Electroshock weapons: physiologic and pathologic effects - literature review

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Abstract: Tasers are electroshock weapons used for incapacitating aggressive persons by disrupting superficial muscle functions through administering electric shocks. The number of taser users and also taser related deaths are increasing every year. Taser effects on humans vary a lot depending on taser associated factors (voltage, wave-length, firing distance, type of use - contact or from the distance) but also on human variability (skin thickness, salinity, associated pathology, etc). A single discharge usually is not usually associated with severe adverse reactions or death, but these can happen in various risk groups (pregnant women, elderly, small children). This review presents the spectra of clinical signs and symptoms associated with taser use and a synthesys of the suggested protocols for the management of forensic cases.

Key words: electroshock weapons, taser related death, physiologic effects, risk groups

Taser®, a registered Taser Inc. Trademark [1], is a type of electroshock weapon that is using thin, flexible, metallic wires to conduct the needed energy (CED – conductive energy device). An electroshock weapon is a type of incapacitated weapon used for subduing a person by disrupting superficial muscle functions through administering electric shocks. Other electroshock weapons such as stun guns, stun batons, and electroshock belts administer an electric shock by direct contact.

The number of electroshock weapons is growing exponentially nowadays because there is an increasing need of nonlethal weapons for crowd control. In 2005 it was estimated a number of 260,000 electroshock weapon users in USA only. Between 2003 and 2005 there are 1095 arrest associated deaths. Between 1999 and 2005 there have been described 167 taser associated deaths in US and Canada only according to www.raidh.org [2,3,4]

Taser classification

- 1\textsuperscript{st} generation (1970’s): TF-76 had an action ray of about 5 meters; they were shooting two darts, connected to the device with metallic wires; propulsion was realized by using gun powder, being for that included in the firearms category.
2\textsuperscript{nd} generation (1994): TASER 34000 used compressed air instead of gunpowder as propellant, not being included for this reason in the firearms category; they had implemented a new technology called AFID (Anti Felon IDentification) which used serialized confetti tags dispersed from every cartridge for misuse identification. The biggest problem of this device to be solved in future generations was its low efficiency on people with high pain tolerance.

3\textsuperscript{rd} generation (1999): ADVANCED TASER M26 was the first one to inflict electro-muscular disruption - EMD - in order to incapacitate even the most pain resistant people. EMD technology paralyzes the skeletal muscular system for a limited, controlled by the user, period of time. The only affected structure is the skeletal muscular system; there is no loss of consciousness and no internal organ involvement. In addition to the AFID system, they’ve implemented a new control technology - the \textit{dataport} which is recording the time and date of every trigger pull in order to better monitor the use of this device. This weapon can be used in two ways – with or without a launching device. If it hasn’t the launching device installed it can only be used in direct contact. If a launching device is present the weapon is sending two metallic darts, connected to the device by thin metallic wires. The darts, in contact with the skin or conductive clothes will immediately discharges an electron beam to paralyse the aggressor in less than one second.

4\textsuperscript{th} generation (2004): TASER X26 – is uses a new technology called „Shaped-Pulse” which allows it to be more efficient but also smaller and lighter by up to 60%.

\textbf{Prototypes}

There are currently in various stages of development a few new electroshock weapon technologies like:

- XREP (eXtended Range Electro-muscular Projectile) – a wireless weapon with a range of up to 100m.
- Electrified water cannon - are using streams of fluid instead of metallic wires.
- Plasma taser (Rheinmetall W&M) uses an aerosol as the conductive medium.
- Electrolaser - uses blooming of a laser beam to create a conductive channel of ionized air (plasma) to carry the electric shock.

\textbf{Mode of action}

Tasers have two dart-like electrodes (metallic probes) which are remaining attached to the main unit by metallic wires; nowadays the propulsion is made with compressed nitrogen; the cartridge contains compressed nitrogen and electrodes, replaceable after each use. There are more cartridge types, classified by their range: for law enforcement agents the maximum range is set to 10,6 m and for civilian use to 4,5 m. The electrodes are able to penetrate clothes (4th generation tasers are even able to penetrate through a level three bulletproof vest).

