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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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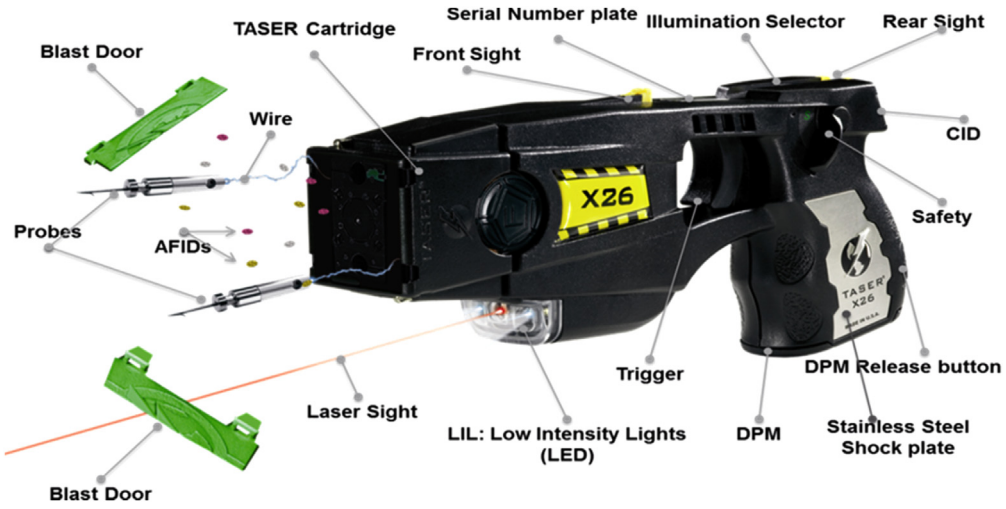

Fig. 1. X26 CEW during probe launch.

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).

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

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:

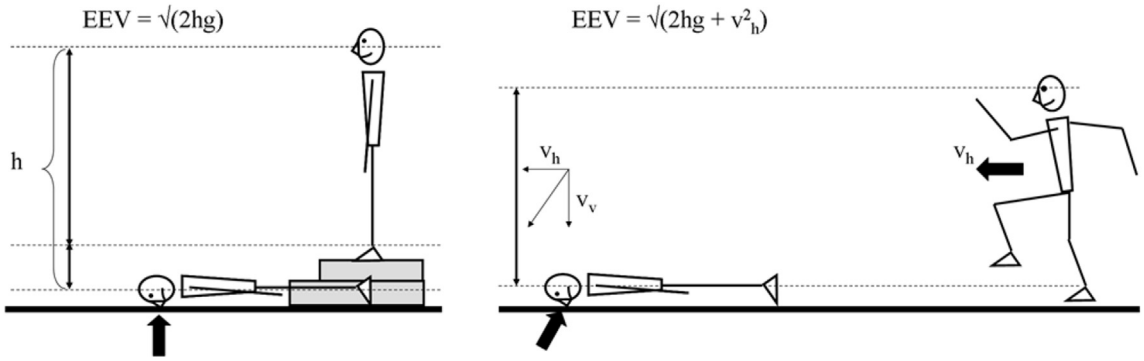

Fig. 2. Energy Equivalent Velocity (EEV) for head injury from standing or running.

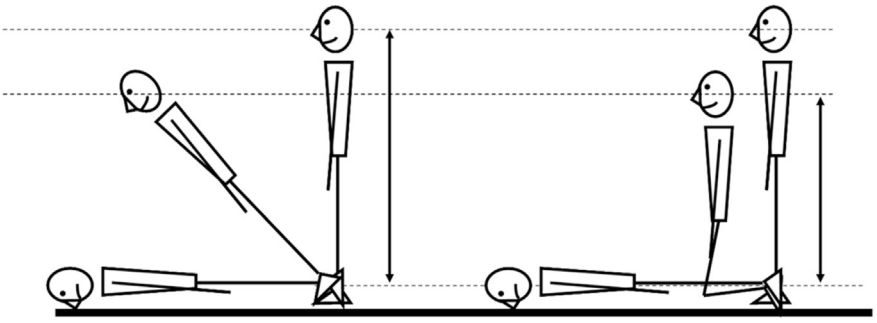

Fig. 3. Forward fall with locked (left) and flexed (right) knees.

