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CASE REPORT

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Fatal blast injuries in tyre blowouts: two autopsy case reports

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Abstract

Background: Fatal blast injuries are generally reported as a consequence of explosions, mainly in terrorist events, work-related detonations, or domestic settings. Although quite rare, blast injuries of high kinetic energy can be seen in tyre blowouts and are very dangerous and potentially lethal because of their unpredictability. This phenomenon is rarely reported in the existing forensic literature.

The aim of this study was to report two cases of fatal truck tyre bursts and to discuss the mechanisms leading to the burst and the pattern of injuries.

Case presentations: Case 1 was of a 58-year-old truck driver man who was standing nearby a detached tyre that was being inflated in a repair shop when the burst occurred. The tyre struck him in the face and threw him. The medicolegal autopsy showed a right periorbital haematoma, a large wound of the left parietal scalp, a diffuse subarachnoid haemorrhage, an atlanto-occipital dislocation, a fracture of the hyoid bone, multiple rib fractures, and lacerations of the ascending aorta and the pulmonary arteries. Case 2 involved a young man of 24-year-old, a worker in a tyre repair shop, who was inflating a truck's tyre when it burst violently. The injuries sustained included bleeding from the right ear, fractures of the facial bones, a left hemispheric subdural haematoma associated with the fracture of the skull base, a rib fracture, and diffuse areas of contusions to the lungs. Toxicological analyses were negative in both cases.

Conclusion: Fatalities related to tyre blowout accidents are uncommon. The mechanisms leading to a blowout can be mechanical or chemical in origin, and the main danger of a burst often occurs when air enters the tyre during inflation. Internal damage caused by the pressure waves of the blast often exceeds what would be expected based on external signs alone.

Keywords: Blast injury, Burst, Death, Tyre, Case report

Background

After the discovery of the rubber vulcanization process by Charles Goodyear in 1839 and the industrial expansion of the 19th century, the tyre became a major feature in most of our transportation technologies and has undergone many evolutions since its invention. Simple in appearance, a tyre is very complex in structure and made of the assembly of several materials with diverse properties (Michel et al. 2011). In road accidents, failures caused by tyres are the most dangerous after those caused by the braking system and the suspensions (Michel et al. 2011). These failures include tyre blowouts which, although relatively rare, are very hazardous. Inflated tyres, especially large trucks and bus tyres, contain tremendous potential energy (Kumar et al. 2016). Tyres should be considered as compressed air tanks, where the average pressure is about 8 to 9 bars for truck tyres (Lenz et al. 2009). The high energy produced by an inflated large tyre blast may cause severe injuries and can even kill a person

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in the vicinity of the tyre (Murty 2009). The severity of the injury is depending on the blast loading to which the body was exposed and its duration (Housden 2012). Only a few cases have been reported in the existing forensic literature (Kumar et al. 2016; Lau 1995; Murty 2009; Obafunwa et al. 1997; Pomara et al. 2013; Rautji et al. 2003).

The purpose of this study was to describe two accidental uncommon cases of lethal blast waves that occurred in a work environment and to discuss the mechanisms that led to the truck tyre blowout and the pattern of injuries.

Case presentation

Case 1

On a Wednesday, at around 12:50 am, a 58-year-old truck driver man fatally suffered a tyre burst. According to witnesses, while a detached wheel was being inflated in a repair shop, the driver was standing nearby facing it, at about 50 cm away, when the burst occurred. The tyre struck him in the face and threw him to the ground. He died at the scene. Examination of the tyre showed a zipper-like appearance burst of the upper sidewall area (Fig. 1). The tyre was manufactured by Amine® and the estimated time of wear was at about 5 years.

A complete medico-legal autopsy was performed. The external examination was of a body averagely built, measuring 178 cm in height, presenting a right periorbital haematoma with petechial subconjunctival haemorrhage (Fig. 2), multiple dermabrasions and ecchymoses of the face and neck, a fracture of the left horizontal branch of the mandible, and a large laceration wound of the left parietal scalp. On internal examination, the brain was normal in size and volume, presenting a left parieto-occipital subdural haematoma associated with a diffuse subarachnoid haemorrhage (Fig. 3). Cranial bones were intact. In the cervical region, there was an atlanto-occipital dislocation and a fracture of the left greater horn of the hyoid bone. The thyroid cartilage was intact. The thoracic region showed multiple fractures of the right 2nd to 5th ribs and the left 2nd and 3rd ribs with mild bilateral haemothorax (110 mL) and congestive partly collapsed lungs weighing 784 g on the right side and 562 g on the left side, with lacerations and multifocal contusions. A large haemopericardium (550 mL) was recorded, caused by lacerations of the ascending aorta and the trunk of the pulmonary arteries (Fig. 4). The heart weighed 298 g and was macroscopically normal in appearance. There was mainly a peri-hepatic haemorrhagic effusion at the abdominal-pelvic level because of multiple lacerations of the liver in segments 7 and 8. Examination of the rest of the viscera was unremarkable. Toxicological screening of samples of biological fluids for alcohol, drugs, and pesticides was negative.