Maximum effect areas for taser guns are: the upper shoulder, lower thoracic cage, superior thigh. In order to overcome the human body resistance tasers are using a low intensity but high voltage electric current. Usually a higher voltage means an increased risk for adverse reactions. The internal circuitry of a taser is composed of an oscillator, a resonant circuit, and an step-up transformer or a diode-capacitor voltage multiplier to achieve the continuous, direct, or alternating high-voltage discharge. The needed power is given by one or more batteries. The output voltage without external load, aka the target's body) is claimed to about 50 to 1000 kV, but most common values tend to be in the 200 to 300 kV range, depending on various skin type, salinity target's resistance, moisture, clothing, the
electroshock weapon's internal circuitry, or battery [3]. The energy released by a single pulse is of about 0.8 J; from the contact point the energy travels inside the body through minimum energy conducts (usually neuromuscular packages).

**Taser effects**

Effects depending on the exposure time:

- 0.5 sec – retropulsion;
- 1 – 2 sec – generalized skeletal muscle tetany
- 3 – 5 sec – the affected person is incapacitated for about 15 min; after that will have muscular rigidity and muscle pain.

Effects on different organs and systems:

1. **Cutaneous.** Frequently the electro darts are making paired, dot-like lesions; surrounding them (or, if the dot-like lesions are not present instead of them) are noticeable 0.5–1 cm erythematous areas [1] sometimes papulous [3] distanced about 5 cm; in time these erytematous areas are becoming pale and then acquiring the surrounding skin colour.

   Sometimes in contact areas may be noticeable first and second degree burns; the histological examination reveals in these cases electrical mark-like lesions. SEM (Scanning Electron Microscopy) and EDS (Energy Dispersive X-Ray Spectrometer) examinations are showing in contact areas metallic deposits; their quantity gives informations about the shooting distance and discharge time and their composition hints the type of weapon [7].

2. **Ocular.** Hitting the eyeball with taser darts may result in scleral wounds or cataract [8].

3. **Musculoskeletal system.** Taser electrical discharge is able to induce skeletal tetany with subsequent incapacitation, transient postagresional palsy, muscular pain; taser related fractures can be determined by:
   - (1) direct taser dart stroke (it was described a thoracic vertebrae fracture determined by taser darts [9]) or
   - (2) fall secondary to muscular incapacitation (there have been described cranial fractures) [8].

4. **Cardiovascular system.** In order for a electrical current to induce a ventricular fibrillation it must be of minimum 0.1A at the ventricular level and must be applied for minimum 0.5 sec. An electrical current applied on skin must have a much higher intensity that can’t be achieved by only one taser discharge. An ECG study realized in 2008 on healthy subjects showed that a 0.5 sec discharge is not enough to produce electrical malignant ventricular anomalies [10]. The only noticeable alterations were (1) short PR and QT and increased heart rate for non-obese subjects and (2) short PR for obese subjects.

   These results are similar with ones obtained in 2007 by Holdes SJ who studied the electromagnetic modelling of current flow in the heart from taser devices (M26 and X26); he established that, although a current with an intensity 60 times higher than normal can induce premature ventricular beats when applied during the vulnerable period to the ventricular epicardial surface of guinea-pig isolated hearts, when applied to the ventricles in trains designed to mimic the discharge patterns of the TASER devices, neither waveform induced ventricular fibrillation at peak currents >70-fold (for the M26 waveform) and >240-fold (for the X26) higher than the modelled current densities [11].
Studies regarding prolonged duration taser effects were made mostly on animal models (usually pigs). Dennis AJ studied the effect of prolonged (40 sec) taser discharge on 6 pigs, of which two died from ventricular fibrillation and the rest presented tachycardia, hypotension, marked acidosis (pH of 6.86 +/- 0.07), increased CO₂ (94.5 +/- 14.8 mmHg; normal values: 45.3 +/- 2.6 mmHg), decreased HCO₃⁻, lactate acidosis (22.1 +/- 1.5 mmol/L; normal values: 1.5 +/- 0.03 mmol/L). These values returned to normal within 24 hours [12]. The only marker that presented a moderate increase after 24 hours was troponin.

