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Health-related outcomes and recommendations for a trial phase with Conducted Electrical Weapon as a forcible mean in the Danish Police

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Content

CONCLUSION

This report, based on a review of original articles, provides support for a low risk of serious adverse events in the use of conducted electrical weapons (CEW) in a population of healthy individuals. Tactical guidelines on when and how to use CEW paired with a medical follow up of each case subjected to a shock from CEW will likely contribute to minimize the risks.

Health risks, even deaths, are described following shocks from CEW. These risks are not possible to quantify, and it is difficult to establish causality with shocks from CEW. Those risks associated with CEW need to be contrasted to the risks associated with other forcible means, such as OC-spray, baton, and weapons with live ammunition, as well as to the situation itself. These are tactical considerations regulated by the Danish Police Act §§ 15 and 16 and are beyond the scope of this report.

We recommend surveillance of health risks during the trial phase. An expert panel should be commissioned by the Danish Police, instructed to continuously monitor the project with the aim to adjust guidelines, investigate potential adverse events and communicate recommendations to the leadership of the trial phase. The expert panel should without delay have access to material, including hospital charts, needed to assess health-related issues.

Recommendations

In this section we present recommendations for using a CEW, and recommendations for medical follow-up for subjects exposed to CEW. These recommendations need to be included in tactical considerations, such as risks associated with use of other forcible means, taking into account the Danish Police's overall framework for the use of forcible means as described in Police Act §§ 15 and 16, which states that; police officers are entitled to use force to the extent that it is necessary, justifiable, and proportionate and use of force must be used as moderate as the circumstances allow, so that any damage to heath is limited to a minimum.

Aim to:
hit the lower part of the body.
avoid placing darts on the chest in such a way that the heart is interposed between the darts.
avoid locating darts in close proximity of the heart.
avoid hitting the upper body, especially face, neck, and testis.
if darts located in a sensitive[¤] body part, if possible, avoid activating shock.
do not extract darts in a sensitive part of the body.
if the dart is hard to extract, do not force. Provide medical expertise.
keep number of pulses (shocks) low, preferably one pulse.
avoid shocking a subject with several CEW simultaneously.

Avoid using CEW:
on children, pregnant women, and elderly.
on subjects with an electronic implantable device such as pacemaker[&].
on subject with severe illness, especially cardiac related illness.
on subjects with severe obesity.
on intoxicated subjects.
on severely agitated subjects.
if it in the situation could be dangerous to lose the ability to voluntary movements e.g. risk of falling from heights, drowning if in water, or being hit by oncoming traffic or in proximity of flammable substances.

Recommendations for medical evaluation after exposure to CEW

If the subject is evaluated to need health care, the police shall offer acute medical care and emergency medical personnel shall be called[*].

If the subject is assessed as unaffected the subject shall be offered a medical checkup at an emergency department[#].

Long terms effects should be evaluated in accordance with a previous report from the Department of Forensic Medicine.

[¤] *Sensitive parts of the body are defined as face including eyes, throat/neck, and testis.*
[&] *Electronical implantable devices such as pacemaker, implantable cardioverter defibrillator (ICD), insulin pump, deep brain stimulation and other.*
[*] *If cardiac dysrhythmia has occurred it could be of benefit that there are cardiac defibrillators in the police car.*
[#] *Including a medical checkup of the cardiovascular- and respiratory system, an electrocardiogram, blood samples focusing on potential acid-base disturbances, muscle cell integrity and cardiac cell injuries. Blood samples for lactate, troponin, myoglobin shall be included. Any sign of blunt force trauma, especially head or spine injuries needs to be checked, as well as potential wounds after the darts. The medical check-up shall also be guided by routines at the hospital.*

SUMMARY OF RESULTS CORRELATED TO AIMS

This report has focused on answering three questions of relevance for the trial phase with CEW in the Danish Police:

A. What adverse events (injuries and/or illnesses) could arise in individuals shot by CEW?

Cardiac dysrhythmias, including fatal cardiac dysrhythmias, are observed after shock from CEW. Animal studies and computational/theoretical models produces somewhat contradictory results in the risk of eliciting cardiac dysrhythmias with the use of CEW. The risk for fatal cardiac dysrhythmias cannot size wise be estimated but seems to be low in a population of healthy individuals without complicating factors such as severe physical agitation, drugs, illness, cardiac disease, pacemaker/ICD or other implantable electrical devices and possible gross obesity. Other groups in which the knowledge of CEW effects is low is children, elderly, and pregnant women.

The electrical stimulation has also been described to cause such forceful muscle contractions that fractures in the spine has occurred. The prevalence of these adverse events cannot be size wise evaluated, but the risk seems to be low and dependent on the location of the darts. Also, if a dart hits a sensitive area of the body serious injury with risks for life-long debilitation, such as blindness, can occur. Sensitive body parts identified in case reports are the eye, throat/neck, and testis but to some extent also the head and torso.

There is a risk of injuries in falls following the muscle incapacitation caused by shock from a CEW. Observed injuries range from abrasions and hematomas to life-threatening intracranial injuries. The muscle incapacitation gives rise to tactical considerations such as the risk of drowning if the subject is in proximity of water or the risk of falling down stairs, of ledges or out in traffic. CEW has also been described to being able to ignite flammable substances giving rise to burn injuries.

