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

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Abstract

Purpose Ascertian 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

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 ± 18.8 years with a slight male preponderance (17 men and 12 women). The mean initial vision in logMAR (mean ± SD) was 2.93 ± 0.87 (hand motion [HM] equivalent) and the final vision was 1.80 ± 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
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 \( R = -0.68 \) \( (p < 0.001) \) (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 \( (\text{logMAR } 3.2 \pm 0.5) \) vs. zones 1 and 2 \( (\text{logMAR } 0.9 \pm 1.1) \) \( (z\text{-score} = -4.2; p < 0.001) \) injuries, as was the initial vision \( (3.3 \pm 0.5 \text{ vs. } 2.7 \pm 0.8; z\text{-score} = -3.1; p = 0.002) \). The eyes with retinal detachment had worse final vision than the eyes without retinal detachment \( (2.5 \pm 0.9 \text{ vs. } 1.7 \pm 2.3; z\text{-score} = -1.1; p = 0.3) \), 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

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**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                    |

**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 | 8 |
|-------------------------|---|
| Expulsive choroidal hemorrhage | 6 |
| Retinal detachment      | 9 |
| Traumatic or ruptured cataract | 9 |
| Eyelid laceration       | 7 |
| Number of subsequent surgeries | 18 |
| 0                       | 11 |
| 1                       | 1  |
| 2                       | 3  |
| 3                       |    |
| Subsequent surgery      |    |
| Pars plana vitrectomy   | 7 |
| Evisceration            | 2 |
| Intraocular lens implantation | 6 |
| Primary                 | 3 |
| Secondary               | 3 |
| Silicone oil removal    | 2 |
| Penetrating keratoplasty| 3 |
| Phacoemulsification     | 2 |
| Lenscetomy              | 1 |
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 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          | 1         | 0 (73%) | 0 (17%) | 1 (100%) (7%) | 0 (2%) | 0 (1%) | 1 zoi3 | 0 |
| 45–65         | 2         | 10 (59%) (28%) | 2 (17%) (26%) | 3 (18%) (18%) | 0 (13%) | 2 (12%) (15%) | 2 zoi1 | 4 zoi2 | 11 zoi3 |
| 66–80         | 3         | 0 (2%) | 1 (7%) (11%) | 3 (21%) (15%) | 4 (29%) (28%) | 6 (43%) (44%) | 6 zoi1 | 7 zoi2 | 1 zoi3 |
| 81–91         | 4         | 0 (1%) | 0 (2%) | 0 (2%) | 0 (21%) | 2 (100%) (74%) | 2 zoi2 | 0 |
| 92–100        | 5         | 0 (0%) | 0 (1%) | 0 (2%) | 0 (5%) | 0 (92%) | 0 |
| Total         | 10        | 3 | 7 | 4 | 10 | 8 zoi1 | 13 zoi2 | 13 zoi3 |

The values between brackets in bold represent the estimated probability.

### 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       | 7500 homeless; 1.7 million USD material damages |
| 21.9.1921 | BASF Plant, Oppau, Germany     | 4500                     | 561        | 1952    | Several cases of ocular injuries | |
| 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  | Gerreitzen 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 | Ryongchon, 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%) | 300,000 homeless |
| 48.2020   | Port of Beirut, Lebanon        | 2700                     | 218        | 14,000  | 60 (0.43%) | |
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 cm²) constitutes only 0.1% of the total body surface (18,000 cm² 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 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

### Table 6

| 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%)                             |
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. Expulsive 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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