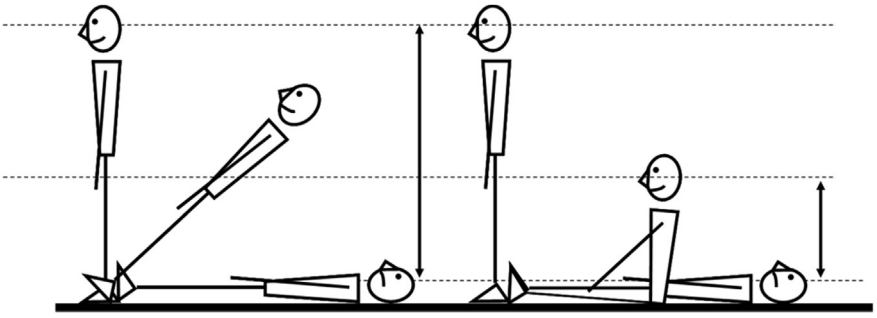

Fig. 4. Backward fall with locked (left) and flexed (right) hips.

1. Arrest-related or in-custody (post confinement) incident
2. Death
3. Electronic control was used in the relevant incident
4. Decedent fell during the incident and the fall was forced by the CEW
5. Traumatic brain injury (TBI) contributed to or caused the death

Co-author HEW maintains a database of worldwide CEW-proximate ARDs. It had 1030 cases (971 from USA) as of 1 Feb 2016. This ARD database has been cross-checked with the TASER International, Inc. internal ARD database and is continuously updated with Internet news scans. Due to the high level of media interest in ARDs, we feel that few, if any, cases are missing from this database. Autopsies and law-enforcement investigative reports are regularly requested and maintained. The HEW database has been used in previous peer-reviewed publications.

There were 5 exclusions for the fall not being forced by the CEW and 3 additional exclusions for the death not being caused by TBI.

2.2. Results: brief case summaries of 19 forced falls

Cases are listed from earliest incident. The Manner of Death and autopsy findings are given when available. See Table 1 for further details.

1. Officers responded to a disturbance call involving a man and his son but the father was intoxicated and uncooperative. As he walked away from officers toward the house, an officer fired a CEW, striking the man in the back, causing him to fall backwards and hit his head on concrete steps. The father was transported to the hospital where he died 3 days later.
2. A woman called police claiming that her ex-boyfriend was intoxicated and had assaulted her. When police arrived, the man was uncooperative and implored officers to shoot him. When he advanced on them, 2 officers fired their CEWs, each striking the man in the chest. The man fell backward and

Table 1
Cases analyzed.

#	Age	Race	Elevation	Posture	Impact surface	Head impact	Probes	Year	Fatal TBI?
1	55	W	BH	Walking	Concrete	Back	Back	2004	Prob
2	55	W	BH	Walking	Trailer park	Rear skull fracture	2 CEWs (4 probes) R & L chest	2007	Prob
3	59	W	BH	Standing?	Pavement	Back	Back	2007	Yes
4	39	H	BH	Running	Pavement	Face	Back	2007	Yes
5	49	W	BH	Walking	Concrete	Frontal and side impact	2 CEWs (4 probes) R back	2007	Yes
6	17	IC	BH	Standing	Pavement	Back	Front	2008	No
7	35	H	3 m	Standing	Concrete sidewalk		Front	2008	Prob
8	39	W	BH	Running	Curb	Face. Right forehead	Back	2009	No
9	42	H	BH	Running	Pavement	Right orbit	Front	2010	Yes
10	68	W	>BH	Standing in Trailer		Cervical fracture	Face	2011	No Cervical fracture
11	22	W	BH	Running	Pavement	Back	Back	2011	Prob
12	61	B	BH	Bicycle	Pavement	Back	Back	2011	Yes
13	57	B	BH	Standing	Jail floor	Back	Both arms	2012	Yes
14	32	H	BH	Standing	Pavement	Back?		2014	Prob
15	23	B	BH	Running	Street lamp pole	Left	Back?	2014	Yes
16	54	H	5 m	Standing	Sidewalk	Frontal and Top	Right arm	2014	Yes
17	57	O	BH	Standing	Pavement			2015	Prob
18	62	W	BH	Standing	Concrete	Back	Back	2015	Prob
19	33	B	2.5 m	Climbing			Back	2015	Prob

