA	2.3	168	684	12 open eye	652 million in material damage
21.9.2001	AZF Toulouse, France	400	31	2442	70 ocular injuries	30,000 damaged buildings; 1.5 billion Euros in damage
22.4.2004	Ryongchŏn, North Korea	NA	162	3000	NA	8000 homes destroyed
24.5.2004	Mihăilești, Buzău County, Romania	20	18	13	NA	
17.4.2013	West Fertilizer Company explosion, West, Texas, USA	30	15	252	31 (12.3%) ocular injuries	
12.8.2015	Port of Tianjin, China	800	173	798	18 (2.3%)	
4.8.2020	Port of Beirut, Lebanon	2700	218	14,000	60 (0.43%)	300,000 homeless

[2] and the short-term results in EEI (31 cases) [3], while the current report details the 1-year outcomes in 29 patients of the originally treated 42 patients with penetrating ocular injuries (among the 48 total cases of sutured lacerations as reported to the Lebanese Ophthalmic Society) [2].

A previous study showed that the most common surgeries performed following the Beirut blast were fractures, tendon repair, and suturing of ocular wounds (Table 3) [1]. This traumatic event with unique ophthalmological importance is reminiscent of the inordinate number of eye casualties following the 1917 Halifax Explosion [5]. When the 2 cargo ships Mont Blanc (loaded with munitions) and Imo collided and caught fire, residents rushed to their windows to watch the fire. As a result, 592 survivors sustained eye injuries caused by shards of shattered glass. Twelve ophthalmologists performed 249 enucleations (16 being bilateral) ending in 40 totally blind patients [5]. Although the total ocular surface (17.6 cm<sup>2</sup>) [14] constitutes only 0.1% of the total body surface (18,000 cm<sup>2</sup> in men and 16,000 in women), the rate of reported ocular damage can be up to 50 times the body surface area [6]. Injuries caused by explosive materials are strongly associated with severe ocular morbidity and visual impairment [4, 7, 10, 15, 16]. In the Halifax disaster, 9000 people were injured, over 2000 died, 592 subjects had eye injuries, and 249 underwent nucleations (42.1%). The general setup in 1917 included chloroform anesthesia and topical cocaine anesthesia, operating with the naked eye under the light of a bulb, use of commercially available silk sutures, and operating over a period of 4 days by a general eye ear nose throat practitioner. In the Beirut disaster a century later, 14,000 were injured, 219 died [1], 48 subjects underwent ocular surgery, and 4 received immediate enucleations (8.3%) [2, 3]. The general setup included development of better instrumentation (operating microscope, vitrector, phacoemulsification, intraocular lens, intraocular magnet and forceps), smaller sutures with needles, use of viscoelastics, and prompt surgical management by vitreoretinal fellowship-trained ophthalmologists well trained in trauma management.

Most bodily injuries from AN involved the hand (Table 6) as many patients tried to protect their eyes with their hands. Hence, the ocular injuries would be expected to be much higher in the absence of the hand protection reflex. The exposure of the face in combat, and the vulnerability of the eye to even tiny flying particles explain the well-known susceptibility of the eyes to explosive injuries [6].

The OTS, which provides prognostic information after general ocular trauma, yields valuable prognostic information for AN-associated ocular injuries [17–20]. It appears that in explosive injuries, NLP initial vision and (intraoperative) expulsive choroidal hemorrhage are the most ominous prognostic variables. The effect of the development of retinal detachment did not appear to be significant on the final

**Table 6** Admissions to the operating room (OR) within the first 52 h after Beirut Blast. There was a total of 534 total OR admissions out of 8643 emergency admissions in 42 medical centers [1]. The current table details the operations performed in 346 OR admissions in 13 major centers

Injury	Operating room admissions in 13 centers
Fractures	127 (36.7%)
Hand	22
Arm	36
Face	12
Rest	57
Tendon repair	68 (19.7%)
Hand	40
Arm	5
Rest	23
Open eye	50 (14.5%)
Craniotomy	28 (8.1%)
Polytrauma	26 (7.5%)
Major plastic surgery repair	16 (4.6%)
Laparotomy	6 (1.7%)
Thoracotomy	4 (1.2%)
Foreign body removal (extremities 2, orbit 2)	4 (1.2%)
Amputation (fingers 2, hand 1, foot 1)	4 (1.2%)
Miscellaneous	14 (4.0%)
Total	346 (100%)