Fig. 1 A zipper-like appearance burst of the upper sidewall area of the tyre

Fig. 2 Right periorbital haematoma associated with petechial subconjunctival haemorrhage

Case 2

A 24-year-old man working in a tyre repair shop was the victim of a tyre blowout accident. According to witnesses, on a Thursday at around 4 pm, the victim was inflating a tyre of a truck that he had been repairing, when it burst violently, throwing the body a few metres

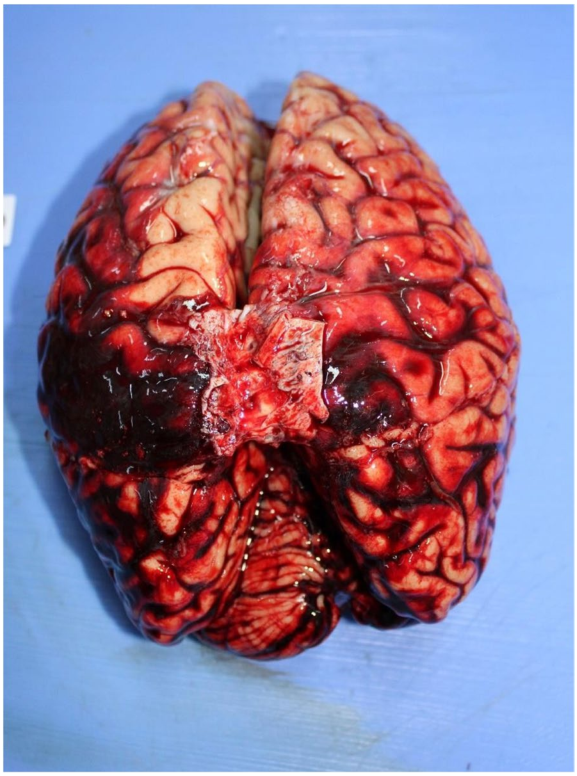

Fig. 3 Diffuse subarachnoid haemorrhage and left parieto-occipital subdural haematoma

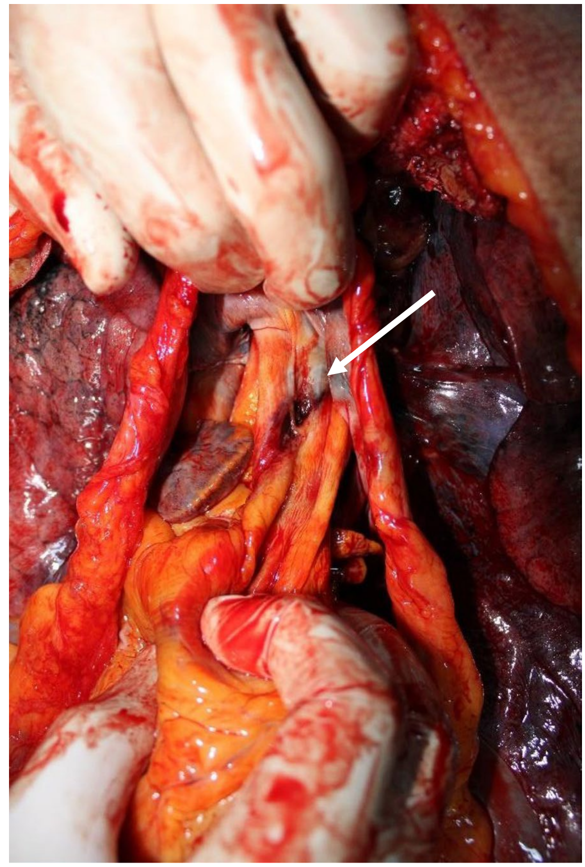

Fig. 4 Lacerations of the ascending aorta and the trunk of the pulmonary arteries

away off the ground. The victim died on his way to the hospital. A complete medico-legal autopsy was performed. The body was of average build, measuring 179 cm in height. The injuries sustained included multiple abrasions and ecchymosis of varying sizes present on the face, neck, and chest, associated with right periorbital haematoma, bleeding from the right ear, and fracture of the nasal, right zygomatic arch, and mandible bones. Upon internal examination, an epidural haematoma of the frontal scalp was noted, associated with a left hemispheric subdural haematoma and a fracture of the skull base passing through the petrous portion of the left temporal bone. The brain was normal in size and volume with mild cerebral oedema. In the cervical region, the hyoid bone and thyroid cartilage were intact. The second left rib was fractured. The lungs were heavy, weighing 1060 g on the right side and 1046 g on the left side, presenting haemorrhagic foam and diffuse areas of contusions. The heart was macroscopically healthy. The viscera of the abdominal and pelvic regions were unremarkable. Toxicological analysis of the samples collected during the autopsy did not detect any drug or alcohol.