On humans though a study on 5 sec exposure on healthy subjects showed normal troponin after 24 hours (< 0.3 ng/ml) with one exception (> 6 ng/ml) but without other AMI signs [13].

Another study, realized by Valentino DJ in 2007, analyzed the effects of another type of electroshock weapon (MK63) on Yucatan pigs – no animal died and all studied biological markers returned to normal within 24 hours [14].

The differences between these two experiments were considered to be secondary to different electrical discharge wave-length. Both studies showed that after prolonged taser discharge there is a metabolic acidosis, fact confirmed on human subjects by Vilke in 2007 – after a 5 sec discharge on normal subjects he obtained the following results: pH decreased with 0.03 1/minute after the discharge, HCO₃⁻ decreased with 2.8 mmol/L, lactate plasma value was double (2.8 mmol/L); in 30 minutes the values became normal.

In order to differentiate metabolic acidosis effects from those given by direct myocardial electrical stimulation Walter PJ (2008) studied the cardiac effect of taser discharge on pigs paralyzed with succinil-choline. One subject from the study group died by VF and all the other presented ventricular tachycardia of 1-17 sec; no subject had acidosis proving the fact that in arrhythmogenesis is also involved a direct, electrical mechanism [15].

Another factor associated with arrhythmogenesis is the localization of the electrical discharge. Nanthakumar K (2006) studied the effect of 5 and 15 sec discharge exposure, both thoracic and non-thoracic, both with and without associated adrenergic hyper stimulation; the results showed that thoracic stimulation often produces myocardial stimulation but non-thoracic stimulation produces no myocardial stimulation. Associated adrenergic stimulation produced one VF and one VT [16].

Lakkiriddy D. (2008) also studied the cardiac effects of discharge location showing that the frequency of VT is higher when the stimuli are applied closer to the heart [17].

Wu JY (2007) showed that the probability of an electrode located in a area of 1 cm² adjacent to the left ventricle to produce ventricular fibrillation is 0.000172 [18].

5. Respiratory system. After the electric discharge there usually is an increased respiration rate (from 19 to 29) with a moderate respiratory volume increase from 16 to 29; these values come back to normal within 10 minutes [14]. There has also been described a hypopharynx traumatic lesion made by a taser dart with subsequent subcutaneous emphysema.

6. Metabolic alterations. After the electrical discharge there is a increase in pCO₂, K⁺, mioglobin and a plasmatic level decrease of pH, HCO₃⁻, proportionate with the intensity and duration of the electric discharge [12,14].

7. Psychiatric alterations. Taser use is sometimes associated with and increase of in and post-aggression stress; it was considered to be an aggravation factor for excited delirium (a syndrome which associates psychosis, agitation, aggressivity, hyperthermia; sometimes the subject has an increased mortality risk); it was proven though that taser use stress risk is not
higher than the usual combative stress. In many cases of death associated with excited delirium the cause of death is represented by hyperthermia. There is no evidence to suggest that taser use is associated with hyperthermia [3,4,1,19,20].

8. **Risk groups.** Even though in general taser use is safe there are a few population groups to which this doesn’t apply – small children (several authors reported taser involvement in battered child syndrome, in utero deaths secondary to taser use, etc), elderly, pregnant women, people with cardiac diseases, etc. [6,8,19,21,22].

**Management of taser exposure**

1. Medical examination is not mandatory after all CED exposures. Usually the aggressed persons do not require any kind of treatment.
2. If the darts had penetrated the skin, especially vulnerable areas of the head, face, neck, genitals, or female breast regions or if the electroshock determined traumatic lesions (subsequent to a fall, burns, etc) they should be appropriately treated as soon as possible.
3. Psychiatric disorders or any kind of abnormal mental status in a combative or resistive subject may be associated with a risk for sudden death. This should be treated as a medical emergency. In these cases, the management includes an assessment of body temperature, obtaining and retaining blood samples and an electrocardiogram as soon as possible. Treatment, if needed, consists of cooling, sedation and hydration as soon as possible. Considering the strong association between drug abuse and aggressiveness, if possible the subject must be toxicologically screened.
4. Sudden lack of responsiveness may occur at any time and may indicate a medical crisis especially for persons included in the above mentioned risk groups or those with psychiatric conditions and they should be provided with appropriate medical care.
5. If the aggressed person is pregnant the baby’s fetal heart rate must be closely monitored.
6. Antibiotics should be given if darts had penetrated the skin or if the patient has septic traumatic wounds. When removing embedded darts, care should be taken to avoid exposure to blood borne pathogens.
7. Darts and clothing removed during medical care should be retained for investigative purposes and handled as evidence.