B. How can adverse events be prevented (tactical considerations)?

To minimize risks with CEW it is advised against general use of CEW on children, pregnant women, and elderly as well as persons with complicating factors such as cardiac disease, having pacemaker/ICD or another electrical implantable device. Furthermore, the use of CEW on subjects with severe agitation, being under the influence of drugs, having other illnesses as well as possibly gross obesity, requires tactically aware decisions. It is advised against giving shocks if the darts is placed in such a way on the torso that the heart is in-between, as well as if a dart is placed in close proximity of the heart. Moreover, the number of shocks should be as few and as short as possible. It could be considered to deploy cardiac defibrillators with each patrol car carrying a CEW, in the case that a potentially fatal cardiac dysrhythmia ensues after shock with a CEW.

To avoid injuries caused by the dart it should be avoided to hit sensitive parts of the body such as the eye, throat/neck, and testis but to some extent also the head and torso. If a dart is lodged in a sensitive body part, it is recommended, if possible, not to use electric shock as this might worsen the tissue damage due to heat effects. If darts are not easily removed or lodged in a sensitive body area, it is recommended that they are removed by professional medical personnel.

We recommend tactical guidelines on when and how to use the CEW. Tactical considerations should include assessments of health-related risks using other forcible means as well as contextual risks. In producing such guidelines, the expertise at the Department of Forensic Medicine is available for expert advice in health-related issues.

C. What medical follow up is advised for subjects shot by a CEW?

Based on the observed health-related consequences of CEW it is advisable that a subject shot by a CEW is offered a medical check-up at an emergency department as soon as possible. The examination should focus on the cardiovascular system, acid-base disturbances, muscle cell integrity, blunt force trauma after a fall and wounds caused by the darts. If darts are left in the body these should be removed. We recommend that for each case an electrocardiogram is taken, a blood sample is drawn and analyzed for lactate, troponin, and myoglobin. Any injuries should be documented. The cardiovascular and respiratory system should be examined. Other investigations should be performed according to the discretion of the medical professional.

To strengthen the knowledge on of the use of CEW in the Danish Police the Department for Forensic Medicine have previously recommended an evaluation of the trial phase to gain further knowledge on short- and long-term health effects.

INTRODUCTION

A conductive electrical weapon (CEW) is characterized as a less-lethal weapon. The operator fires darts that attaches to the body, and by wires attached to those darts electricity is delivered into the body. The pulse characteristics should be sufficient to pacify an individual temporarily by making it impossible/hard to voluntarily control muscles. Although considered less lethal compared to weapons with live ammunition, health risks are described to be associated with the use of CEW. Those risks need to be evaluated against the benefits of CEW and contrasted against risks associated with other uses of forces, such as baton, OC-spray and weapons with live ammunition. This report is commissioned by the Danish Police to increase the knowledge on health effects of CEW to be applied in guiding a trial phase of CEW as a forcible mean in the Danish Police.
The report was commissioned with the aim to answer the following questions:

A. What adverse events (injuries and/or illnesses) could arise in individuals shot by CEW?
B. How can such adverse events be prevented (tactical considerations)?
C. What medical follow up is advised for subjects shot by a CEW?

Tactical considerations generated by this report are left to the Danish Police. As such tactical considerations needs to consider both health effects and the framework on use of force described in the Police Act (Politiloven) §§ 15 and 16 stating that:

1. Police officers are entitled to use force to the extent that is necessary, justifiable, and proportionate.
2. Use of force must be as moderate as the circumstances allow, so that any injury to health is limited to a minimum.

Previously the working group on CEW at the Department of Forensic Medicine were asked to compare two models of CEW, Taser 7 and Taser 10, from a health perspective. The main conclusion is that there does not seem to be any scientific evidence that suggests that the TASER 10 model carries a larger risk for adverse health outcomes compared to the TASER 7 *(Health related considerations when choosing between Taser 7 and Taser 10).*
The working group on CEW at the Department of Forensic Medicine provides expert assessments on the health-related issues of CEW and provides recommendations for the trial phase initiate. The working group has had no mandate in the decision to initiate a trial phase using CEW in the Danish Police force.

METHODS

Literature search

A literature search using PubMed (scientific database on biomedical and life science topics) was conducted. Initially using words such as *TASER*, *conducted electrical weapon*, *electronic control weapon* and *less-lethal weapon*. The reference lists of identified articles were screened, and eligible synonyms were included in the final search strategy (Supplement 1). The conclusive search was conducted on 28th of September 2023. The search retrieved 2135 studies.

These studies were screened on title and abstract for inclusion, leaving 380 studies eligible for full text screening in agreement with inclusion and exclusion criteria, see table 1.

Table 1: Inclusion and exclusion criteria for the articles identified in the search in the PubMed database.

Parameters	**Inclusion criteria**	**Exclusion criteria**
Study population	Human, animals, phantoms	None
Study topic	Health-related consequences of CEW Electrophysiological characteristics (including the characteristics of the pulse) Care of tased individuals in emergency settings	Electrophysiological characteristics with no relevance to health effects
Study type	Case reports Experimental studies Observational studies	Letters to editor, narrative reports, commentaries, editorials, descriptive autopsy reports, reviews not adding evidence to the question at hand nor including new data
Study language	English	Other languages than English
Study time frame	None	None

Finally, 162 studies remained for data extraction. These studies were categorized into case reports, experimental human studies, observational human studies, experimental animal studies and theoretical experiments.

