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GENERAL INFORMATION

Injury mechanisms in extreme violence settings☆

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Abstract Extreme violence events are consequence of current world-wide economic, political and social conditions. Injury patterns found among victims of extreme violence events are very complex, obeying several high-energy injury mechanisms. In this article, we present the basic concepts of trauma kinematics that regulate the clinical approach to victims of extreme violence events, in the hope that clinicians increase their theoretical armamentarium, and reflecting on obtaining better outcomes.

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Mecanismos de lesión en actos de violencia extrema

Resumen Los actos de violencia extrema son una consecuencia de las condiciones económicas, políticas y sociales que privan en el mundo actual. Los patrones lesionales que se encuentran en las víctimas de actos de violencia extrema son muy complejos y obedecen a distintos mecanismos de lesión de alta transmisión de energía. En este manuscrito exponemos los conceptos básicos en cinemática del trauma que rigen el abordaje clínico de las víctimas de actos de violencia extrema, en espera de que el clínico aumente su armamentario teórico, reflejándolo en la obtención de mejores índices pronósticos.

Background

Violence and its various manifestations can prevail in situations that do not formally constitute armed conflict such as, meetings and demonstrations, internal disturbances and states of emergency, and in situations of actual armed conflict which can be domestic, international or internationalised.[1] It is also worth mentioning that so-called ''acts of extreme violence'' can occur in the course of these events. The specialist social terminology for this area refers to 2 concepts: (1) *qualitative*: such as the atrocities which are often committed during the act of violence, and which some authors term ''cruelty'' and (2) *quantitative*: the destruction of various human or material elements of a population, not directly involved in the conflict.[2]

It is indisputable that acts of extreme violence have occurred throughout the history of humanity and have certainly shaped its course. As part of the large scientific community which seeks to deal with acts of extreme violence, doctors are often involved in the care of the victims of such events, and it is therefore their duty to keep their skills up to date in order to provide efficiently and appropriate care.

In addition to the importance of extreme acts of violence for healthcare professionals they also have great impact on urban, governmental and military settings. In cities, due to economic and moral poverty, different ideological differences and social disorder, extreme acts of violence are frequently reported in confrontations between sects, groups or segregated comunities.[3] Furthermore, in a government setting, conflict between these sects, groups of communities and the federal authorities have the potential to result in extreme acts of violence. Illegal arms acquisition and organised crime are involved in a great many of these events.[4] In the military arena, of course, the very nature of armed conflict generates acts of extreme violence. The missions of the Mexican Army and Air Force place these armed forces at constant risk of participating in acts of extreme violence; they may incur injuries as a consequence, generating enormous costs to the institution, job losses, and the consequent negative effect on the moral of the troops.

Due to all of the above, the General Management and the Trauma Team of the *Hospital Central Militar* set themselves the task of performing a specialist review of the trauma mechanisms which are frequently seen in acts of extreme violence, proposing a technical stratification of these mechanisms and introducing their readers to the concept of an *injury pattern*; a vital element in the clinical application of knowledge on trauma kinematics which, based on the implementation of various educational tools, has proved useful.

Trauma kinematics: the mechanisms of injury and their importance as determining factors of injury pattern in acts of extreme violence

Dealing with the causal physical mechanisms of trauma is a part of warfare as well as daily life. With current technology, the biophysics of the penetrating mechanisms of injury by low-speed instruments and injury caused by high speed missiles, manufactured using advanced technology, have been studied in great detail. Moreover, developments in motor vehicles have enabled the study of different types of multi-systemic blunt injuries with high energy exchange.