Note: Cases 6, 8, and 10 were excluded from statistical analysis as not being fall-induced traumatic brain injury. Case 11 was the only female. BH = Body Height. IC = Indigenous Canadian. Prob = most likely TBI but autopsy not available. A blank space represents an unknown datum.

struck his head on the ground. Following surgery for head injuries, he lapsed into a coma and died 2 days later.

3. Subject was attacking a woman in a pharmacy parking lot. The man remained agitated and refused to cooperate with police when they arrived. An officer deployed a CEW striking the man in the back. The man fell and hit his head on the pavement. He later died from his injuries in the hospital. Autopsy found craniocerebral trauma with subdural hematoma and his death was ruled an accident.
4. Sheriff's deputies attempted to arrest a parole violator on outstanding warrants, but he fled on foot down the street. During the chase, a deputy deployed a CEW, striking the man in the back and causing him to fall face down on the pavement. An ambulance took the man to a hospital where he refused medical treatment so deputies then took him to jail. The jail nurse ordered that the man be taken to a hospital 2 days later, where, about 5 h after arrival, he died from his fall injuries. Autopsy found multiple skull fractures and epidural and subdural hemorrhage. Tissues were positive for methamphetamine and amphetamine. His death was ruled a homicide.
5. Officers responded to a call of a man pounding on a neighbor's front door and making threats. When officers arrived, they found the intoxicated subject back at his own home. He came out on his front porch cursing and threatening the officers. When officers moved to arrest him, the man tried to walk back inside his front door where he claimed he had a weapon. Two officers simultaneously fired CEWs, both striking the man in his back. He fell backward, striking his head on the concrete porch. He did not immediately appear to have any injuries, but, as a precaution, an ambulance took him to a local hospital. He died early the next morning. Autopsy found subdural hematoma and temporal lobe contusions. His death was ruled a homicide.
6. Police received a call of a man who had tried to break into an automobile, but who then ran 1500 m after the vehicle's owner confronted him. Officers then found the man carrying a knife but he refused orders to drop the knife. An officer discharged a CEW causing the man to fall backwards and strike his head on the sidewalk. He was bleeding from the head wound and never regained consciousness. Emergency services was called for the bleeding and he was taken to a hospital where he died. The autopsy found no skull fracture or intracranial hemorrhage. The initial autopsy report listed a hamartoma of mature cardiac myocytes (which is known to be very arrhythmogenic). Toxicological analysis revealed a blood alcohol concentration of 0.18% along with tetrahydrocannabinol and its metabolites. The chief medical examiner later changed the cause of death to electrocution from the CEW. No molecular autopsy was performed for channelopathy risk. Inquest expert testimony opined that the cause of death was stress-induced ventricular fibrillation along with a possible channelopathy.
7. Officer received calls of a naked man standing on the ledge of a building, screaming at passersby, and swinging a long florescent tube. When they arrived, officers found the emotionally disturbed man on a 2nd story ledge. When efforts to talk the man into coming down from the ledge failed, an officer fired a CEW at him, causing him to fall head first onto the sidewalk about 3 m below his feet for a ~5 m fall for his head. He suffered an obvious head injury and died soon thereafter. The autopsy report was not released but media reports suggested that the autopsy was inconclusive. https://www.youtube.com/watch?v=Sg5RVq4m8xg
8. Officers confronted a man with bipolar disorder who had sexually harassed a female clerk at a gasoline station. When they asked for his identification in the parking area, he knocked both officers to the ground and ran at the clerk, who was now standing outside in front of the station. An officer deployed his CEW, which struck the man in the back and caused him to fall face-first onto a curb. When officers completed handcuffing him, they realized the man was not breathing and resuscitation efforts were unsuccessful. The autopsy found bilateral fractures of the orbital plates, with extensive right retrobulbar hemorrhage and concluded that death was due to posttraumatic concussion. His death was ruled an accident. The conclusion of forensic pathologist co-author CVW was different. He noted a lack of intracranial injury along with a history of bipolar disorder and sudden loss of vital signs, after being handcuffed, which is typical for an excited delirium death.
9. During a routine traffic stop, the driver struck the deputy and fled on foot. The deputy caught up to the man and deployed a CEW hitting the man in the chest. The man fell face-down

