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Fatal traumatic brain injury with electrical weapon falls

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ABSTRACT

Introduction: While generally reducing morbidity and mortality, electrical weapons have risks associated with their usage, including eye injuries and falls. With sufficient probe spread, an uncontrolled fall to the ground typically occurs along with the possibility of a fatal brain injury.
Methods: We analyzed possible risk factors including running and elevated surfaces with established head-injury criteria to estimate the risk of brain injury. We searched for cases of arrest-related or in-custody death, with TASER® electrical weapon usage where fall-induced injuries might have contributed to the death. We found 24 cases meeting our initial inclusion criteria of a fatal fall involving electronic control. We then excluded 5 cases as intentional jumps, leaving 19 cases of forced falls. Autopsy reports and other records were analyzed to determine which of these deaths were from brain injury caused by the fall.
Results: We found 16 probable cases of fatal brain injuries induced by electronic control from electrical weapons. Out of 3 million field uses, this gives a risk of 5.3 ± 2.6 PPM which is higher than the theoretical risk of electrocution. The mean age was 46 ± 14 years which is significantly greater that the age of the typical ARD (36 ± 10). Probe shots to the subject's back may present a higher risk of a fatal fall.
Conclusions: The use of electronic control presents a small but real risk of death from fatal traumatic brain injury. Increased age represents an independent risk factor for such fatalities.

1. Introduction

Arrest-related-death (ARD) is a well-recognized syndrome often with no clear single pathological mechanism or obvious anatomical or toxicological basis.[1,2] Annually there are about 800 000 arrests in which force is used in North America and approximately 800 ARDs yielding a mortality rate of about 1:1000 for a law-enforcement interaction associated with force.[3,4] About 80% of resistant subjects have co-morbidities of mental illness, drug abuse, or intoxication; the majority have at least 2 of these.[5]

The conducted electrical weapon (CEW) is involved in a minority of ARDs.[2,6] The largest manufacturer, TASER International, tracks the number of field uses based on sales and known usage patterns.[7] This is continuously updated on their website and reveals 2.98 million field uses as of January 2016 (https://www.taser.com/lives-saved). There have also been 1.95 million CEW training exposures for a total of ~5 million human CEW exposures.

Electronic control with the CEW has gained widespread acceptance as the preferred force option due to suspect injury reduction. Large prospective studies have consistently found suspect injury rate reductions of about 65%.[8,9] Of the 310 000 annual CEW field uses, only 1 in 3500 is involved in an ARD vs. the baseline ARD rate of 1:1000. This reduction in fatality rate is consistent with prospective published data, which showed that 5.4% of CEW uses "clearly prevented the use of lethal force by police."[10] It is also consistent with a 2/3 reduction in fatal police shootings where CEW usage is not overly restricted.[11]

The short-duration (50–100 μs) electrical pulses applied by TASER CEWs (see Fig. 1) are intended to stimulate type A-α motor neurons, which are the nerves that control skeletal muscle contraction, but with minimal risk of stimulating cardiac muscle. This typically leads to a loss of regional muscle control and can result in a fall to the ground to end a potentially violent

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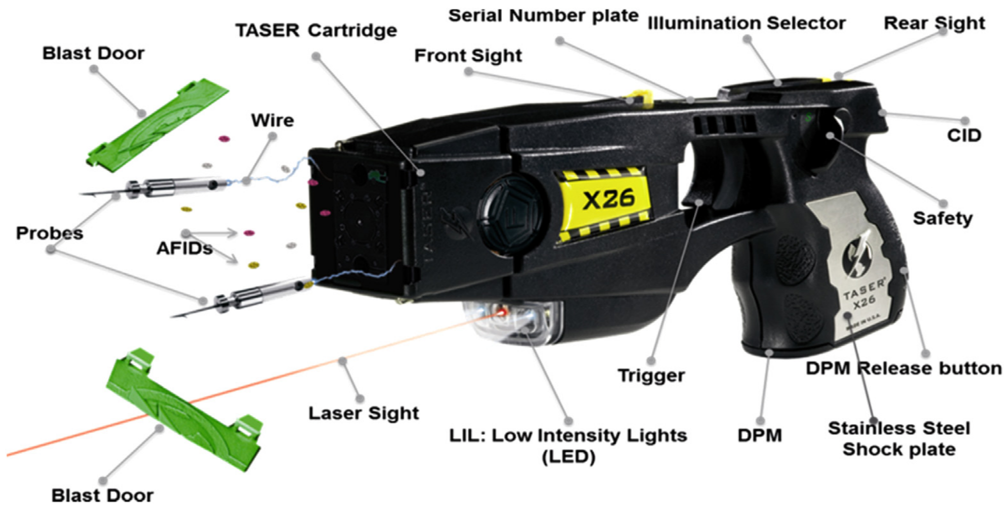

Fig. 1. X26 CEW during probe launch.

confrontation or suicide attempt.[12,13]

Electrical weapons are, after all, weapons and there are indeed risks associated with their usage, including eye injuries and falls. With sufficient probe spread (30 cm in the front or 20 cm in the back) an uncontrolled fall to the ground is possible.[12] The goal of our research was to analyze the risks of such falls from both analytical and epidemiological frameworks.