Weaknesses

PubMed was the only database screened for relevant articles, as well as we did not screen references of included papers. Most of the articles is concerned with older models of CEW, such as the Taser X26. None of the scientifically published articles concerned specifically Taser 10.
Some of the effects of CEW is associated with pulse characteristics that may vary across models, the representativeness of an experiment or an observation to another CEW, such as the Taser 7 or Taser 10, is hard to assess but it is presumed that the development of the pulse characteristics has progressed in such a way that risks for dysrhythmia are either similar or reduced. On the other hand, since the kinetic energy is larger in the Taser 10 compared to the previous model (Taser 7), this might not be reflected in the identified studies. Some studies are performed by researchers affiliated with companies with financial interests in CEW.
This report has not focused on the drive stun mode (not using the darts) and we have not compared health-related consequences of other forcible means such as baton, OC-spray or weapons with live ammunition.

RESULTS

In the following the literature is presented according to study methodology: epidemiological observations in larger populations, case reports, human experiments, animal models and theoretical computational models. The different types of study methodology vary in strengths and weaknesses, which in brief is discussed as an introduction to each section.

Observations on CEW use in larger populations

Epidemiological observations are valid when drawing conclusions on the consequences of using CEW in operational police work in an unselected population, i.e. the prevalences of adverse outcomes are reflected.

Main findings

We identified 9 epidemiological studies with varying subject size (n=49 to n=2452). CEW exposure was observed to cause minor injuries such as puncture wounds and burns, mild to moderate injuries related to blunt force traumas after fall such as hematomas, abrasions, and fractures, and moderate to severe injuries/illnesses such as head injuries caused by fall, muscle cell injuries (rhabdomyolysis) and cardiac arrest. Death in the proximity to CEW exposure has also been described, in one study the CEW exposure was assessed as being either a potential or a contributory cause of death in 10 cases. To establish causality between deaths and CEW exposure is difficult because of co-association with drug use, severe agitation and preexisting cardiovascular disease.

Results

In a consecutive case-series (n = 1201) subjected to CEW, including drive stun mode (n=388), three cases (0.25 %) suffered moderate or severe injuries such as head injuries after falls and muscle cell injuries (rhabdomyolysis). No death ascribed to the CEW was observed, but two deaths (cases with agitation, drugs, and cardiac disease) occurred and were attributed excited delirium. In 178 cases the darts were located with the heart in the path of the current, no event of cardiac dysrhythmia was observed though.

In a consecutive case-series (n = 100) of minors (< 18 years) no major injuries were observed, but there were 20 cases with mild injuries such as puncture wounds following the darts, superficial abrasions, minor lacerations, and nose bleeds. There were five cases in which the cardiac rhythm was analyzed using electrocardiogram (ECG), one case had a fast cardiac rhythm that was later normalized.

In a case-series of non-fatal CEW associated injuries (n=816) it was observed that injuries were mostly puncture wounds, contusions/abrasions, foreign bodies (not specified, but presumably lodged darts), and lacerations. Of these 3.1 % were treated for chest pain or a heart condition following a shock.

In a study that focused on deaths occurring in a context in which CEW had been used (information on 37 cases out of 75 identified cases), it was reported that at autopsy 54.1 % (n=20) had cardiovascular disease, 75.7 % (n=28) were assessed as having the diagnosis excited delirium, and illegal substances were detected in 78.4 % (n=29). The use of CEW was assessed as a potential cause of death in three cases (8.1 %) and a contributory cause of death in six cases (16.2 %).

In a US population of in-custody deaths (n =77) occurring in association with the use of CEW, it was observed that in 18 cases (23.4 %) only drive stun mode was applied. The median exposure time of the shock period in projectile (dart) mode was 20 s. However, in the study there was no assessment as to whether the deaths were caused by the CEW, or by other factors. The authors conclude that since some deaths were noted in those only exposed to the drive stun mode, this lend support to that other factors besides CEW use are at play.

A study set at the emergency department at a hospital in Los Angeles between 1980 and 1985 registered all patients (n=218) seeking medical care after being shot with CEW. It was observed that many patients had used illicit substance the same day as being shocked by CEW, and in line with this a large proportion tested positive for drugs and/or alcohol. Three patients died in this cohort, all of which had high levels of PCP (phencyclidine, hallucinogenic drug) that was assessed as the cause of death, of these one had preexisting heart disease. Complications such as cellular muscle damage (rhabdomyolysis) was noted in 1 % of the cases, however it could not be determined if it was due to PCP use or the effect of muscular damage due to electricity. Moreover, 45 % of patients received tetanus prophylaxis to avoid wound complications.

A large database in US were sampled for cases exposed to CEW that involved emergency medical services and in which the darts needed removal (n=648). One case of cardiac arrest (0.2%) was observed, in contrast the most common complaints were burns (29.9 %) and traumatic injuries (16.1 %). It is also stated that fire and flames was the main cause of injury. In the study, the context of these injuries is not reported, but it is described that it might be an issue with how such complaints are registered.

Using a register kept by the company producing the CEW named Axon Enterprise, Inc. and in which police authorities voluntarily reports instances in which a CEW is used, it was observed that

in 23.1 % (n=2452) of these instances the subject could be classified as mentally ill. Using the database kept by the company to study registrations for the period December 1999 to 2002, 2016 entries were identified (both officers and cases). Among cases it seems as if 1.7 % had moderately severe injuries, with reservations for interpretation of the data (by the authors of the current report).
In a US cohort study including 233 cases subjected to CEW by police, it was observed that one death was caused by CEW. The information around this case is sparse, but it seems like the subject was shocked twice, died on the way to hospital and was under the influence of stimulants. In 35.2 % of the cases drugs were confirmed present and individuals with mental illness were shocked more times than cases without such a diagnosis.
In a case-series in which 49 persons between 2006 and 2011 attended an emergency department with CEW associated injuries it was noted that most injuries were related to a fall and consisted of fractures, hematomas, and abrasions. No fatalities or cases with cardiac dysrhythmia or with serious respiratory symptoms was observed.