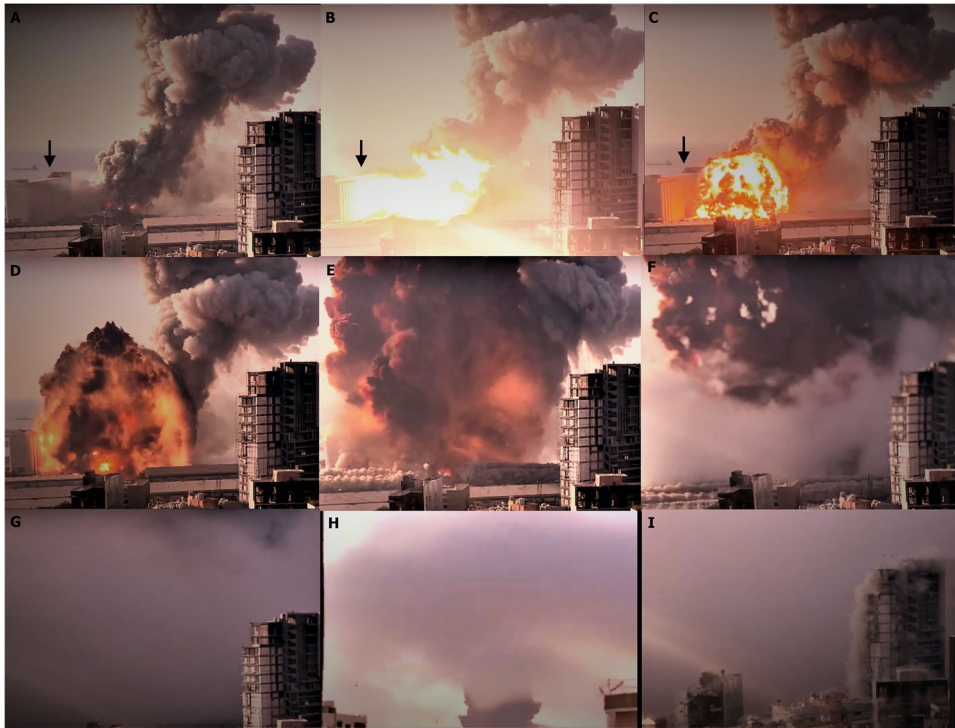
prognosis, although this may be due to its low incidence and to the concomitant complex ocular morbidities [18–21].

AN is highly explosive and can produce an overpressurization shock wave travelling to great distances, shattering glass in doors and windows. Footage of the blast consisted of several stages (Fig. 1) that starts with formation of a semi-nuclear orange mushroom-shaped cloud. The magnitude of the blast overpressure and the injuries are proportional to the amount of exploded AN and to the distance from the blast [1]. A second wave of injuries can occur due to the collapse of buildings or because of falling objects [22].

Besides terrorist attacks, most explosions are caused by fire during storage or transportation. Several actions are necessary to prevent such disasters [23]: (1) storage away from housing facilities, fuel tanks, or fireworks facilities; (2) adoption of strict storage-safety measures supervised periodically by local authorities; (3) UN surveillance of production and distribution of AN under the Terrorism Prevention Act.

Limitations of our study include its retrospective study design and the small number of patients. The latter is due the low percentage of patients returning for follow-up (13 out of 42 subjects were lost to follow-up)—partially explained by a large post-blast emigration wave. In addition, eye-injury patients with polytrauma





**Fig. 1** Composite serial images of events at the Beirut Port at the time of the explosion (with written permission from the owner of the video footage by Nemeth Agoston on YouTube <https://www.youtube.com/watch?v=rlvnsecLRmM>). **A** A small explosion at a quayside building in the port of Beirut was followed by a fire from multiple firework explosions. **B** Several minutes later, a very big blast happened which also caused a huge shockwave. **B** Yellowish bright spark light; **C** then red smoke ball; **D, E** growing ball over microseconds; **F, G** white cloud extend in all directions; **H** mushroom shape of the white cloud; **I** the blast shattering buildings. Half the explosive force radiated away almost harmlessly over the sea (west direction) and south wise

the grain silo (arrow) dampened its effect tremendously leaving the northeastern part of the city to the full-blown effects. The red smoke visible before the shockwave is nitrogen dioxide, one of the chemicals produced when ammonium nitrate explodes. The white cloud during the main explosion is the shockwave making water in the air condense. Immediately behind the high-pressure shockwave, there is a sudden drop in pressure and temperature, leading to condensation of water in the air. The mushroom effect: the explosion produces a layer of hot gas that quickly rises. The air above blunts this hot gas as it tries to move upward, literally pushing it downward and forming the distinctive cap

and life-threatening conditions were treated at a general hospital; only patients with isolated ocular injuries were admitted to the 2 major eye specialty hospitals. Orbital and adnexal injuries were not included and nonsurgical traumas (superficial corneal trauma, hyphema, etc.) were not ascertained in the current study.

In conclusion, we found that the OTS also provides reliable prognostic information on patients who sustained explosion (ammonium nitrate) injuries and who then undergo complex visual rehabilitation including pars plana vitrectomy for the surgical removal of intraocular foreign bodies, repair of retinal detachment, corneal transplant, and phacoemulsification or lensectomy with intraocular lens implantation. OTS may offer the possibility of approximation of the functional result in these patients before the surgery, and it is also helpful when triaging is necessary in cases of mass casualties. Explosive choroidal

hemorrhage and NLP vision remain very poor prognostic signs. Explosions of AN fertilizer in storage, transportation, or terrorism are preventable accidents and should be closely monitored by a UN special agency.

## Declarations

**Research involving human participants** This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee (IRB) of BESH and EEI hospitals approved this study.

**Informed consent** Informed consent was obtained from all individual participants included in the study.

**Competing interests** The authors declare no competing interests.

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