onto the pavement. After handcuffing him, the deputy noticed the man was in an altered mental state. An ambulance transported him to the hospital, but, despite surgery, he died the next morning. Autopsy found frontal skull fractures and subdural hemorrhage. His death was ruled a homicide.

10. An elderly man (age 68) was involved in a disturbance with his landlord. When police arrived, the man had locked himself in a trailer and refused to come out. Believing he was armed, officers cut into the trailer. One officer fired a CEW at the man, hitting him in the face and causing the man to fall and injure his neck. An ambulance transported him to a hospital where he died from complications of his injuries 7 days later. Media reported that the autopsy found the cause of death to be "spinal cord injury due to cervical spine fractures due to blunt face and neck injury."
11. A state highway officer arrested a woman for fleeing the scenes of 2 separate collisions within an hour. When he took her out of his patrol vehicle at the station, she ran. The officer deployed a CEW striking the woman in the back while she was still handcuffed, causing her to fall head-first onto the pavement. She was taken to a hospital where she remained in a coma until she died 725 days later. No autopsy was performed. As seen on the video, the escapee was running and the horizontal velocity increased the resulting head impact velocity; the feet and the buttocks decelerated rapidly on the tarmac. Because of the friction, the inertia caused a rotation of the upper body and head. She was initially higher than the head impact location (running down a slight slope) and the fall was uncontrolled as no self-protection measures can be observed. The tarmac is extremely hard and the impact in the occipital region (the woman spun as she fell) resulted in very high linear accelerations of the head. Brain contusions (more pronounced in frontal region than the occipital), subdural hematoma and skull fracture are expected but no autopsy was performed. https://www.youtube.com/watch?v=mpV7qqhxZ_4
12. While investigating a citizen report about an intoxicated man on a bicycle, an officer observed an elderly (age 61) man pedaling down the street and putting something into his mouth. When the man refused to stop, the officer got out of his vehicle and deployed a CEW to the man's back, causing him to fall from the bicycle and hit his head on the pavement. The man, who had a history of seizures and a craniotomy, died the next day. According to media reports, the autopsy found the cause of death to be blunt force trauma to the head.
13. A county jail inmate was in a fight and a jailer applied a CEW to him. The man fell backward onto the floor, striking his head. The jail nurse initially treated him for a small cut to his head, but 90 min later he was transported to a local hospital where he died 4 days later. Autopsy found subdural and subarachnoid hemorrhage.
14. When police conducted a routine traffic stop, the driver exited the vehicle and ran. One officer deployed a CEW, causing the man to fall backward onto the ground. Whether he hit his head, during the fall, is in dispute. Other officers arrived and used additional force to get the man into custody. The officers took the man to a local hospital where he spent 5 days before his release. After 7 days, he complained of severe headaches and returned to the hospital where he died of head injuries after an additional 5-day stay. Cause of death was blunt craniocerebral trauma.
15. An officer deployed a CEW on a shoplifting suspect who had fled the store. The man fell to the ground, but he got up and tried to flee again. The officer again applied the CEW, and the man fell forward striking the left side of his head on a light pole. The man was unconscious when he arrived at the hospital via ambulance. He never regained consciousness, and he died from his injuries 13 days later. Autopsy found multiple cerebral contusions. His death was ruled an accident.
16. A mentally ill man climbed atop a billboard and was threatening to jump off. When responding officers failed to talk him down, they called for SWAT officers. When SWAT officers arrived, the man climbed down from the billboard onto the roof of a building. As officers approached him, however, he began to again climb a ladder back up to the billboard. An officer deployed his CEW with a probe striking him in the right arm. (The other probe injury was not located at autopsy.) The man fell from the ladder and then fell head-first onto the sidewalk, missing the airbag rescue teams had placed for him. He was transported to a hospital where he died. Autopsy found skull fracture and subdural hematoma. Tissues were positive for cocaine and cocaine metabolite. His death was ruled an accident.
17. Police received calls about a group of people fighting with weapons in the parking lot of an auto body shop. Police found a man wielding a crowbar. When he refused orders to drop the crowbar, an officer deployed a CEW. The man fell to the ground striking his head on the pavement. He was transported to a hospital where he had surgery for a head injury, but his condition deteriorated, and he died 2 days later. Autopsy was not released: however, the death certificate gave a cause of death as blunt force craniocerebral trauma. His death was ruled a homicide.
18. Police received a call from an elderly (age 62) man who reported a disturbance with his son. He told dispatchers that he had a gun and had already fired 3 rounds. When officers arrived, they confronted the man, who refused to comply with their orders to get on the ground. An officer deployed a CEW into the man's back, causing him to hit the back of his head when he fell to the concrete driveway. He was treated and released from a hospital for the laceration to his head. However, he died 8 days later from complications of injuries sustained in the fall. According to litigation filings, the autopsy found the cause of death to be "blunt force head trauma."
19. When officers stopped a vehicle, a passenger jumped out of the vehicle and fled on foot. Officers gave chase and found the man trying to climb a cement wall behind a business. An officer deployed a CEW, striking the man in the back, and causing him to fall head-first from the 2.5 m wall. He was transported by ambulance to a hospital where he died. According to media reports, the autopsy found the cause of death was "head and neck trauma resulting from the fall."