Observed associations with fatal outcome

The following information is a compilation of those cases, also mentioned in the previous section, that died in association with being subjected to CEW.
Two studies, that we presume reported on the same 2 deaths, noted that one subject died after 2 CEW discharges were applied, the subject had a high body mass index, had a prolonged struggle with the police and was observed to collapse 20 minutes after CEW exposure. At autopsy preexisting cardiac diseased was observed. The other case was agitated, exposed to OC-spray and two CEW were used after an extensive struggle, and he was restrained in prone position and collapsed 5 minutes after CEW use. At autopsy olanzapine (antipsychotic medicine) was observed in a slightly increased concentration. The authors assessed these deaths as unrelated to the direct effects of CEW use.
In a review of CEW-related deaths between 2001 to 2005 in the US, 75 cases were observed. Of these 38 cases were excluded since further information about the cases were not obtained (n=33) or that the deaths were assessed as unrelated to CEW (n=5). In the remaining 37 cases, 20 cases were observed with cardiovascular disease at autopsy, 20 cases were considered cases of excited delirium, and illegal substances were found at screening during autopsy in 29 cases. In six cases CEW use was described as a potential cause of death, and in four cases as a contributory cause of death. In the article, there are no more information to be gained on the exact cause of death in these cases.

In a case-series of fatalities there were 118 CEW proximity deaths classified as that the death occurred during a police intervention or while apprehended by the police and a CEW has been used at any time point. In the study no conclusions are drawn as to whether the CEW was causally associated with the death.

Another study included cases in which emergency medical personnel performed dart extraction, why it could be presumed that cases that died before this were excluded. However, in 648 cases that were one cardiac arrest noted, however no further details were outlined.

Another study identified deaths (n=118) occurring in proximity to CEW use (collapse within 15 min of use) by searching the internet. The authors sent out requests to medical institutions for information from e.g., autopsies, and other information that could guide the assessment of the cause of death. In 56 cases such information was retrieved. Of these 45 cases were on illegal drugs. The conclusion of the study was that the data did not support that electrically induced ventricular fibrillation (a type of potentially deadly cardiac dysrhythmia) was a common cause of death after exposure to CEW. The cause of death was not elucidated in most of the cases.

In a study of all patients shot with a CEW and that attended a specific emergency department in Los Angeles between 1980 and 1985 (n=218) three deaths were observed, all had high levels of PCP, one had preexisting cardiac disease. All cases were referred to as deaths due to PCP.

Spectrum of injuries associated with CEW in case reports

Case reports describes anecdotal information, and it is generally recognized that the scientific value is low, since the setting is not experimental, only observational. Moreover, case reports often focus on describing rare and sensational cases, without being able to put these in relevant context, i.e. in what proportion of cases being shot does these adverse events occur. Case reports can also lack important information on potential confounders such as diseases and substance abuse. Nonetheless, case reports capture the panorama of outcomes associated with being shot by a CEW.

Main findings

We identified 57 case reports where CEW exposure inflicted injuries on 152 subjects. Injuries can be categorized in three lesion types. 1) Primary lesions caused by impact of the darts. These are penetration injuries such as fractures, pneumothorax and eye injuries resulting in vision impairment. 2) Primary lesions caused by electrical exposure leading to cardiac disturbances and/or forceful muscle contractions resulting in burst fractures of the spine, muscle/tendon injuries, aspiration

leading to pneumonia and rhabdomyolysis. 3) Secondary lesions described as accidents because of being hit by a CEW such as fall injuries resulting in traumatic brain injuries.
Death has been reported as result of CEW exposure. In most cases these are related to burns after ignition of flammable substances and traumatic brain injuries after fall. However, deaths in association with CEW exposure has also been described, but to establish causality with the shock is difficult due to preexisting cardiac diseases, drugs or medication in the blood.
See figure 1 for an overview of observed CEW associated injuries.

Mechanical injury following darts penetrating the body

Often case reports concern direct effects of darts penetrating the body. It is described that darts can penetrate the cranium and into the brain, penetrate facial skeleton, and cause fractures of the scapula and the bones in the hand. Penetration of the darts into the pharynx and trachea are also described with resultant air leakage into soft tissues as well as with penetration into the pleura cavity with resultant minor pneumothorax. Mechanical injury has also been observed in the testis as well as in the eye, where the latter injuries often are assessed as extensive.
The mechanical trauma caused by darts penetrating the body, are in some cases also described with injuries caused by electricity, such as tissue coagulation. This results when the darts hit a sensitive body part, and the person is shocked leading to heating of tissues.

Cardiac pathology and CEW

There are case reports describing serious cardiac arrythmias in persons being shocked, and in some cases, these are described as being fatal. In such instances the persons are often assessed as being agitated or exerted, being under the influence of substances or having preexisting disease. One case report also describes an association with myocardial infarction. See further discussion in the section "Observed association with fatal outcome" in the case report section.

Mechanical injury caused by the electricity

The muscular contraction caused by the electricity have been described, in some instances, to be so forceful that burst fractures occurs in the spine, and that muscular/tendon injuries occurs. The convulsions are also described as having caused aspiration into the lung, which might cause serious pneumonias. In forceful and probably lasting muscular contractions injured muscle cells can leak cellular substances that causes kidney failure, this is described as rhabdomyolysis, and is potentially fatal.