Kinematics is the branch of mechanics which studies the motions of a body or system of bodies, and the mass and types of action exercised over it; the essence of kinematics, therefore, lies in motion. The 3 laws of Newton summarise the study of motion in the universe: (*1*) the law of inertia; (*2*) the law of force and momentum, and (*3*) the law of action and reaction. For practical purposes, the combination is reduced into the formula of kinetic energy $EK = (m)(v^2)$, where EK is the kinetic energy, m is the mass and v^2 is the velocity squared.[5]

Biophysics of trauma

The interaction between the host and the energy-transmitting object determines the presence of a *trauma*, whereas the *injury pattern* is the set of morbid organic and pathophysiological manifestations defined by Newton's mechanisms and the physical and anatomical properties of the victim. It is important to be aware of the specific trauma mechanism in order to anticipate possible injury patterns in the patient. The concepts required to understand these phenomena are as follows[5–7]:

I. *Stress*. The force applied to a body per unit area, causing deformation.
II. *Strain*. Deformation due to stress on the volume of a body. There are 4 types of strain: (*1*) tensile; (*2*) rupture; (*3*) compressive; (*4*) overpressure.
III. *Young's modulus*. This is a graph which defines the ratio between stress and strain. A body will respond to stress by means of strain. When the interaction starts, stress will cause a rapid and large strain (ascending part of the curve, known as the ''elastic modulus''); this strain will reduce in magnitude and speed as the stress over the body increases (plateau of the curve, known as the ''plastic modulus''). This strain will increase to a critical point called ''rupture point'' or ''tensile strength point'', where permanent structural damage takes place. The area under the curve represents the magnitude of the energy applied to the body up until this rupture or tensile strength point.[8]

In the specialist trauma literature there are 5 mechanisms which combine to create the complex injury patterns seen in acts of extreme violence: (*1*) penetrating; (*2*) blunt; (*3*) blast injury; (*4*) trauma from deceleration/shearing forces; (*5*) thermal and electrical trauma, and (*6*) suspension trauma.[5,9]

Penetrating trauma

An awareness of the following concepts is essential in order to understand the physical phenomena which create injury patterns in penetrating trauma:

I. *Penetration*. The distance of the tract of the wound.
II. *Fragmentation*. The difference in weight of a missile before and after passing through the body.
III. *Permanent cavitation (tract)*. Tissue destroyed by penetration.
IV. *Temporary cavitation*. Tissue forced out of the way by the pressure wave surrounding the trajectory of the projectile. It can be eccentric or concentric.

Based on the 3 laws of Newton and the law of kinetic energy, Hunt et al.[8] indicated that ''it is the velocity of an object, more than its mass, that determines the extent of the damage''.[5–10]

Thus it is understood that penetrating injuries caused by low velocity objects, knives or low velocity firearm projectiles (< 1000 feet/s) generally limit their damage to the wound tract, causing minimal or no injury secondary to temporary cavitation.[5,11]

Furthermore, projectiles have 4 phenomena in their own right, which gain in significance in defining the injury pattern as the velocity of the projectile increases: (*1*) gravitational drag; (2) yaw: movement of the nose of the projectile in an upper and lower direction with respect to the horizontal; (*3*) precession: spiral motion of a projectile through a motion axis traced from the centre of its mass; this precession motion tends to carry the nose of the projectile and the centre of its mass towards this axis, the breadth of the spiral reducing as the distance of travel through space increases; (*4*) nutation: spiral motions within the trajectory of precession; (*5*) tumbling: anteroposterior turn of the projectile on its centre of gravity once it is within its target, and (*6*) *conformational decoupling*: the separation of the rigid component (jacket) from the soft component (core) as the missile turns inside the body; this is a phenomenon which is practically exclusive to medium (1001–2000 feet/s), high (2000–3000 feet/s) or ultra-high velocity (military assault or > 3000 feet/s) military projectiles, causing a double Y track inside the substance of the target. The rigid component, generally more lightweight, continues its route through the planes of least resistance, while the heavier soft component moves caudally following the law of universal gravitation.[5,12]

Blunt trauma

Here, the injury mechanism is more complex than that of penetrating trauma, and the injury pattern is more heterogeneous. Most cases are due to road traffic accidents, collisions, falls from a great height and urban assault, a variant of which, extreme assault (lynching), is commonly seen in acts of extreme violence, often combined with other injury mechanisms, defining a mixed injury pattern which is difficult to tackle, and presents a challenge to clinicians. Very serious contusions, cases of crushing with great weight (crush syndrome) and their known consequences (decompression syndrome) are also found in acts of extreme violence by terrorism and the structural collapse of buildings. Mortality with blunt trauma is directly associated with the transmission of energy.[5,8,9,13–18]

Blast injury

There are 5 phases to this type of injury which cause a mixed injury pattern. The 5 types of injury presenting in these patients are as follows: (*1*) *primary injury*: exclusive to high-energy (high-order) explosives, resulting from the impact of the overpressure wave on the body; the hollow organs are most affected, and injuries include blast lung and ruptured eardrum; (*2*) *secondary injury*: resulting from the objects ejected by the explosive, for example: penetrating ballistic injuries, due to fragmentation or blunt trauma, by larger objects thrown by the blast; (*3*) *tertiary lesion*: a consequence of the impact of the individual being thrown by the blast wind, where any part of the body might be injured causing: fractures, traumatic amputations and trauma to the head; (*4*) *quaternary injury*: damage to health which is not the result of previous injury and (*5*) *quinary injury*: a phenomenon of systemic superinflammation, probably due to inflammatory response without counterregulatory control, or due to the deleterious effects of resuscitation. These victims should be initially attended following the ATLS® protocols, without overlooking any injuries caused by this very particular kinematics. The following should be taken into account to take the appropriate approach with these patients[19]:

I. *Order of explosives*. There are 2 large categories of explosives: (*1*) *high-order*, which produce a supersonic over-pressurisation shock wave, with a detonation rate of 1000–10,000 yards/s, examples include: dynamite, pentaerythritol tetranitrate, cyclonite, ANFO, nitroglycerin, Semtex®, and C-4® and (*2*) *low order*, which create a subsonic blast, do not produce an over-pressurisation wave, and have burn (not detonation) rates of several inches to yards, examples include: gunpowder, domestic ignitions, petrol vapour and Molotov cocktails.[19,20]
II. *Closed space and proximity*. When the victim is in a closed space or when the blast is at a proximity of < 5 m for portable devices, and < 20 m for artillery explosives, mortality increases significantly.
III. *Additional elements*. Explosive devices can contain additives such as radioactive (''dirty bombs''), biological (bacterial or viral), or chemical material which increase the rate and magnitude of the damage inflicted by the original device.

It is essential to assess the tympanic membrane, as 25% of patients with a ruptured eardrum present ''blast lung'' and 1% to 4% have hollow visceral rupture. Recent studies attach great value to the combination of eardrum rupture and traumatic amputation (the so-called ''prognostic duo'') as an independent predictive factor of high mortality.[5,8,9,19–22]

Trauma from deceleration/shearing force

During the phenomena of sudden deceleration (falls from a height, extreme assault), the organs with anatomical fixation sites can be torn due to the shearing force on these fixed points. Clear examples of this are aortic pseudoaneurysms at the level of the arteriosus ligamentum and the pulmonary hila. However, the solid organs can also suffer intraparenchymal injury when they comprise structures of different density; here we can find intracerebral lacerations at the level of the dural reflections, and intrahepatic damage, due to displacement and shearing force from the hepatic substance over the rigid vasculobiliary tree. This type of trauma should always be considered when assessing patients who have been subjected to violent deceleration.[5,8,9,14–18]

Suspension trauma

Due to the popularity of extreme sports and high impact military activities, a particular injury pattern has been reported termed ''suspension trauma''. In acts of extreme violence, this is found above all in extreme assault events (lynching), where victims give up due to physical or emotional hardship, and are generally found hanging in public places and in sight of the community. The effects of suspension trauma are due to neuro-vegetative imbalance and stretching, shearing force and ruptured anatomical fixation points, such as the brain stem, the aortic root, the tracheal carina, the splenic hilus, the round ligament, etc., in a person who has undergone sustained hanging over a long period of time or come to a sudden stop in space after a fall at great speed.[23] Due to the consequences in the individual which include cardiorespiratory dysfunction, rhabdomyolysis and haemorrhage due to trauma to the above mentioned anatomical regions, suspension trauma is often fatal.[5,8,9,24]