2.3. Results: analysis

We found 24 initial cases from screening for fatal falls involving electronic control. See Fig. 5 for classification details. Based on the investigative reports and autopsies, we classified 5 cases as "intentional" as they were either suicides or escape attempts. These cases are summarized in the Appendix and will not be analyzed here.

For the 19 "forced" falls, we obtained 11 full autopsy reports and 5 autopsy summaries from litigation filings, police reports, a death certificate, or news accounts directly quoting from the report. Of the remaining 3 cases there were 2 cases (#1 and 2) with sufficient incident detail from litigation filings, police reports, or news

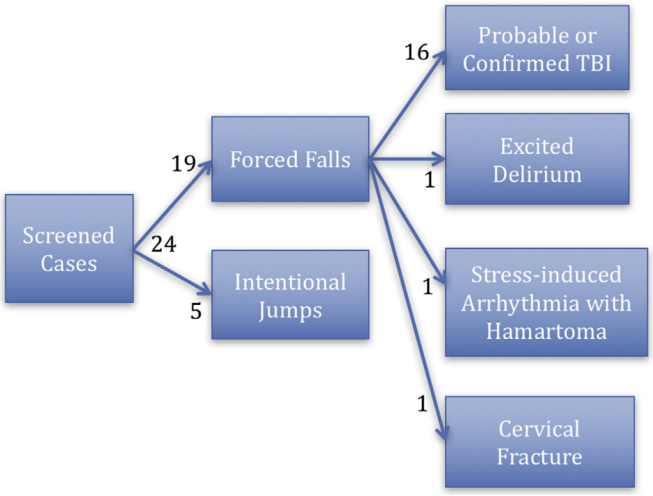

Fig. 5. Case report processing flowchart.

accounts to support a classification of an electrical-weapon forced fall. Case #11 did not receive an autopsy but her highly-publicized case has no causal controversy and is well-supported by a lengthy incident video.