Discussion

A radial truck tyre is constructed from rubber components and layers of cord reinforcements made of polyester, steel, and nylon. These cords are embedded in a rubber matrix with specific spatial orientations. The tyre is mounted on a rim made of steel or aluminium (Michel et al. 2011).

A tyre burst refers to a rupture of the tyre structure when the latter cannot maintain the pressure contained inside. Schematically, the cause can be mechanical, chemical, or a combination of both (Michel et al. 2011). The primary cause of chemical bursts is the application of heat to the tyre or the development of heat within the tyre. The thermal expansion of the air inside the tyre leads to the reduction of the mechanical resistance properties of the tyre structure and thus to its bursting or even explosion in certain circumstances. For example, a welding operation on the rim can create enough heat to initiate an internal chemical reaction (Dolez et al. 2008).

Mechanical tyre bursts can result from an over-pressurization, tyre demounting, or "zipper" failure in tyres in poor condition or with a structural weakness (Michel et al. 2011). Possible causes of over-pressurization of the tyre are an inadequately adjusted compressor pressure, a malfunctioning pressure gauge or valve, or deliberate over-pressurization when mounting the tyre to the rim.

The name zipper failure comes from the zipper-like appearance of the mid to upper sidewall area of the tyre after bursting, exposing an even line of severed casing steel cords (Hefny et al. 2009; Murty 2009; Pomara et al. 2013). Possible mechanisms include casing damage exposing the tyre's inner liner to air or moisture contamination, overloading, the mechanical impact that has damaged the tyre's structure, and driving with an under or over-pressurized tyre (Murty 2009; Pomara et al. 2013).

Handling a deflated tyre has no risk of bursting, the real danger exists when air enters the tyre during inflation. Summer heat can be an additional factor in tyre bursting due to the increased pressure inside the tyre (Hefny et al. 2010). This phenomenon commonly occurs when the vehicle is in motion, but it can also occur when the vehicle is stationary and when the tyre is being inflated or secured to the axle (Hefny et al. 2009; Obafunwa et al. 1997). According to Hefny's series combining cases of non-fatal and fatal large tyre blast injuries, the majority of injuries occur in service stations during tyre mounting and servicing. Young men working as mechanics are by far the most affected (Hefny et al. 2009).

An experimental study that focused on establishing the strength limits of a tyre during inflation, showed that the tyre burst pressure obtained for a 11R22.5 truck tyre in a hydrostatic burst test was 1.826 MPa (18.26 bar or 264.85 psi) which corresponds to a pressure of 2.5 times the maximum inflation pressure recommended by the tyre manufacturer (Michel et al. 2011). The main danger results from the brief evacuation of the air contained, which can propel the tyre and cause very serious injuries to people nearby. The severity of the injuries depends on the size of the tyre, the contained air pressure, and the distance between the tyre and the victim (Hefny et al. 2009). Blast injuries in the case of bursting tyres can be caused by the single or more commonly, the combined effect of three main entities which are the pressure wave of the blast, the impact of the tyre rim or other fragments, and the displacement of the body being thrown against the ground or other surfaces or objects. Schematically, these constitute respectively the well know primary, secondary and tertiary classification of blast injuries described in explosions caused mostly by armed conflict, terrorist bombings, industrial disasters, aeroplane crashes, and domestic gas leaks (Galante et al. 2021). The main difference is the absence of thermal or chemical effects that belong to the quaternary blast injuries (Blechner and Seiler 1995; Larkins et al. 2020)

A study (Hefny et al. 2009) reported that the most commonly injured body parts are the head and facial bones, which is explained by the fact that the victims were facing the tyre when it burst (Hefny et al. 2010), and about 25% of the injured had multi-trauma. The reported overall mortality was 19% (Hefny et al. 2009).