Secondary and other injuries following exposure to shock from a CEW

The principle of the CEW is that the person loses voluntary control of skeletal muscle, which may result in a fall resulting in similar injuries as observed after other type of falls, including severe head injuries that might be fatal. It is also reasonable to expect other types of injuries in various anatomical regions such as bruises and fractures. If the muscular incapacitation occurs in a hazardous environment, such as heights, traffic, and water, there is a risk of falls, being hit by traffic respectively drowning. One case report describes a person holding a knife, and the muscular contractions causes a “self-inflicted” stab. Several cases are described with burns resulting from flammable substances ignited by the electricity.

Pacemakers and implantable cardioverter defibrillators (ICDs)

Pacemakers supports the cardiac rhythm and ICDs delivers shock to the heart when serious dysrhythmias are detected. In 6 cases with pacemakers or ICDs that were exposed to shocks by CEW, one case with ICD was at risk of receiving a shock induced by the CEW, but since the CEW pulse was too short the ICD reset. No equipment malfunction was detected after the CEW pulse. The study concluded that the risk for CEW to induce pacemaker or ICD response are if the darts are at some distance from each other with the heart in between. Furthermore, they state that a 5 s pulse is too short to cause discharge of ICD. In another case-report a woman with an ICD was shocked with darts in the sternum and a 5 s pulse, the ICD sensed a cardiac dysrhythmia induced by the shock, but the 5 s pulse was too short for the pulse to be delivered. Another case with an ICD was shot with a CEW using 2 pulses that induced a shock by the ICD.

Associations with other serious adverse effects

One case report describes an association between being shocked by CEW and the later abortion of a pregnancy, the causality is not clear and could be questioned. Also, a cerebrovascular accident and a seizure (e.g. such as epileptic seizure) has been described in association with being shocked.

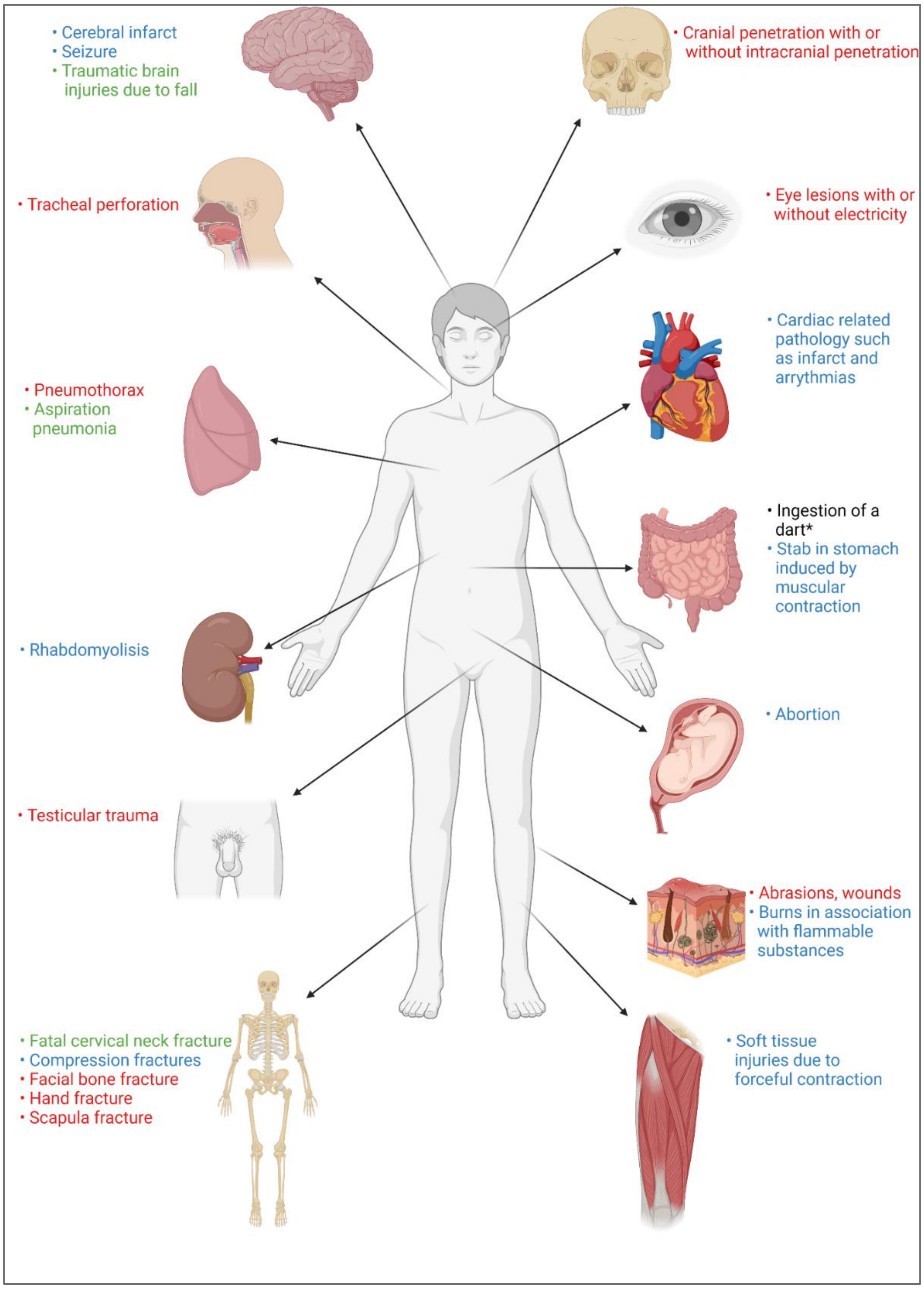

Figure 1: An overview of injuries associated with CEW as reported in case reports. Colours represent different types of injuries:

Primary lesion – caused by impact of darts

Primary lesion – caused by electrical exposure of CEW

Secondary lesion – accident as a result of being hit by CEW

*not related to any of the above listed categories

Observed associations with fatal outcome

Among the case reports we identified 37 cases that were described has having a fatal outcome after being shocked by a CEW. However, these deaths were mostly associated with secondary effects such as burns after ignition of flammable substances (n =6), and head or spine injuries associated with falls (n = 16), and hence not directly relatable to the electrical shock.
There are 7 cases described in the literature whose deaths are associated with being shocked with the darts placed near the heart. All cases were part of litigations. The age range of these cases were between 16 to 48 years, some cardiovascular pathologies were described in a few of the cases, some had alcohol, cannabis, or medication in the blood. But most notably is that a majority was shocked several times. In two cases (16 y, 17 y) the number of pulses or the length of the pulses are not listed clearly, but probably 5 s, which is an indication that CEW using short pulses have been associated with deaths in previous healthy persons. But the evidence presented in the case report is sparse, and causality is not clear. One case suffered from heart disease, had a drug (PCP) and cardiac medicament in the blood.

Another 6 cases are described as deaths after being shocked, this includes a 7-month-old baby that was fatally stunned by a relative. Another fatal case was a 17-year-old, which was described as having a congenital malformation in the heart predisposing for cardiac rhythm disturbances. One case was ruled as a death due to excited delirium, however skull fractures after a witnessed fall was described at autopsy, why the cause of death is debatable. One case died of aspiration pneumonia, however the case suffered from several diseases, was agitated and obese. Finally, an intrauterine abortion is described to have occurred several days after the mother had been shocked, in the description of the case it seems as if the mother also used heroin.

Results of CEW associated experiments on human subjects.

In human experiments the conditions for eliciting adverse outcomes are explored. Due to its experimental setup, these studies are expedient in exploring under which circumstances an adverse outcome can arise. Controlled trials on human subjects have high grade of evidence for causality between being exposed to CEW and an adverse outcome. However, due to obvious limitations in what type of experiments that can be allowed, the extrapolation of results obtained in experiments to factual situations can be limited. As an example, in a factual situation a person might be severely agitated, be under the influence of substances and have some form of sickness of importance for the outcome.

Main findings

In the literature search we observed 38 studies associated with experiments on human subjects. For the most part subjects were healthy and some studies were funded by the CEW manufacturer. CEW exposure causes an increase in heart rate and lactate (an indicator of insufficient circulation and/or oxygen supply that could cause acidosis), as well as affects respiration. No cardiac muscle cell injury, risk of thrombosis, neuroendocrine stress response, infection, derangement of serotonin levels and neurocognitive disabilities were observed.

Effects of CEW on the circulatory system including the heart

In relation to the cardiovascular system, it was observed that following the electrical shock the heart rate increased. In one study the electrical properties of the heart were affected when the so-called QT-time was increased. No adverse outcome was observed in that study, but such a finding carries the risk for serious adverse effects in the cardiac rhythm. One study on Taser X3 needed to be stopped since an event of cardiac pacing was observed, the Taser overtook the cardiac rhythm and the heart frequency was 240 beats per min (normally 50 to 100 beats per min). No studies reported signs of cardiac muscle cell injury as measured biochemically (troponin I) in the blood. Exposure to the Taser caused an increase in lactate, that was assessed as what can be seen in exercise and was often assessed as without clinical importance. However, lactate is a marker for insufficient oxygenation and in cases of agitation, such as described in excited delirium, it needs to be considered that even slight increases in lactate with resultant decrease in pH, might cause serious adverse effects, and it cannot be excluded that it can contribute to a death in selected cases. However, the subject of excited or agitated delirium is controversial.

Effects of CEW on the respiratory system

A few studies concentrate on respiratory effects, and these indicate that during the exposure respiration is affected, and possibly inspiration more so. But studies indicate that the respiration within short after the exposure, returns to normal. These conclusions should be valid in healthy subjects without serious acid-base disturbances of the body, as such disturbances requires compensatory respiration that can be vigorous.

Effects of the darts on the body

In a study darts were shot at human torsos (postmortem samples), and one dart was observed to penetrate the abdominal cavity.

Other outcomes studied for association with CEW

There are single human experiment studies performed on outcomes such as risk of thrombosis, neuroendocrine stress response, levels of serotonin, infections following the darts and neurocognitive abilities, however no relevant associations have been observed.

Results of CEW experiments in animal models

As to whether knowledge obtained from animal studies can be extrapolated to human beings is a subject for debate. There seems to be similarities of pigs compared to humans in terms of chemical and physical characteristics of blood and respiratory parameters. Moreover, it is proposed that the weight range and the ratio of heart size to body weight are like that in humans. However, some authors claim that pigs are more sensitive to electrical induction of ventricular fibrillation (VF) than humans. Specifically, studies of small swine could exaggerate the risks of CEW to human due to small weight, unrealistic dart-to-heart distance, and lack of electrical protection by the sternum. In animal studies, animals are sedated with anesthetic and analgetic agents prior to CEW exposure, affecting pain perception, circulation, respiration and possibly blood chemistry. Hence, the validity of translating results from CEW experiments on animals to humans is debated.

Main findings

We identified 42 articles reporting the results of CEW associated experimental studies in animals. CEW induced cardiac dysrhythmia seems to depend on dart location, dart-to-heart distance (DTH - distance between the tip of the dart to the heart), subject size and characteristics of the CEW pulse. After CEW exposure animals are biochemically deranged primarily in terms of increase in lactate. The degree of the increase seems to be dependent on longer pulses and exposure times as well as repeated exposures. CEW exposure does not seem to negatively impact pacemaker or ICDs.