Of the 19 forced-fall cases, we excluded another 3 as not being due to TBI. Subject #6 fell backwards onto pavement and was immediately bleeding from a laceration. Even though he never regained consciousness, he had no brain injuries at autopsy. The inquest consensus was that this was a stress-induced cardiac arrhythmia in a subject with a proarrhythmic cardiomyopathy (hamartoma), high alcohol levels, and a possible channelopathy. The primary acute stressors were probably running 1500 m, fear of arrest, electrical shock from the CEW, and the traumatic shock of the head impact. In a sense, one could argue that the external head injury, therefore, contributed to the death. We found this hypothesis tenuous and did not classify him as a fall-induced death.

The forensic pathologist co-author (CVW) disagreed with the original medical examiner cause of death (TBI from the fall) in case #8 as the subject had only orbital fractures without any intracranial injury. Subject #10 died from a cervical fracture and, thus, TBI (if any) was not considered to be a contributor to his death. Thus, we excluded cases #6, 8, and 10 from our statistical analysis.

We found 16 cases of fatal TBI from falls most likely forced by electronic control. Out of 3 million field uses, this gives a risk of 5.3 ± 2.6 PPM. The mean age was 46 ± 14 years which is significantly greater than the age of the typical ARD. Strote reported a mean age of 35.6 (median 36), Stratton reported 32.1 ± 6.4 years, and Ho reported 35.7 ± 9.8 years.[6,26,27] ($p = 0.0002$ vs. Ho with $n = 162$).[6] There were 6 whites, 5 Hispanics, 4 blacks, and 1 South Asian in our series.

Only 3 were elevated in any way. Case #7 was standing on a 2nd floor ledge (3 m), #16 was on a rooftop (5 m) and #19 was climbing over a 2.5 m concrete wall. Thus 13 of the cases had no elevation.

Only 5 subjects were moving rapidly. Case #12 was riding a bicycle while 4 others were running. Only 3 subjects were walking while 8 were either standing or climbing. Of the 16 cases, 6 suspects were fleeing police and were not armed. Taking police and media reports as accurate, 5 subjects were armed and 6 represented a threat to themselves, police or another party.

Probe locations were known for 14 of the 16 included cases. They were in the back for 9 of these 14 cases. Bozeman reported that 37% (628/1703) of CEW probes land in the back.[28] This difference was barely statistically different from our 9/14 fraction ($p = 0.034$ by Chi-square) suggesting a possibly increased mortality risk with probe deployments to the back. However, Bozeman published his data in 2009, the same year that the major manufacturer modified their training suggestions to encourage more back deployments.[29] This confounding variable mitigates against any conclusions regarding probe-deployment locations.

3. Discussion

We believe that this paper represents the first methodical analysis of the death risk from falls induced by electronic control. Fox and Payne-James first reported that the majority of "definite or probable" deaths strongly associated with electronic control were the 8 cases of fatal falls that they found.[30] Mangus reported 2 serious non-fatal head injuries from CEW deployments: (1) basilar skull fracture, right subarachnoid hemorrhage, and left-sided epidural hemorrhage necessitating craniotomy and (2) a concussion, facial laceration, comminuted nasal fracture, and orbital floor fracture.[31]

The warnings of the largest CEW manufacturer appear to be consistent with our results. They warn against use on elevated subjects; we found 3 such deaths. They warn against use on running or bicycling subjects; we found 5 such subjects. With hindsight, one could say that strictly following these warnings could have prevented 8 of the 16 fatalities, which is ½ of the cases. Such utopian reasoning, of course, does not suggest a viable control alternative for the officer at the time of the incident.

The unexpected finding was the increased age for the subjects. This is consistent with other studies finding that the mortality risk from head injury increases with age.[32,33]

Due to the CEW using an electrical current, the primary concern in the media and some peer-reviewed literature has been the possibility of electrocution. There have been 12 published case reports suggesting a potential cardiac arrest link giving an incidence of 4 PPM.[34–39] Such assertions have always been made without mention (or apparent consideration) of the relatively low outputs of these devices. CEW pulses deliver <110 microcoulombs of charge, far less than that required for transcutaneous pacing, making any cardiac effects (much less VF) highly unlikely.[40,41] Low average CEW currents of <2 mA are comparable to TENS pain-blocking units.[42] CEWs deliver < 2 W of power, which can be contrasted with the 100 W used in internal cardiac RF ablation and the 2.5 W IEC limit for electric fences.[43] In fact, current CEWs satisfy all relevant electrical safety standards including those for the electric fence.[44,45] None of the published electrocution-alleging case reports have stood up to careful scrutiny.[46] It appears that the risk of a fatal head or neck injury far exceeds the hypothetical risk of electrocution which has been estimated at ~ 0.3 PPM.[47]

4. Limitations

A prospective experimental study would generate superior data compared to our retrospective data. However, an experiment — designed to cause people to fall to determine what injuries or fatalities can be generated — would have difficulty obtaining ethical approvals.