When a large tyre bursts, an increase in atmospheric air pressure is created, known as an overpressure or blast wave, and can induce severe barotrauma. Sudden excess of pressure, even if small, causes significant physical effects on the body (Kumar et al. 2016; Pomara et al. 2013). The pressure wave travels through media of different densities, provoking acceleration and deceleration as it passes through the tissue (Housden 2012). The absorbed part of the shock wave has variable effects depending on the tissue. Solid organs are not very sensitive, while hollow viscera are very vulnerable, as well as pulmonary alveolae and eardrums. This is well demonstrated in the studies reporting this phenomenon, where autopsy findings related to the primary blast injuries showed haemopneumothorax, partially collapsed lungs with foci of parenchymal contusions, and haemorrhagic suffusion of the mesentery, stomach, and intestines (Hefny et al. 2009; Murty 2009; Pomara et al. 2013). Intestinal perforation or rupture is rare (Larkins et al. 2020). Injuries to solid viscera are related to very high blast loading (Housden 2012). The reported cases above have shown that the first victim had lacerations of the proximal aorta and the pulmonary artery. It is explained by the rapid deceleration that produces shear forces resulting in tearing injuries to semi-mobile body structures at their attachment sites (Parmley et al. 1958; Pomara et al. 2013). We also observed the presence of hyoid bone fracture in the second case. There was no similar finding in the previously reported tyre burst cases, but it has been documented that hyoid bone and thyroid cartilage fractures can be seen in explosion-related primary blast injuries with high levels of blast overpressure (Galante et al. 2021). As shown, the majority of primary blast injuries are internal and the shock wave can cause death without obvious visible external injury (Pomara et al. 2013). A safety distance of 2.5 m from the tyre is recommended when inflated (Yu et al. 2017).

Secondary blast injuries are the consequence of the projection of the tyre or one of its components and surrounding debris energized by the blast and propelled outward, causing non-penetrating and penetrating injuries (Murty 2009; Pomara et al. 2013). It can be particularly dangerous and explains the variety of sustained injuries. These projectiles can cause superficial erosions, ecchymosis, haematomas, contused wounds, and even bone fractures. Direct impact injuries typically cause focal damage at the site of impact. Cases of foreign objects penetrating the eyes (Choi et al. 2009; Žiak et al. 2017) and the maxillary sinus are reported (Malachovský et al. 2016). In one reported case, Lau (Lau 1995) described a penetrating mandibular injury from the handle of a sledgehammer when the inner tube of a military truck burst associated with an atlanto-occipital dislocation. We reported a similar finding in the first case. The victim got hit in the face by the tyre and upon internal examination, an atlanto-occipital dislocation was discovered. Atlanto-occipital dislocation is primarily an injury of the ligaments between the occiput and upper cervical spine (Hall 2015). The most common mechanism of this lesion is sudden hyperextension of the atlanto-occipital joint. This induces disruption of the tectorial membrane and alar ligaments, allowing dislocation of the craniovertebral junction to occur (Fard et al. 2016; McKenna et al. 2006). In both cases, the projectile striking the face had the effect of a violent blow throwing the head backwards, resulting in posterior hyperextension and dislocation of the cervical spine (Lau 1995).

Tertiary blast injuries are explained by the propulsion of the body and subsequent impact against a surface or other environmental structures, resulting in blunt trauma (Hefny et al. 2010; Obafunwa et al. 1997). Head injuries are major tertiary blast injuries and lead in most cases to instantaneous death. They are the most common findings in fatalities (Pomara et al. 2013). The displacement of the body can result in scalp contused laceration, subarachnoid haemorrhage, subdural haemorrhages, cerebral contusion, and cranium fractures. Rib fractures disrupting the chest wall are also seen and can alter the mechanics of pulmonary ventilation (Marro et al. 2019).

Conclusions

Death related to tyre burst accidents is infrequently encountered, with the majority of cases occurring in the workplace. This study detailed the mechanisms leading to the burst and the patterns of blast wave injuries. Highlighting the seriousness of this phenomenon should contribute to raising awareness about the dangers and promote developing means of protection to reduce the risks of death. Such incidents should not be taken lightly and surviving victims must be thoroughly examined because, as it has been shown, the internal damage often exceeds what would be expected based on external signs alone.

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None.

Authors' contributions
ABD and SG assisted in the autopsy and wrote the first draft of the manuscript. MJ and MZ performed the autopsy and commented on the first version of the manuscript. BG helped in editing the manuscript. MKS and MBD contributed to the revision and final editing of the manuscript. All authors have read and approved the final manuscript.

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Availability of data and materials
Not applicable.

Declarations

Ethics approval and consent to participate
No ethical approval is required in this case.

Consent for publication
Oral consent was taken from the deceased's families after informing them of the purpose of the case report. There is no identification or private details of the deceased in the mentioned cases and we did not need to take written consent.

Competing interests
The authors declare that they have no competing interests.

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