1.1. Biomechanics of head injury from a fall

The relationship between the physical parameters of a fall and the risk of life-threatening injuries is complex and influenced by many factors, such as the shape and material properties of the object impacted, the exact fall kinematics, the individual anatomy, and the biomechanical tolerance of various body tissues.

The most common relevant parameter is the head injury criterion (HIC), based on the resultant head linear acceleration (or deceleration) calculated with Eq. (1).

$$\mathrm{HIC} = \max\left\{ (t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right\} \tag{1}$$

where a(t) is the resultant head linear acceleration (as a function of time) and t_1 and t_2 define the time interval that maximizes the HIC. The duration, (t_2 - t_1) is typically taken as 36 ms or 15 ms and the corresponding HIC-values are referred to as HIC_{36} or HIC_{15}. Eq. (1) can be simplified as follows. Take the average deceleration to the 2.5 power and multiply times the exposure time. The probability of skull fracture (Abbreviated Injury Score ≥ 2) with a $HIC_{15} = 700$ is ~30% for a mid-size male.

The energy equivalent head impact velocity (EEV) is a meaningful reference comparison of biomechanical head loading and defined as the head impact velocity that results from a fall if the initial state of the body (the potential as well as the kinematic energy of the head) is transformed in an undamped fall. In a person initially standing still, it is the velocity of a free fall from the height of the head center-of-gravity. With walking, running, or riding a bicycle the EEV increases accordingly (see Fig. 2).

If a forward fall occurs with braced hip and knee joints (i.e. the whole body tilts rigidly), the actual head impact velocity is well approximated by the EEV. In case of free knee-joint landings, the subject falls first on the knees and the tilting movement then occurs from a lower position of the head (see Fig. 3); this leads to a slightly lower head impact velocity and injury risk. Hajiaghamemar found a minor reduction of both head impact velocity (6.5 ms^{-1} vs. 6.7 ms^{-1}, or 21 fps vs. 22 fps) and HIC_{15} (3300 vs. 4100) for forward falls with free vs. locked knee joints.[14] A much stronger effect was observed in backward falls, where free hip movement leads to an impact in the buttocks first and the head impact is the result of the following tilting movement of the torso (see Fig. 4). The difference between this scenario and a backward fall with stiff hips was dramatic, giving a head impact velocity of 4.9 ms^{-1} vs. 6.8 ms^{-1} (16 fps vs. 22 fps) and HIC_{15} of 1800 vs. 4100.

The biomechanical tolerance of different skull regions varies substantially. While some facial bones can fracture well below impact force levels of 3 kN, the calvarium is more stable and, at the occiput, forces well above 10 kN can be tolerated.[15–22] Forward falls have lower risks of life-threatening injuries compared to backward falls. A severe impact on the face causes fractures at moderate force levels resulting in energy absorption and a reduction of the resulting head acceleration similar to that seen with crush zones in an automobile body. The higher stability of the occiput region leads to higher accelerations and a higher risk of intracranial injuries (contre-coup contusions with subdural hematoma).

The head impact velocity in falls from a standing position can reach values exceeding 6 ms^{-1} (20 fps).[14,23] Such an impact on a hard surface can cause severe or life-threatening injuries even on flat ground. The EEV for a mid-size male (body height 1.75 m) for a fall from a standing position (locked joints) is ~5.7 ms^{-1} (19 fps). If the subjects runs or rides with a speed of 5 ms^{-1} (11 mph) and then falls, the EEV reaches ~7.5 ms^{-1} (25 fps). A fall from a standing position on a platform 3 m above the head impact location results in an EEV of ~9.5 ms^{-1} (31 fps). The ability to break the fall with coordinated arm movements prevents most fatalities from ground-level falls. Consistent with this, Thierauf et al. reported that the majority of fatal ground-level falls featured an alcohol-intoxicated subject.[24] Injuries from ground-level falls are most commonly to the skull vault while elevated-fall injuries tend to be found at the skull base or cervical vertebrae.[25]

2. Epidemiological data

2.1. Methods

The inclusion criteria for our study were: