BASIC INVESTIGATIONS

Respiratory Effect of Prolonged Electrical Weapon Application on Human Volunteers

Jeffrey D. Ho, MD, Donald M. Dawes, MD, Laura L. Bultman, MD, Jenny L. Thacker, MD, Lisa D. Skinner, MD, Jennifer M. Bahr, MD, Mark A. Johnson, BS, James R. Miner, MD

Abstract

Background: Conducted electrical weapons (CEWs) are used by law enforcement to subdue combative subjects. Occasionally, subjects will die after a CEW has been used on them. It is theorized that CEWs may contribute to these deaths by impairing respiration.

Objectives: To examine the respiratory effects of CEWs.

Methods: Human volunteers received a 15-second application of electrical current from a CEW while wearing a respiratory measurement device. Common respiratory parameters were collected before, during, and after exposure. Health histories and demographic information were also collected.

Results: Fifty-two subjects were analyzed. Thirty-four underwent a 15-second continuous exposure, and 18 underwent three 5-second burst exposures. In the continuous application group, the baseline mean tidal volume of 1.1 L increased to 1.8 L during application, the baseline end-tidal CO_2 level went from 40.5 mm Hg to 37.3 mm Hg after exposure, the baseline end-tidal oxygen level went from 118.7 mm Hg to 121.3 mm Hg after exposure, and the baseline respiratory rate went from 15.9 breaths/min to 16.4 breaths/min after exposure. In the 5-second burst group, the baseline mean tidal volume increased to 1.85 L during application, the baseline end-tidal CO_2 level went from 40.9 mm Hg to 39.1 mm Hg after exposure, the baseline end-tidal oxygen level went from 123.1 mm Hg to 127.0 mm Hg after exposure, and the baseline respiratory rate went from 13.8 breaths/min to 14.6 breaths/min after exposure.

Conclusions: Prolonged CEW application did not impair respiratory parameters in this population of volunteers. Further study is recommended to validate these findings in other populations.

ACADEMIC EMERGENCY MEDICINE 2007; ■:■■–■■

Keywords: TASER, conducted electrical weapon, electronic control device, in-custody death, respiratory

The conducted electrical weapon (CEW) is a device used by law enforcement to subdue violent or combative subjects. Basic CEW technology has been available for many years, but its use has become more popular in recent times. Critics have attempted to link CEW use to sudden, unexpected in-custody death (ICD) events.[1–3]

One of the theories for ICD events involves impairment of respiration by CEW devices. This theory is included in medical examiner autopsy reports and media sources as a hypothetical contributor or cause of the custodial death.[4,5] It is not uncommon for these sources to list shortness of breath or difficulty breathing proximal to the CEW application as a notable preterminal event.

From the Department of Emergency Medicine, Hennepin County Medical Center (JDH, LDS, JMB, JRM), Minneapolis, MN; Department of Emergency Medicine, Lompoc District Hospital (DMD), Lompoc, CA; Department of Emergency Medicine, Northern California Kaiser Permanente (LLB), Sacramento, CA; Department of Emergency Medicine, Banner Good Samaritan Medical Center (JLT), Phoenix, AZ; and Division of Medical Research, TASER International (MAJ), Scottsdale, AZ.

Received October 26, 2006; revision received November 17, 2006; accepted November 17, 2006.

TASER International provided partial funding for this project; the total funding contribution was for analysis equipment and was $1,708.20. Drs. Ho and Dawes currently serve as independent, expert medical consultants to TASER International and own stock shares of the company. Mr. Johnson is an employee of TASER International. Dr. Miner has served as a statistics consultant to TASER International.

Contact for correspondence and reprints: Jeffrey D. Ho, MD; e-mail: hoxxx010@umn.edu.

doi: 10.1197/j.aem.2006.11.016
ISSN 1069-6563
PII ISSN 1069-6563583

This leads to the belief that, because CEW technology is known to cause muscular incapacitation, it might be possible to incapacitate the muscles of respiration, such as the intercostal muscles and the diaphragm, during its application. If true, this would be especially concerning during prolonged CEW application (e.g., the trigger of the CEW is continuously depressed or depressed multiple times during an encounter). To the best of our knowledge, this is the first study to undertake the examination of the respiratory effect of prolonged CEW application on human volunteers.

METHODS

Study Design

This was a prospective observational study of resting adult volunteers recruited at several TASER International training courses between May 2005 and June 2006. The term "TASER" is an acronym for Thomas A. Swift's Electric Rifle and is a concept based on a fictional series of children's literature involving hi-tech solutions to problems and conflicts. The institutional review board of Hennepin County Medical Center approved the study. Subjects provided informed written consent upon enrollment.

Study Setting and Population

This study was performed in adult (age older than 18 years) volunteer subjects. All volunteers were personnel involved in various aspects of law enforcement and were recruited at various training classes held by the manufacturer of TASER technology (TASER International, Scottsdale, AZ). Volunteers were taken on a first-come, first-served basis. As a standard part of their CEW training course, they were to receive a 15-second CEW application. They did not have to participate in our study as a requirement for successful course completion, but declining to participate in the study did not absolve them from receiving the standard CEW application required by the training course. The application consisted of a 15-second burst with applied electrodes powered by the TASER X-26 model CEW (Figure 1). The exclusion criteria were pregnancy and persons with mental illness diagnoses. Volunteers were given a TASER X26 CEW upon successful completion of the study protocol.

Study Protocol

All subjects completed a questionnaire to determine age, gender, body mass descriptors, past medical history, current medications, and history of significant exertion within the 24 hours before the study.

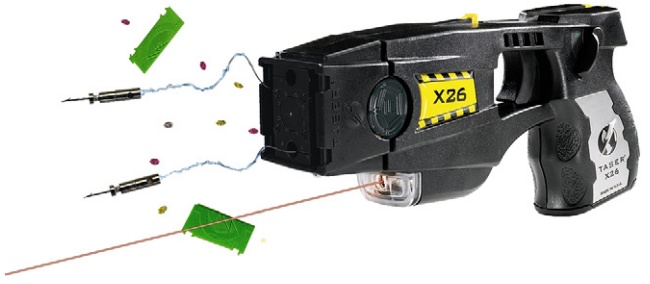

Figure 1. The TASER X26 device.

Upon completion of the medical questionnaire, the volunteer was given a form-fitting neoprene mask to wear during the study period. The fit of the mask was tested to ensure no air leakage. The mask was connected to a CPX Ultima Analyzer (Med Graphics, St. Paul, MN). This is a breath-by-breath digital analyzer that provides measurement of multiple functional respiratory parameters and displays the information graphically. Upon ensuring that the analyzer was functioning correctly, a short period of rest was given to allow for baseline, pretest respiratory data collection. Once the analyzer had collected baseline data, the volunteer was subjected to the CEW application. Respiratory data were collected continuously from the baseline period until after the CEW application. The end of the data collection was determined by an investigator observing the subject's return to baseline respiratory pattern. The volunteers were not told in advance what data points were being collected during CEW exposure. Data points collected included oxygen and carbon dioxide concentrations of expired air, respiratory rate, and tidal volume on a breath-by-breath basis. The minimum tidal volume to trigger a measurement was 50 mL, according to the manufacturer.

The graphical data were processed by Breeze Suite 6.2 software (Med Graphics). Data were divided into four phases for comparison: phase 1, the start of the subjective baseline measurement to the start of the CEW application; phase 2, during the CEW application, either 15 seconds (for the 15-second continuous discharge) from the start of the application or 17 seconds (for the 5-1-5-1-5 second discharge) from the start of the application; phase 3, the first minute after the end of the CEW application; and phase 4, from the end of phase 3 to the return of baseline tidal volume. All tidal volume data are reported at body temperature and ambient pressure saturated with water vapor. The normal quiet-breathing tidal volume of a 70-kg adult is about 500 mL/breath (about 7 mL/kg), with a rate of about 12–20 breaths/min (a rate of 12 means one breath every 5 seconds).[6]

The CEW application consisted of manually applying electrodes to the volunteer while he or she was lying on a padded mat in the supine position. The electrodes were manually placed on each subject, instead of fired from the weapon, to ensure exact placement of electrodes from volunteer to volunteer. The electrodes were placed on the subject's trunk in positions to span a majority of the trunk while including transdiaphragmatic positioning. Common placement included ipsilateral and contralateral positioning at shoulder and hip, pectoral region and leg, and scapula and buttock. The electrodes were then connected to a factory-standard TASER X26 CEW. A programmable logic controller (PLC) was used to accurately control the duration of current delivered (Allen-Bradley MicroLogix 1500; Maple Systems, Inc., Everett, WA). The purpose of the PLC was to enable the CEW current application to be delivered in an objective, reproducible, and controlled fashion. With the exception of this PLC, the CEW was not altered from the factory standard. The PLC was programmed to deliver the CEW current for a total of 15 seconds in either a 5 seconds on/one second off fashion

repeated three times in succession or as a 15-second continuous application. The first 18 subjects included in the study received the 5/1/5/1/5 application protocol. The remainder of the subjects received the 15-second continuous application protocol. Upon completion of the application protocol, the electrodes were removed, the attachment points were disinfected, and adhesive bandages were applied if needed. Immediately following the CEW application, all subjects were released from the study area to go back into the classroom to complete the didactic portion of their TASER training session.

Data Analysis

Data were entered in an Excel (Microsoft Corp., Redmond, WA) database for analysis. Data analysis was performed using Stata 9.0 (Stata Corp., College Station, TX). Data are described using descriptive statistics and 95% confidence intervals. The percentage change from baseline values to the three other phases of data collection is presented with 95% confidence intervals.

RESULTS

Sixty subjects were eligible for study enrollment. One subject was excluded before the study because of his current medication history (the subject was on an unmonitored anticoagulant). Seven of the tested subjects were excluded due to either data collection malfunction (CPX Ultima instrument wires inadvertently touching the TASER X26 wires during the test [$n = 4$]) or due to record keeping (loss of the TASER application time on the timeline [$n = 3$]).

Data from 52 subjects were therefore analyzed. Their mean (±SD) age was 31.5 (±6.4) years (range, 19–49 years), and 92.3% were male. Their mean (±SD) weight was 199.9 (±39.8) lb (90.9 kg) (range, 125–325 lb). Their mean (±SD) body mass index was 28.8 (±4.76) kg/m^2 (range, 21.9–44.1 kg/m^2). Past medical histories included asthma ($n = 3$), hypertension ($n = 2$), hypercholesterolemia ($n = 2$), atrial fibrillation ($n = 1$), spontaneous pneumothorax ($n = 2$), a bowel obstruction ($n = 1$), depression ($n = 2$), and hypothyroidism ($n = 1$). Three subjects reported having a cough at the time of enrollment, and five of 52 (9.6%) reported a history of dyspnea on light exertion due to their underlying medical condition. Of note, nine of 52 subjects (17.3%) used tobacco. Thirty-four subjects underwent the 15-second CEW exposure, and 18 underwent three successive 5-second exposures. Respiratory data for the two exposure groups are shown in Tables 1 and 2.

Table 1
Respiratory Data for Continuous 15-second CEW Exposure ($n = 34$)

Parameter	Phase	Mean Value over Phase	95% CI
Tidal volume (L)	1	1.1	0.9, 1.3
	2	1.8	1.4, 2.2
	3	1.7	1.5, 1.9
	4	1.3	1.1, 1.4
Heart rate* (beats/min)	1	104.7	97.8, 111.6
	2	—	—
	3	116.3	107.3, 125.3
	4	91.9	87.2, 102.8
End-tidal CO_2 (mm Hg)	1	40.5	39.2, 41.7
	2	37.3	35.5, 39.0
	3	42.1	40.4, 43.8
	4	42.4	40.9, 43.9
End-tidal O_2 (mm Hg)	1	118.7	116.4, 121.0
	2	121.3	117.8, 124.8
	3	114.0	11.2, 116.9
	4	122.4	120.3, 124.4
Respiratory rate (breaths/min)	1	15.9	14.4, 17.5
	2	16.4	12.2, 20.7
	3	18.3	16.5, 20.1
	4	17.1	15.7, 17.4
Minute ventilation (L/min)	1	16.3	14.7, 17.9
	2	20.9	18.0, 23.8
	3	29.9	27.5, 32.3
	4	21.3	19.1, 23.5

Phase 1 = baseline measurements pre-exposure; phase 2 = measurements during conducted electrical weapon exposure; phase 3 = measurements during first minute postexposure; phase 4 = measurements from second minute postexposure to return to baseline.
CEW = conducted electrical weapon.
* Heart rate was unobtainable during CEW application.

DISCUSSION

Conducted electrical weapons are considered to be an intermediate weapon by law enforcement agencies. Intermediate weapons are those devices that generally can induce subject compliance due to pain or incapacitation, and examples include aerosolized chemical irritants, impact batons, and projectile beanbags. The CEW is used frequently, and the manufacturer reports more than 100,000 voluntary training exposures and more than 119,000 field uses by law enforcement (S Tuttle, personal communication, November 16, 2006). It provides a painful stimulus to encourage compliance, as well as physiologic and neuromuscular incapacitation in many cases. Currently, TASER International is the dominant manufacturer in the CEW market and represents the majority of CEWs in use today in this country. The most common CEW currently used by law enforcement is the TASER X26, which is why it was chosen as the test model for this study. It is considered to be a nonlethal weapon, under the definition set forth by the U.S. Department of Defense.[7]

The X26 is programmed to deliver a roughly rectangular pulse of approximately 100-μs duration with about 100 μC of charge at 19 pulses/s for 5 seconds.[8] The peak voltage across the body is approximately 1,200 V, but the weapon also develops an open circuit arc of 50,000 V to traverse clothing in cases where no direct contact is made. The average current is approximately 2.1 mA. It uses compressed nitrogen to fire two metallic darts up to a maximum of 35 ft with a predetermined angled rate of spread. When it makes adequate contact and the darts are of adequate separation, it causes involuntary contractions of the regional skeletal muscles that render the subject incapable of voluntary movement. If the darts are fired at very close range and do not achieve adequate separation, full muscular incapacitation may not be achieved, and the device is then used to encourage certain behavior through pain compliance.

Table 2
Respiratory Data for Three 5-second CEW Exposures (n = 18)

Parameter	Phase	Mean Value over Phase	95% CI
Tidal volume (L)	1	1.4	1.2, 1.7
	2	1.5	1.2, 1.8
	3	1.9	1.7, 2.2
	4	1.7	1.2, 1.6
Heart rate* (beats/min)	1	87.1	75.9, 98.3
	2	—	—
	3	95.8	80.8, 110.8
	4	81.8	70.1, 93.5
End-tidal CO_2 (mm Hg)	1	40.9	39.1, 42.7
	2	39.1	36.8, 41.4
	3	40.0	38.1, 41.9
	4	41.2	39.3, 43.0
End-tidal O_2 (mm Hg)	1	123.1	118.5, 127.7
	2	127.0	121.2, 132.8
	3	124.2	118.6, 129.7
	4	127.6	123.3, 131.8
Respiratory rate (breaths/min)	1	13.8	11.5, 16.0
	2	14.6	12.1, 17.2
	3	18.7	15.1, 22.2
	4	17.2	14.8, 19.5
Minute ventilation (L/min)	1	17.7	16.2, 19.3
	2	19.5	16.9, 22.2
	3	30.1	30.1, 36.3
	4	20.8	20.8, 24.0

Phase 1 = baseline measurements pre-exposure; phase 2 = measurements during conducted electrical weapon exposure; phase 3 = measurements during first minute postexposure; phase 4 = measurements from second minute postexposure to return to baseline.
CEW = conducted electrical weapon.
* Heart rate was unobtainable during CEW application.

Critics of CEWs have attempted to link CEW use with ICD events. It is important to realize that deaths very similar to modern-day ICD events occurred decades before CEW technology was invented.[9] Previously, it has been theorized that ICD events proximal to CEW application were due to electrocution. However, recent work in this area has not supported this theory.[10–13] Because the majority of CEW research has concentrated on the cardiac arena and has failed to show a significant association with ICD, attention has recently turned to the possibility that it could impair respiration. This would be especially concerning in an acidotic subject (it is presumed that the vast majority of ICD subjects are in the throes of significant metabolic acidosis from excited delirium type behavior, which has been described in previous studies).[14] It would also be concerning in subjects who receive prolonged CEW application. We found no evidence of breathing impairment during either type of CEW exposure, as shown in Tables 1 and 2.

Current law enforcement CEW applications are for 5 seconds each time the trigger is pulled (the operator has the option to turn it off sooner or to continue to depress the trigger, which results in continuous application until the trigger is released, or to depress the trigger multiple times, which results in a 5-second cycle each time it is depressed). Approximately 70% of reported field applications are for 5 seconds or less.[8]

Prior work in humans failed to demonstrate a statistically significant change in electrocardiograms, serum markers of cardiac damage, hyperkalemia, or induced acidosis following a 5-second CEW application.[12] Because of this, we elected to extend the duration of exposure to 15 seconds, because some field CEW uses are for longer than 5 seconds, and longer duration exposures would intuitively yield more impairment if any was to be found. We used two different exposure patterns (5 on/1 off/5 on/1 off/5 on versus 15 seconds continuous on) because these represent the only ways that subjects could receive prolonged CEW application in the field (intermittent, multiple applications vs. continuous application).

It is interesting to note that the volunteers in this study had high minute ventilations in the range of 15–19 L/min before the application of the CEW. The expected range would be about 6–10 L/min based on a 70-kg adult.[6] We believe that this is likely due to involuntary hyperventilation after their baseline serum values had been determined but just before activation of the CEW. We believe that this represents a period of heightened anxiety associated with the anticipation of the painful stimulus. While this finding is noteworthy, we do not believe it has much effect on the generalizability of our data, because we believe that most subjects in real-life situations would also have an involuntary hyperventilatory response due to conditions surrounding their confrontation with law enforcement, such as fighting, fleeing, and resisting.

LIMITATIONS

A limitation of this study is the small number of volunteers involved. However, in light of the small number of volunteers willing to endure a prolonged CEW exposure because of the discomfort involved, it would be difficult to conduct this same methodology with a larger number of volunteers. We believe that the number of volunteers that we have tested is adequate to detect respiratory impairment due to CEW exposure.

An additional limitation of this study is that it does not exactly reproduce the conditions found in most ICD events. In the field, the majority of ICD subjects are using illicit substances, exhibiting bizarre, agitated behavior, and are presumably acidotic when law enforcement officials encounter them.[15] There has been some work done in this area on animal models with regard to cardiac effects of CEW application after illicit stimulant administration, but there is no literature available in this area examining the respiratory effects of these substances when coupled with CEW application.[11] We are unable to reproduce these field conditions in our volunteers due to the illegality of the conditions often found in the field subjects.

Furthermore, our volunteers were almost all law enforcement officers and with the exception of two, none admitted to mental illness or illicit substance abuse. However, our study population was also not in pristine health and likely resembles the normal American population (overweight, with medical issues such as hypertension, coronary artery disease, asthma, and so on). The mean body mass index of our volunteers placed them

in the "overweight" category per current federal standards.[16] Had we obtained volunteers who were young and fit from the local police academy recruit class, we may have had a "healthy" population bias issue with this study. We do not believe this to be the case.

In addition to this, we preplaced our CEW electrodes on our volunteers and placed our volunteers in a supine position for data collection. While this also does not mimic the conditions of CEW use in the field, this was a more practical study method, and we are doubtful that this aspect of our protocol is a significant limitation.

CONCLUSIONS

We were unable to detect any respiratory impairment during either prolonged continuous or prolonged intermittent CEW exposure in this study population. It does not appear that prolonged CEW exposure causes a decreased tidal volume, hypercapnia, hypoxia, or apnea. We recommend further study in this area to validate our results.

The authors thank Matthew Carver and Andrew Hinz for their diligent help with data collection. This project would not have been possible without their assistance.

References

1. Amnesty International. Excessive and lethal force? Amnesty International's concerns about deaths and ill-treatment involving police use of tasers. Amnesty International Library, Nov 30, 2004. Available at: http://web.amnesty.org/library/index/engamr511392004. Accessed Sep 23, 2006.
2. Anglen R. 73 cases of death following stun gun use. Arizona Republic. Oct 12, 2004. Available at: http://www.azcentral.com/specials/special43/articles/0915taserlist16-ON.html. Accessed Sep 23, 2006.
3. American Civil Liberties Union. Citing deaths in police custody, ACLU of Colorado calls for limits on use of electroshock weapons. ACLU Library, Feb 26, 2004. Available at: http://www.aclu.org/CriminalJustice/CriminalJustice.cfm?ID=15167&c=15. Accessed Sep 23, 2006.
4. Anglen R. 167 cases of death following stun gun use. Arizona Republic. Jan 5, 2006. Available at: http://www.azcentral.com/specials/special43/articles/1224taserlist24-ON.html. Accessed Nov 15, 2006.
5. Mitchell K, Marcum K. Jailers cleared in culpability of suffocation. Denver Post. Oct 17, 2006. Available at: http://www.denverpost.com/newsheadlines/ci_4508387. Accessed Nov 15, 2006.
6. Levitsky MG. Pulmonary Physiology. 6th ed. New York, NY: McGraw Hill, 2003.
7. United States Department of Defense. Jul 9, 1996. Department of defense directive 3000.3 policy for nonlethal weapons. Available at: http://www.dtic.mil/whs/directives/corres/pdf/d30003_070996/d30003p.pdf. Accessed Sep 23, 2006.
8. TASER training video and information disk, version 13. Scottsdale, AZ: TASER International, Apr 2006.
9. Bell L. On a form of disease resembling some advanced stages of mania and fever, but so contradistinguished from any ordinary observed or described combination of symptoms as to render it probable that it may be overlooked and hitherto unrecorded malady. Am J Insanity. 1849; 6:97–127.
10. McDaniel WC, Stratbucker RA, Nerheim M, Brewer JE. Cardiac safety of neuromuscular incapacitating defensive devices. PACE. 2005; 28(Suppl):S284–7.
11. Lakireddy D, Wallick D, Ryschon K, et al. Effects of cocaine intoxication on the threshold for stun gun induction of ventricular fibrillation. J Am Coll Cardiol. 2006; 48:805–11.
12. 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.
13. Levine SD, Sloane C, Chan T, Vilke G, Dunford J. Cardiac monitoring of subjects exposed to the TASER [abstract]. Acad Emerg Med. 2005; 12(Suppl 1):71.
14. Hick JL, Smith SW, Lynch MT. Metabolic acidosis in restraint-associated cardiac arrest: a case series. Acad Emerg Med. 1999; 6:239–43.
15. Ho JD, Reardon RF, Heegaard WG. Deaths in police custody: an 8 month surveillance study. Ann Emerg Med. 2005; 46(Suppl):S94.
16. Department of Health and Human Services, National Institutes of Health. Standard BMI calculator. Available at: http://www.nhlbisupport.com/bmi/. Accessed Oct 8, 2006.