**Management of taser related deaths**

If there is evidence that a taser use was associated with a person death the medical-legal autopsy is compulsory, being a violent death. Even if between 1999 and 2005 there were 167 taser related deaths in US and Canada only, in most cases the coroner couldn’t find a causal link between taser use/abuse and death, the latter one being frequently associated with a drug overdose (usually cocaine or methamphetamine) or excited delirium.

The association taser related death – drug abuse might suggest that there might be a direct causal link between them. Although this association seems plausible, there are experimental evidences that cocaine increases the level at which VF appears in taser discharges and also decreases cardiac vulnerability for as much as 200% [17,23,24].

In order for an autopsy to demonstrate a causal link between taser use and death the coroner and the investigation team must obtain some specific information and also realize some specific tasks before, during and after the autopsy. The investigation team should answer and do the following before the autopsy:
1. Finding out if and how the taser was used (witness accounts, police reports, emergency medical services records, medical and psychiatric records, and any videos, photographs or digital images of the events.
2. A timeline of all events with attempts to verify, to the extent possible, the accuracy of the dates and times of reported events, with specific emphasis on the interval between CED use, unresponsiveness, and death.

3. The CED was used in drive stun and/or cartridge mode(s)?

4. Taser type (producer, model, waveform, range, etc. (useful for these are the AFID and dataport systems described above but also the type of residual metallic waste).

5. Darts should not be removed from the decedent’s body or clothing before police arrival/before autopsy.

6. What were the recent activities of the deceased? What was it’s emotional state?

7. Medical history with emphasis on cardiac events, epilepsy, psychiatric disorders (especially excited delirium), malnutrition. Very important to know is if the deceased used psychotropic medication, antiepileptic, or recreational drugs, including alcohol abuse. If death occurs after arrival at a hospital, is it recommended a toxicological screening. The investigation of the subject’s place of residence and its recent activities may also provide information about a possible drug abuse.

8. What was doing the deceased recently before the death? What was his emotional state?

9. Measurement and documentation of body and ambient temperature at the scene and other locations such as the hospital may provide useful information, especially if excited delirium is a possible or definite diagnosis.

During the medical-legal autopsy (mandatory) the medical-legal MD should:

1. A complete postmortem toxicological examination is useful (including illicit drugs, alcohol, psychiatric medication, anti-epileptic drugs, nervous system stimulants, etc)

2. Measurement of the thickness of the anterior chest wall from the skin to the rear of the pre-pericardial sternum at intercostal space between the left fourth and fifth ribs and also the thickness of clothing in the area(s) where CED darts or prongs were applied.

3. Documentation of the CED dart’s barb length(s), manufacturer, etc Metallic residues analysis (if possible by SEM or EDS)

4. Consideration of unusual or atypical current flow paths, such as body to ground, body to water, body to metal, etc.

5. Determination of the nature of any other forms of subdual or restraint that were employed in the case in question. Traumatic lesion complete description.

6. A skin histological examination may provide further info regarding skin lesions determined by the darts.

Conclusions

Even if in Romania allegations of taser abuse are not very frequent and taser related deaths are exceptional, the forensic MD should be prepared to handle such cases (both in clinical legal medicine and in the autopsy room/ crime scene).

It is essential to There are specific techniques and proceedings needed to be done in order In all taser related death cases a drug overdose or excited delirium must be ruled out as they are the most frequent causes of death associated with taser use before taking into consideration the hypothesis that taser use contributed or determined the death.

Special check-up list of information must be gathered before the autopsy and a forensic special procedure should follow the steps suggested in the text.
References