There is no national database that records data in such incidents, so secondary sources are the only sources of information available to identify the relevant cases. When primary sources of data, such as autopsy reports, were available, we used them. However, autopsy and police reports are not available in all states, depending on each state's public information laws. Police reports, autopsy reports, and news accounts are also subject to bias.

We also note that the sampling frame is less rigorous than we would prefer. However, there is no practical alternative. We spent

significant time searching open records sources trying to identify cases for this study. We limited our examination to those cases when the electrical weapon caused someone to fall, and that fall resulted in a fatality. Those instances are rare, but they are critically important to understanding the risks of using such weapons. Medical records are not available to us to study the effects of this force on people who suffered non-fatal injuries, and the effects on people — who did not fall — add nothing to the understanding of the risks of fatal falls once the rate is calculated, as we did.

5. Conclusions

The use of electronic control presents a small (5.3 ± 2.6 PPM) but real risk of death from fatal traumatic brain injury. This risk exceeds the theoretical risk of electrocution. Increased age represents an independent risk factor for such fatalities.

Disclosures

MWK & CVW have been expert witnesses in law-enforcement litigation. MWK is a member of the TASER corporate and scientific advisory board who partially funded this work. HEW is a retired Police Chief.

Appendix. Excluded cases

These cases were judged to involve intentional jumps, either for escape or suicide. The CEW was not judged to have caused the fall.

1. Officers received a call of a naked man behaving bizarrely at an apartment building. When officers arrived, they found a 26-year-old man climbing on the balconies of the apartment building, jumping from balcony to balcony. The man broke a window to an apartment and began stabbing himself in the thigh with a shard of glass. An officer attempted to use a CEW to subdue the man, but it appeared to have no effect. The man then either jumped or fell from a 4th floor balcony to the sidewalk below. He was taken to a hospital where he died the next day from a closed head injury. Autopsy found numerous cranial and skull injuries along with methamphetamine. His death was ruled an accident.
2. Police received a call of a man running in and out of traffic. When officers arrived, they found a 35-year-old man sitting on the wall of a highway overpass threatening to jump. For 3 h police tried to talk the man down from the wall. When negotiations broke down, an officer tried to subdue the man with a CEW. The attempt failed, and the man jumped about 30 m to the pavement below and died at the scene. Autopsy found multiple internal and external injuries with no TASER probes penetrating the skin. His death was ruled a suicide.
3. Police received a call of a suicidal man threatening to jump from a bridge. Police arrived and found a 28-year-old man standing on the bridge edge. The officers spent about 20 h negotiating with the man. When the man stepped away from the edge of the bridge, an officer attempted to subdue him with a CEW, but the CEW did not disable the man. Instead, he jumped over the railing and died when he hit the rocks below.
4. Officers went to the home of a 21-year-old man to arrest him on warrants. As the officers approached him, the man dove through a closed 2nd story window. To prevent his escape, an officer deployed a CEW, striking him in the back as he was diving through the window. The probes were only 6 cm apart and thus achieved no muscle control. He struck his head on the pavement below and died 4 days later. The autopsy was not released, but litigation allegations cited multiple skull fractures and brain injury. An appeals-court decision noted that the death was due to "massive brain trauma."
5. Police had been searching for a suspect in a murder. They found him perched on a boulder on a cliff. They negotiated with the 34-year-old man for 3 h. Police tried to subdue the man with less-lethal munitions and a CEW. Their efforts failed, and the man jumped to the ground 14 m below. He died at the scene.

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