Effects of CEW on the circulatory system including the heart in animals

The risk of dysrhythmia induced by CEW in animals has been investigated in several studies. In general, authors agree that CEW can induce cardiac dysrhythmia in animals, even though fatal outcome is scarce. It is proposed that CEW induces dysrhythmia causing the heart to work inefficiently and that the blood supply to the body becomes insufficient which increases the risk for fatal dysrhythmias. The cardiac stimulation induced by CEW in animals seems to be dependent on dart location, subject size, and the characteristics of the CEW pulse e.g., charge, duration and waveform.

In a pig model it has been observed that if the dart to heart (DTH) distance is short, the risk of inducing a potentially fatal cardiac dysrhythmia is increased. The DTH in pigs has been shown to be 4-8 mm, and that theoretically such a low DTH can also be achieved in humans, especially if the individual is thin. Other studies have shown that cardiac stimulation of CEW is possible even when the darts are more than 5 cm from the heart. How the darts are positioned in relation to the heart is also a factor of interest, if the heart is positioned in the path of the current the risk of dysrhythmia is increased, and in contrast, dart placement on the back and abdomen seems not to cause cardiac dysrhythmia. In smaller sheep (32kg or less), CEW exposure was associated with a larger risk for cardiac dysrhythmia compared to in larger sheep. This might support that a larger DHT, lowers the risk of cardiac dysrhythmia.

Differences in electrical output of CEW influence the ability to stimulate the heart. Short pulse duration, lower pulse charge and lower amplitude seems to be protective of inducing cardiac dysrhythmias. In contrast, a higher pulse rate and a longer pulse duration seems to increase the risk of cardiac dysrhythmias, and the latter more so. In a study with an exposure time to electric shock of 2 x 40 s, two out of eleven pigs died of cardiac dysrhythmia. In animals that survived, the heart rate was increased, the blood pressure was decreased, and the blood chemistry was deranged. Mimicking an agitated state (such as the setting for an excited delirium), animals were infused with epinephrine (stress hormone) prior to exposure to CEW and in 13 out of 16 pigs a potentially fatal cardiac dysrhythmia was observed. On the other hand, another study indicated that cocaine, in contrast, might act protective of cardiac dysrhythmias when the animal is exposed to a CEW.

Effects of CEW on the biochemistry

CEW applied on pigs, results in biochemical derangements. One study argues that acid-base disturbances are primarily a result of intense skeletal muscle contractions, not depressed cardiac function or apnea. A CEW pulse of 5 s was associated with an increase in lactate and a corresponding drop in pH (acid-base disturbance). The increase in lactate was observed to increase with longer pulses, an exposure time of 10 s led to, amongst other, a significantly higher lactate concentration compared to an exposure time of 5 s. In pigs, CEW discharges with a duration of 60 to 180 s were fatal in 3 out of 18 pigs. A mixed metabolic and respiratory acidosis was observed. However, at necropsy all three pigs were assessed as having preexisted cardiac disease. A CEW exposure has been associated with a decrease in blood pressure. That CEW exposure time increases the risk of fatal outcome was illustrated using CEW pulses with durations of up to 30 minutes. Furthermore, longer pulses as well as repeated exposure to a CEW resulted in respiratory and circulatory changes as well as an increased lactate level. Furthermore, the electrical output of CEW seems to influence biochemical changes, as an increase in current resulted in more biochemical derangement of the pigs, whereas a different waveform, lower voltage, and shorter pulse duration did not seem to affect pigs biochemically at all. After CEW exposure, a transient change was observed in e.g. electrolytes. However, the clinically importance of these changes was assessed as negligible.

Effects of CEW on pacemakers and implantable cardioverter defibrillators (ICDs)

Few studies investigated the effects of CEW on ICDs, and pacemakers implanted in pigs. CEW impulses were observed to be detected by ICDs and pacemakers when the heart was positioned in the flow of the current. A short CEW exposure (5 s) did not lead to an ICD shock, as the tachycardia detection abruptly terminated at the end of the 5 s CEW application. However, prolonged CEW exposure of 15 s led to an ICD shock. Hypothetically, if the detection and charging time of the ICD is under 5 s, a shock could be delivered prior to the termination of the 5 s CEW application. Regarding pacemaker, the pulse generator recognized the CEW discharge and sensed high-rate atrial or ventricular activity, but this had no effect on the native rhythm or on the paced rhythm. The functional integrity of the intracardiac devices post exposure were intact. Repeated exposures where not investigated in terms of material durability.
However, these findings should be interpreted with caution, as the studies were conducted from 2007 – 2011, not considering the technical development in the field of ICD’s, pacemakers, and CEW.

Effects of CEW on bone

30 s of CEW exposure caused musculoskeletal fatigue-related stress fractures in the lumbosacral region in 89% of the pigs tested. However, the waveforms used were not representative of commercial CEW, hence the results cannot be directly extrapolated.

Efficacy of CEW in animals

Few studies elucidated the efficacy of CEW in animals. One study demonstrated that muscle-contraction force increased as the distance between darts increased from 5 to 20 cm. There was no further change in muscle-contraction force above 20 cm of distance. Moreover, it has been shown that an increase in pulse repetition rate resulted in a lower amount of energy required for stimulation and an increase the muscle-contraction force.

Studies that use theoretical models to assess the effect of CEW on the human body

Theoretical models are used for approximating the effects of CEW on the human body. The relevance of such models to the real-world setting are uncertain, however a piece of the puzzle is provided, but the results need to be interpreted with caution.

