JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, November 2012, Vol. 57, No. 6
doi: 10.1111/j.1556-4029.2012.02167.x
Available online at: onlinelibrary.wiley.com

TECHNICAL NOTE

ENGINEERING SCIENCES

Sebastian N. Kunz,[1] *M.D.; Bettina Zinka,*[2] *Ph.D.; Sybille Fieseler,*[2] *M.D.; Matthias Graw,*[2] *Ph.D.; and Oliver Peschel,*[2] *Ph.D.*

Functioning and Effectiveness of Electronic Control Devices Such as the TASER® M- and X-Series: A Review of the Current Literature

ABSTRACT: Conducted electrical weapons (CEWs) such as the TASER® M- and X-series deliver short high-voltage, low-current energy pulses to temporarily paralyze a person by causing electrical interruption of the body's normal energy pulses. Despite many scientific publications, which classify the health risks of an appropriate use of the TASER device as minor, there still is a continuous uncertainty about possible side effects with human application. Based on a literature search of the National Library of Medicine's MEDLINE database's PubMed system of current publications, the following article describes the mechanisms by which the device operates and discusses possible pathophysiological consequences. The majority of current human literature has not found evidence of clinical relevant pathophysiological effects during and after an exposure of professionally applied CEWs. However, to be able to exclude possible health risks, a medical checkup of people who have been exposed to CEWs is essential.

KEYWORDS: forensic science, conducted electrical weapon, electrocution, stopping power, nonlethal weapons, medical consequences, TASER

Nonlethal weapons are weapons, devices, and ammunitions, which are explicitly designed to immediately incapacitate opponents without significant or lasting injuries (1). Conducted electrical weapons (CEWs), such as the TASER® device or products under the Stinger® trademark, deliver short high-voltage, low-current energy pulses to temporarily paralyze a person by causing electrical interruption of the body's normal energy pulses. After the application, the opponent is fully recovered within a short time-period without any long-term effects.

While CEWs have been used by the police force in the United States and elsewhere since the mid-1970s, they were introduced to the special forces of the German police not earlier than 2000. The first report on TASER use in Germany was published by Bux et al., in which they pointed out possible physiological side effects (2).

With the proliferation of these nonlethal devices, such as the TASER X26 or M26, new questions have arisen regarding their safety. Amnesty International listed over 300 deaths, where CEWs are declared as causal or contributory factor in the cause of death (3), but in none of these cases, a causal connection between CEWs and physiological changes could be proven beyond doubt.

The focus of this article is a comparative, methodologically analysis on the functioning and effectiveness of electronic control devices and their possible pathophysiological effects on the human body during and after application. The results are based on wide-ranging literature analysis of the National Library of Medicine's MEDLINE database's PubMed system of current publications, source studies, and expert interviews.

[1]Institute of Forensic and Legal Medicine, Paris-Lodron-University Salzburg, Ignaz-Harrer-Straβe 79, A-5020 Salzburg, Germany.
[2]Institute of Forensic and Legal Medicine, Ludwig-Maximilians-University Munich, Nussbaumstr. 26, 80336 Munich, Germany.

Received 9 Mar. 2011; and in revised form 24 Aug. 2011; accepted 17 Sept. 2011.

Development of the TASER as an Example of CEW

The first long-distance CEWs were introduced by the company TASER Int. The term "Taser" is an acronym from *Thomas A. Swift Electric Rifle*, referring to the science fiction novel "Tom Swift and His Electric Rifle" by the author V. Appleton 1911 (4,5). In the mid-1960s, NASA aerospace physicist John H. Cover followed the idea of stunning people with electricity, as described in his favorite novel. He invented the first handheld, battery-powered "electric rifle," which was released on the American market in April 1974 (6).

The main basis of the device is the continuous transmission of short electrical pulses of low current and high voltage (Fig. 1) causing transient paralysis.

In Germany, prior to changes in the weapons law in April 2009, purchasing and possessing CEW devices were legal for those holding a weapon possession card. Since that date, CEW weapons have been prohibited to the public.

Structure and Function of CEWs

Despite minor differences in pulse duration and electrical potential (Table 1), the TASER X26 and M26 devices (Fig. 2) show no significant divergence in the effect they have on application. The TASER M- and X-series are based on the same electrophysiological principles (7,8). In the following, the structure and function of electronic impulse devices will be illustrated based on the X26 model.

TASER and other CEWs are battery-powered electromuscular incapacitation devices that propel two darts (electrodes) into the target with compressed gas propellant (nitrogen with a pressure of

© 2012 American Academy of Forensic Sciences

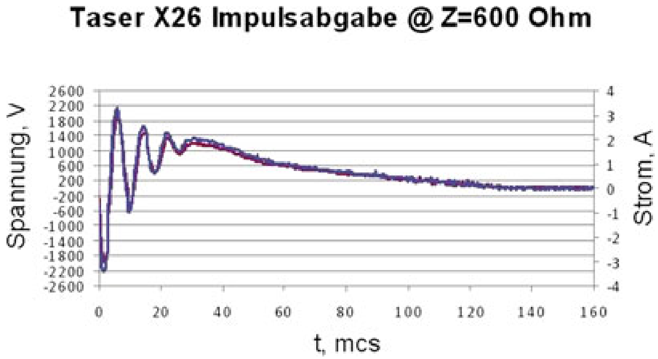

FIG. 1—*Impulse of the TASER X26.*

TABLE 1—*Electrical characteristics of the TASER X26 and M26.*

Type	Pulse Duration (μs)	Transmitted Charge (μC)	Energy per Impulse (J)	Voltage—Peak Main Phase (V)	Current (mA)
X26 (7)	105–155	80–125	0.095–0.125	1400–2520	1.5–2.4
M26 (8)	32–60	70–120	0.69–1.05	6900–9400	1.4–2.4

FIG. 2—*Electronic control device TASER X26 and M26.*

c. 125 bar). The darts (weight 1.75 g) have harpoon-like probes and are being shot under a shooting angle of 8° and connected with the device through high-voltage insulated, *c*. 0.5-mm-thick, and up to 10.6-m-long steel core copper wires. The maximal firing distance varies with the replaceable air cartridge and can be up to *c*. 10 m.

When hit, the darts penetrate the soft tissue of the target up to 2.5 cm, depending on the cartridge. A current flow is realized between the electrodes, which can reach up to 9400 V and 2.4 mA, depending on the ohmic resistor within the soft tissue of the target.

If the probes do not penetrate the body surface and become lodged in light clothing, the distance to the final target is overcome by a high-resistance arc of suspense, an open-circuit voltage of up to 50,000 V. That voltage is never delivered into the body, so that the target itself is only affected by a low-resistant pulse frequency. To proof and reproduce the usage of electric control devices, 20–30 small, confetti-like matching identification tags are being released, upon activation of the device.

The basic principle of CEW devices is to over-ride the command and control system of the human body to immobilize the target (subcutaneous electromuscular disruption) by applying high-voltage and low-current electrical impulses with a duration of about 100 μsec. The pseudomonophasic waveform delivered by the TASER (1) has an electric charge of 100 μC (in compliance with *c*. 6×10^{14} electrodes) and a repetition rate of 15–20 impulses per second (9).

The electric field created by the device does not directly activate the muscle tissue but stimulates type A-α motoneurons, which then continuously forward the impulse to the neuromuscular junction terminal, initiating a tonic muscle contraction. Once activated, this temporarily impairment of muscular control is independent of the size or pain tolerance of the target.

The final effect of the CEW application correlates with the electrophysiological characteristics of the current flow and therefore depends on the localization and distance of the electrodes, the clothing, and the physiological and psychological conditions of the opponent (6). Initially, after terminating the application, the organism returns to its normal state, and electrophysiological long-term effects are not to be expected (10).

Potential Health Risks Owing to the Use of CEW

The risk evaluation of the CEW devices is widely discussed in the scientific literature. There are a number of cases, where these devices have been associated with some sudden in-custody deaths (3,11,12). In the majority of these cases, the usage of CEWs involves multiple discharges of the weapon (13) or long-duration applications (14). Because of insufficient documentation of the police operation and a noticeable frequent occurrence of alternative causes of death, such as intoxication, extreme agitation, or cardiovascular diseases, a direct correlation of causality could not yet be proven beyond doubt (15).

There is a wide range of research work devoted to different health-related subjects around CEWs, which give an insight into possible pathophysiological changes during and after CEW application. Certain potential risk factors, such as acidosis and lack of effective respiration, have been studied with anesthetized animals (16–19), but could not be verified in humans (20,21). Because of the questionable transferability of animal studies considering CEW research (22,23), the main focus on this article lies on human studies.

Cardiovascular System

It is well known that direct electrical stimulation of the heart can cause fatal cardiac arrhythmia and ventricular fibrillation (24). For instance, household current, at a frequency of 50 Hz, has a threshold value for causing ventricular fibrillation of *c*. 100 mA (25, p. 826). A possible deadly outcome hereby depends on the heart's state of agitation and the current applied.

In comparison, CEWs create relevant minor current and essentially longer impulse duration (Table 1), which does not have a direct influence on the heart rhythm. Together with the anatomical separation from the power source and the electrical shield function of the lungs (9), the current flow follows the line of the least resistance, spreading within the superficial tissue layers. Various human researches have shown that CEWs appear to exhibit a reasonable degree of cardiac safety with no potential of inducing ventricular fibrillation.

Ho et al. (26) performed a 24-h follow-up ECG study with 66 human subjects after a 5-sec application with the TASER X26. In a similar study, vital signs before and after the application, ECGs, and blood samples were analyzed on 53 volunteers after a 10-sec application with the TASER X3 (27). In none of the tests, heart arrhythmia or significant changes in blood levels of basic parameters could be determined.

Muscular System

Creatine kinase is an intracellular muscle enzyme, which catalyses the conversion of adenosine diphosphate within the muscular system and can be used as a marker for mechanical and metabolic muscle damages. In this context, it is questionable whether a maximal tension of the skeleton muscular system, as initiated by CEWs, can lead to muscle cell damages and eventually causes an increase in creatine kinase. In the clinical treatment, the concentration of creatine kinase is used as an indicator for rhabdomyolysis. In the literature, different cut-off concentrations, where a medical intervention is absolutely essential, are given, varying from 5000 U/L (28) up till 75,000 U/L (29).

Even though the medical literature on this subject is rather sparse, there are a few cases where the effect of modern electronic control devices on potential muscle injury is described. In an article by Sanford et al. (30), the probability of a TASER-related increase in creatine kinase with the potential risk of acute renal failure as one of the possible complications of rhabdomyolysis is discussed. In this case study, two opponents are described on which CEW devices were applied during a police investigation and who developed symptoms of rhabdomyolysis afterward. They reached creatine kinase levels of 3166 and 8086 U/L. One of them was under the influence of cocaine and the other one has been shot with the device after an excessive physical confrontation with the police. As described by a retrospective study of Sinert et al. (31), extreme physical exertion alone can also be the reason for critical creatine kinase levels between 700 and 165,000 U/L. In a recent human volunteer evaluation by Dawes et al. (32), a correlation between electrical control devices and an increase in creatine kinase of up to 1456 U/L was noticed, but none of the 156 participants showed any clinical features.

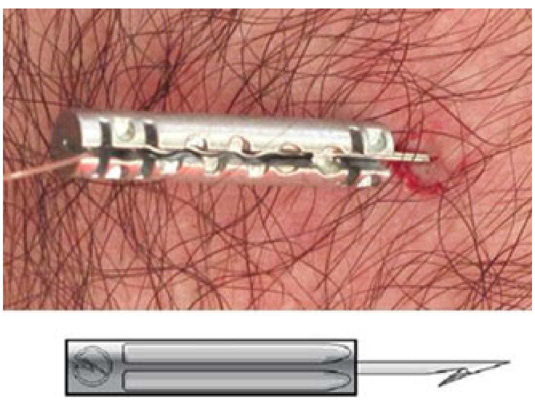

FIG. 3—*Penetrated dart of the TASER X26.*

In conclusion, it can be said that electronic control device exposure can lead to modest increase in creatine kinase without a risk of developing rhabdomyolysis.

Neuroendocrine System

Because the exposure to CEWs is an extreme situation for the human organism, it is important to be able to exclude possible dangerous neuroendocrine effects. The sympathetic–adrenal–medulla axis and the hypothalamic–pituitary–adrenal axis are the two main mechanisms for stress-related interactions controlling a complex set of hormonal influences and physical reactions. The human stress response initiates so-called fight-or-flight hormones like catecholamines (adrenaline, noradrenaline, dopamine), which have ergotropic effects on the body such as an increase in heart contraction and metabolism. In cases of intense physical strain, especially, they can lead to an up to 50-fold increase in hormones with correlating pressure on the cardiopulmonary system (33).

Ho et al. (34) and Dawes et al. (35) performed a study on 53 and 60 volunteers to examine the differential stress response between a TASER application and extreme physical challenge (e.g., 150 m sprint, 45 sec kick-box-training, etc.). Both analyses have shown a relationship between TASER exposure and an increase in stress hormones. But compared to the commonly employed uses of force, the examined literature asserts that an application of CEWs can function as a stressor and therefore influence the human stress response, but only to a degree where no important changes in vital signs are to be expected.

Mechanical Injuries

An application of CEWs can leave purely mechanical injuries caused by the penetrating darts. When being shot by the TASER device, two darts penetrate the skin a few millimeters and are fixated by an *c*. 5-mm-long harpoon-like probe (Fig. 3). The resulting injury pattern is a central puncture wound surrounded by an erythematous circular lesion of 2–5 mm (Fig. 4*a*). In addition, the application of electrical energy to the surrounding tissue can result in minor localized burns, especially if the dart has not fully penetrated the skin and lies on its surface (Fig. 4*b*). The darts should only be removed by medical staff, and the resulting skin lesions should be examined. In situations, where the dart has penetrated vulnerable areas, such as the eye, the genital area, the neck, throat,

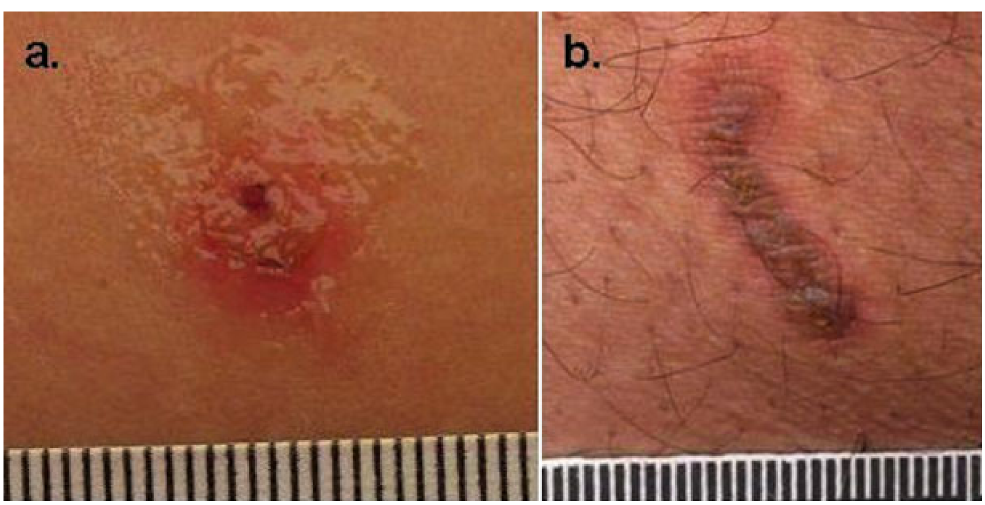

FIG. 4—*Mechanical (a) and electrical (b) skin lesions after TASER application.*

or vascular structure, the electrodes should not be removed on site, but under medical supervision in an operating room at a hospital.

Ideally, the recommended point of aim is the lower center of mass. On incorrect application, head injuries cannot be excluded. If there are any indications of cranial penetration, appropriate imaging and neurosurgical consultation are essential.

Ophthalmic injuries, especially, bear the risk of permanent damages and therefore require special considerations in managing patients (36). In these cases, it is more the mechanical injury than the tissue wound from the electrical current, which determines the degree of damage.

Most of the records on TASER show that a person who has been hit with the device falls uncontrollably to the ground. Depending on the position of the target, the characteristics of the ground surface, and surroundings, an unintentional fall can lead to severe injuries. As forensic experience shows an undamped fall on a hard surface can reach the tolerance threshold for skull fractures (37), which increases the risk of possible intracranial bleedings with a correlating fatal outcome. For that reason, a neurological examination of the person in question is indicated.

Conclusion

The majority of current scientific research has not found evidence of clinical relevant pathophysiological effects during and after an exposure of professionally applied CEWs on a healthy subject.

However, to be able to exclude possible health risks, a medical checkup of people who have been exposed to CEWs is essential. All subjects should undergo cardiac examination with control of common cardiovascular parameters, a complete blood count, and a neurological observation. In the event of possible TASER-related deaths, a forensic autopsy is unavoidable. Furthermore, all potential associated factors must be analyzed to be able to confirm or disprove a true causal relationship.

References

1. Thiel KD. *Nicht—letale wirkmittel für asymmetrische konflikte*, 2009, http://www.ict.fraunhofer.de/kernko/ES/schu/NLW/index.jsp (accessed August 23, 2011).
2. Bux R, Andresen A, Rothschild M. Elektrowaffe ADVANCED TASER M6. Rechtsmedizin 2002;12:207–13.
3. Amnesty International. List of deaths following use of stun weapons in US Law Enforcement, 2008, http://www.amnestyusa.org/uploads/ListOfDeaths.pdf (accessed July 12, 2011).
4. Kroll M, Ho J. Taser® conducted electrical weapons: physiology, pathology, and law. New York, NY: Springer, 2009.
5. Victor (pseudo) Appleton. Tom Swift and his electric rifle, 1911, http://www.gutenberg.org/etext/3777 (accessed July 20, 2011).
6. Resnick B, Murray J. A guide to TASERTechnology: stun guns, lies and videotape. Whitewater, CO: Whitewater Press, 1997.
7. TASER X26 electrical characteristics, 2009, http://www.ecdlaw.info/outlines/EC_02-01-09_%20X26_Elec_Char.pdf (accessed November 1, 2010).
8. TASER M26 electrical characteristics, 2009, http://www.ecdlaw.info/outlines/EC_02-01-09_M26_Elec_Char.pdf (accessed January 1, 2010).
9. Kroll MW. Physiology and pathology of Taser® electronic devices. J Forensic Leg Med 2009;16:173–7.
10. Sun H. Models of ventricular fibrillation probability and neuromuscular stimulation after Taser® use in humans [PhD Thesis]. Madison (WI): University of Wisconsin, 2007.
11. Kornblum RN, Reddy SK. Effects of the TASER in fatalities involving police confrontation. J Forensic Sci 1991;37:434–48.
12. Strote J, Hutson HR. TASER use in restraint-related deaths. Prehosp Emerg Care 2006;10:447–50.
13. Strote J, Hutson HR. Taser safety remains unclear. Ann Emerg Med 2008;52:84–5.
14. Williams HE. Taser electronic control devices and sudden in custody death: separating evidence from conjecture. Springfield, IL: Charles C. Thomas, 2008.
15. Kroll MW, Panescu D, Ho JD, Luceri RM, Efimov IR, Calkins H, et al. Potential errors in autopsy reports of custodial deaths temporally associated with electronic control devices: a cardiovascular perspective. Proceedings of the 59th Annual Meeting of the American Academy of Forensic Sciences; 2007 Feb 19–24; San Antonio, TX. Colorado Springs, CO: American Academy of Forensic Sciences, 2007;284–5.
16. Jauchem JR, Cook MC, Beason CW. Blood factors of Sus scrofa following a series of three Taser® electronic control device exposures. Forensic Sci Int 2008;175:166–70.
17. Jauchem JR, Seaman RL, Fines DA. Survival of anesthetized Sus scrofa after cycling (7 s on/3 s off) exposures to a Taser® X26 electronic control device for three minutes. Am J Forensic Med Pathol 2011;32(2):124–30.
18. Jauchem JR. An animal model to investigate effectiveness and safety of conducted energy weapons (including TASER devices). J Forensic Sci 2010;55:521–6.
19. Dennis AJ, Valentino DJ, Walter RJ, Nagy KK, Winners J, Bokhari F, et al. Acute effects of TASER X26 discharges in a swine model. J Trauma 2007;63:581–90.
20. Dawes DM, Ho JD, Reardon RF, Strote SR, Nelson RS, Lundin EJ, et al. The respiratory, metabolic, and neuroendocrine effects of a new generation electronic control device. Forensic Sci Int 2011;207(1–3):55–60.
21. Ho JD, Dawes DM, Bultman LL, Moscati RM, Janchar TA, Miner JR. Prolonged TASER use on exhausted humans does not worsen markers of acidosis. Am J Emerg Med 2009;27:413–8.
22. Pippin JJ. Taser research in pigs not helpful. J Am Coll Cardiol 2007;49:731–2.
23. Pound P, Ebrahim S, Sandercock P, Bracken MB, Roberts I, Reviewing Animal Trials Systematically (RATS) Group. Where is the evidence that animal research benefits humans? BMJ 2004;328:514–7.
24. Reilly JP. Cardiac sensitivity to electrical stimulation. In: Reilly JP, editor. Applied bioelectricity: from electrical stimulation to electropathology. New York, NY: Springer, 1998;194–239.
25. Brinkmann B, Madea B. *Handbuch gerichtliche medizin, Band I*. Berlin, Germany: Springer Verlag, 2004.
26. Ho JD, Miner JR, Lakireddy DR, Bultman LL, Heegaard WG. Cardiovascular and physiologic effects of conducted electrical weapon discharge in resting adults. Acad Emerg Med 2006;13:589–95.
27. Ho JD, Dawes DM, Reardon RF, Strote SR, Kunz SN, Nelson RS, et al. Human cardiovascular effects of a new generation conducted electrical weapon. Forensic Sci Int 2011;204(1–3):50–7.
28. Lappalainen H, Tiula E, Uotila L, Mänttäri M. Elimination kinetics of myoglobin and creatine kinase in rhabdomyolyis: implications and follow-up. Crit Care Med 2002;30:2212–5.
29. Oda J, Tanaka H, Yoshioka T, Iwai A, Yamamura H, Ishikawa K, et al. Analysis of 372 patients with crush syndrome caused by the Hanshin-Awaji earthquake. J Trauma 1997;42:470–5.
30. Sanford J, Jacobs G, Roe E, Terndrup T. Two patients subdued with a TASER device: cases and review of complications. J Emerg Med 2011;40(1):28–32.
31. Sinert R, Kohl L, Reinone T, Scalea T. Exercise-induced rhabdomyolysis. Ann Emerg Med 1994;23:1301–6.
32. Dawes DM, Ho JD, Sweeney JD, Lundin EJ, Kunz SN, Miner JR. The effect of an electronic control device on muscle injury as determined by creatine kinase enzyme. Forensic Sci Med Pathol 2011;7(1):3–8.
33. Strobel G. *Sympathoadrenerges system und katecholamine im sport*. Deutsche Zeitschrift für Sportmedizin 2002;53:84–5.
34. Ho J, Dawes D, Nelson R, Lunden EJ, Ryan FJ, Overton KG, et al. Acidosis and catecholamine evaluation following simulated enforcement ''use of force'' encounters. Acad Emerg Med 2010;17(7):e60–8.
35. Dawes D, Ho J, Miner J. The neuroendocrine effects of the TASER X26: a brief report. Forensic Sci Int 2009;183:14–9.
36. Chen SL, Richard CK, Murthy RC, Lauer AK. Perforating ocular injury by Taser. Clin Exp Ophthalmol 2006;34:4–80.
37. Yoganandan N, Pintar FA. Biomechanisc of temporo–parietal skull fracture. Clin Biomech 2004;19:225–39.

Additional information and reprint requests:
Sebastian Kunz, M.D.
Institute of Forensic and Legal Medicine
Paris-Lodron-University Salzburg
Ignaz-Harrer-Straβe 79
A-5020 Salzburg
Germany
E-mail: sebastian.kunz@med.uni-muenchen.de