Thermal and electrical trauma

Extreme cold or heat cause tissue changes due to a combination of noxious phenomena: coagulation, necrosis, liquefaction and, in the case of heat, carbonisation. Electricity causes tissue injury because the body presents great resistance to the passage of an electrical current. There is a great difference between the prognosis after low-voltage injuries (< 1000 V) and after high voltage injuries (> 1000 V); furthermore, tetany, rhabdomyolysis and cardiac dysrhythmias are common amongst patients injured by electricity. It is not uncommon for victims of ''extreme assault'', from penetrating and blunt mechanisms, to be burned, left exposed to very cold temperatures or tortured by electrical shocks, and they present the characteristic pattern of this particular variant of extreme violence.[5,8,9,25]

The role of anatomy on injury mechanisms and patterns

Although the injury mechanism is the main determinant of the injury pattern, in some special cases, anatomy also determines the pattern. Tissue density plays a fundamental role in the morphology of injuries, the densest organs and those of mixed composition (the brain, bone, liver, kidney, blood vessels, for example) are the most prone to structural alteration during energy exchange.

Because it is inside the skull and its mobility is limited, the brain can suffer a combined mechanism of contusion/deceleration plus shearing force, termed *contrecoup injury*, which consists of the appearance of microhaemorrhages with the potential to coalesce in an area of the brain diametrically opposite to the site of the primary contusion.

Organs attached to fixed sites in the chest (distal aortic arch, tracheal carina) are prone to rupture by deceleration and shearing force. There can be injury to the chest and the abdomen due to direct compression (fracture of the pancreas, for example), hollow viscera perforation due to direct or devascularising trauma (the small intestine and mesentery, for example), *blow out* phenomenon (intraperitoneal rupture of a full bladder, for example), and stretching or tearing (liver injury by the falciform ligament, for example)[5,8,15,17,18]. Due to their non-penetrating and initially discreet nature from a clinical point of view, it is common for doctors who are not familiar with these injuries to overlook or fail to suspect them during the diagnostic phase. They present clinically in advanced stages with a poor function and life prognosis for the patient.[16]

Spinal cord injuries are devastating and incapacitating, and unfortunately are common amongst victims of acts of extreme violence. In general, the spinal cord is affected in 55% of cases. The most frequently involved mechanisms are: (*1*) deceleration; (*2*) hyperflexion; (*3*) hyperextension; (*4*) axial load, and (*5*) torsion. Frequently injuries are due to the combination of hyperflexion and axial load. Given the great mass of the head over the body, ''whiplash'' is a unique phenomenon in neck injuries. This phenomenon consists of the displacement of the head in the opposite direction to the impact, and then in the same direction, which causes great stress to the cervical vertebrae, possible fractures/facet dislocations, and compression fractures of the vertebral bodies. Major neurological impairment is commonly seen in children with no bone injury apparent on X-ray, known as SCIWORA (Spinal Cord Injury Without Radiological Abnormality) and the required spinal protection is not provided, worsening the functional prognosis and life prognosis of those affected.[26–28] Impact fractures (axial load), spiral fractures (torsional load), short and long diagonal fractures (lateral and axial load) are seen in the long bones of the limbs. Impact from firearm projectiles, principally high or ultrahigh velocity, cause comminuted fractures and major loss of bone tissue.[5,8,9]

Conclusions

Due to the economic, political and social conditions of today's world, acts of extreme violence are commonplace. The complex injury patterns encountered in victims of extreme acts of violence follow different injury mechanisms of high-energy transmission, which are often combined. Doctors must constantly update their skills in this area. Irrespective of the great importance of how these patients are approached clinically and the good prognosis rates that appropriate intervention can provide, the role of the physician in providing emotional support is essential in times when moral and humanitarian values are scarce.

Conflict of interests

The authors have no conflict of interests to declare.

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