Main findings

The literature search identified 16 theoretical studies assessing the effect of CEW on the human body. The theoretical risk of CEW induced lethal cardiac dysrhythmias is low and seems to depend on the size of the current, placements of darts and duration of exposure time. CEW seems to not have effect on pacemakers and ICDs.

Use of CEW and the risk of cardiac dysrhythmia

An experimental study making use of computer simulations have indicated that use of CEW (X26) has a safety margin of 5-fold for inducing lethal cardiac dysrhythmias. Another studies, combining a purely theoretical approach with previously reported experimental data indicated that it was highly unlikely that a CEW (X26) could cause a potentially fatal cardiac dysrhythmia in a healthy adult. A report stated that the theoretical risk for a potentially lethal cardiac dysrhythmia was about 1 in 2,5 million and other has stated similar safety margins, however it is unclear if these reports were peer-reviewed. A study combining a theoretical approach with animal experiment indicted that the waveform of a CEW has the capability of inducing a lethal cardiac dysrhythmia, however that the current needed to be much higher than what is observed to be achieved in experiments. Using a theoretical model and animal experiments it indicated that the risk for lethal cardiac arrythmias was low, but not non-existent. In the conclusion the authors stated that the lethal cardiac arrythmia (ventricular fibrillation) can be reversed with a defibrillator. Previously it has been suggested that the police car equipment should include a defibrillator, not by indication of CEW, but by indication to be able to handle cardiac arrythmias in general. Using a computational model, it has been indicated using characteristics of the CEW (X26) that in worst case scenarios induction of a potentially lethal cardiac arrythmia cannot be excluded. Another study by the same author stated, based on a computational model on X26 characteristics, that the risk of inducing lethal cardiac arrythmia is small, but not insignificant. In a worst-case scenario of dart position the risk of a potentially lethal cardiac arrythmia could reach 30 %. In another study the same author stated that for the risk of the model X26 was higher than for the model Taser X3 and that the risk increased with increasing duration of the exposure to electricity. In general, the risk was assessed as 1 % for a general weight of 72 kg, but with lesser weight the risk was observed to increase.

Risks associate with CEW in persons with pacemakers and/or implantable cardioverter defibrillators (ICDs)

In an experimental set up using Taser X2 and Taser X26 on pacemakers and ICDs it was observed that during shock with the taser the pacemaker was not seriously affected, however ICDs could be triggered to start shock therapy. With shorter pulses (5 s) shocks were not delivered by the ICD. There was no observed effect if the user of the Taser had a PM or an ICD.

Injuries due to darts

In a physical model of the human skull, it was shown that darts of different design fired by a CEW has the potential to penetrate the skull, and more so at shorter distances.

Experiments assessing the efficiency of nerve stimulation

Using a computer model, it was assessed that larger dart separations caused larger currents at the heart, and the model observed that nerves in the spinal cord could be stimulated.

Injuries caused by electricity in other areas than heart

In a computer simulation a report indicated that the energy supplied by the CEW shock is lower than threshold for causing actual cellular injury, however it is not clear if the report was peer-reviewed.

REPORTS AND STATEMENTS SUPPLIED BY THE DANISH POLICE

The Swedish report from the implementation of CEW is based on surveys to police officers having experience of the CEW. However, there are no systematic evaluation about health-related consequences for the subjects on whom the CEW is used. In the report statements from police officers indicate an opinion that the access to a CEW carries the potential to save lives and minimize injuries when used in certain contexts such as when suicidal individuals need to be incapacitated to prevent them from hurting themselves by e.g. jumping of ledges.

In the implementation phase of CEW in the Norwegian police it was reported that 5 persons were injured following exposure to CEW, none of these were serious. All the injuries were secondary, such as following a fall or similar. One person required medical care to remove a dart. No injuries related to electrical effects on the cardiac system was observed. CEW was fired 73 times during the implementation phase, hence the scientific evidence on numbers of injuries and types of injuries is low.

A report from the implementation of CEW in the Netherlands stated that CEW was deployed 1112 times in 2022, 43 of these were in drive stun mode. The report does not give insight into injuries inflicted by a CEW. However, it is noted that 22 complaints (not further specified) were made about the use of CEW.

The Danish Police supplied older expert statements on injuries following the use of CEW, however these did not supply any additional information, why these are not further mentioned in this report.

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Risling M. Bedømning av medicinska effekter av Taser 7. Vedlegg 14.2.

SUPPLEMENT

Supplement 1: Search terms used in PubMed.

Terms	Hits
“Axon enterprise”	25
“CEW”	366
“Conducted electrical weapon”	68
"Conducted energy device"	9
"Conducted energy weapon"	142
"Electric weapon technology"	102
“Electrical stun gun”	7
"Electrical weapon"	82
"Electromuscular incapacitating device"	23
"Electronic control device"	45
"Electronic control weapon"	645
"Electronic weapon"	5
"Electroshock weapon"	103
"Energy weapon"	145
"Human electrical muscular incapacitation"	15
"Incapacitation device"	495
"Less-lethal technology"	30
"Less-lethal weapon"	13
"Neuromuscular incapacitating defensive device"	4
"Neuromuscular incapacitating device"	3
"Neuromuscular incapacitation"	11
"Nonlethal device"	222
"Nonlethal force"	5
"Nonlethal weapon"	12
"Stun gun"	31
"Taser"	402
"Taser electrical weapon"	4
"Taser electronic control device"	12
"Taser exposure"	12
"Taser shocks"	3