Echocardiographic Evaluation of a TASER-X26 Application in the Ideal Human Cardiac Axis

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Abstract

Objectives: TASER electronic control devices (ECDs) are used by law enforcement to subdue aggressive persons. Some deaths temporally proximate to their use have occurred. There is speculation that these devices can cause dangerous cardiac rhythms. Swine research supports this hypothesis and has reported significant tachyarrhythmias. It is not known if this occurs in humans. The objective of this study was to determine the occurrence of tachyarrhythmias in human subjects subjected to an ECD application.

Methods: This was a prospective, nonblinded study. Human volunteers underwent limited echocardiography before, during, and after a 10-second TASER X26 ECD application with preplaced thoracic electrodes positioned in the upper right sternal border and the cardiac apex. Images were analyzed using M-mode through the anterior leaflet of the mitral valve for evidence of arrhythmia. Heart rate (HR) and the presence of sinus rhythm were determined. Data were analyzed using descriptive statistics.

Results: A total of 34 subjects were enrolled. There were no adverse events reported. The mean HR prior to starting the event was 108.7 beats/min (range 65 to 146 beats/min, 95% CI = 101.0 to 116.4 beats/min). During the ECD exposure, the mean HR was 120.1 beats/min (range 70 to 158 beats/min, 95% CI = 112.2 to 128.0 beats/min) and a mean of 94.1 beats/min (range 55 to 121 beats/min, 95% CI = 88.4 to 99.7 beats/min) at 1 minute after ECD exposure. Sinus rhythm was clearly demonstrated in 21 (61.7%) subjects during ECD exposure (mean HR 121.4 beats/min; range 75 to 158 beats/min, 95% CI = 111.5 to 131.4). Sinus rhythm was not clearly demonstrated in 12 subjects due to movement artifact (mean HR 117.8 beats/min, range 70 to 152 beats/min, 95% CI = 102.8 to 132.8 beats/min).

Conclusions: A 10-second ECD exposure in an ideal cardiac axis application did not demonstrate concerning tachyarrhythmias using human models. The swine model may have limitations when evaluating ECD technology.

ACADEMIC EMERGENCY MEDICINE 2008; 15:838–844

Keywords: TASER, conducted electrical weapon, electronic control device

TASER electronic control devices (ECDs) are primarily used by law enforcement officials to subdue or repel aggressive and potentially violent persons. Some deaths have occurred temporally proximate to ECD use. Human research has not demonstrated a connection between these two events to date, but there has been speculation that these devices could cause death by induction of dangerous cardiac rhythms, such as ventricular capture with resultant tachycardia or ventricular fibrillation (VF).[1]

Previous studies in this subject area have not demonstrated a dangerous effect on human volunteers.[2–5] However, some recent swine model research supports the hypothesis that ECD application can cause or contribute to sudden death and has demonstrated cardiac capture rates of 300 beats/min as well as induced VF, especially when the ECD probes or electrodes are placed in specific locations that appear to mimic an ideal cardiac conduction pathway along the cardiac

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Received March 8, 2008; revisions received April 24 and April 26, 2008; accepted April 26, 2008.

Presented at the 2008 Heart Rhythm Society Annual Meeting, San Francisco, CA, May 2008; and at the 2008 CARDIOSTIM Annual Meeting, Nice, France, June 2008.

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ISSN 1069-6563
PII ISSN 1069-6563583

doi: 10.1111/j.1553-2712.2008.00201.x

axis.[6–8] This pathway is defined by the American Heart Association as the recommended path for electrical discharge during emergency defibrillation techniques and was used to create a discharge vector with a higher likelihood of producing cardiac capture. We conducted this study to re-create the animal research with human subjects to examine this possibility.

METHODS

Study Design

This was a prospective, nonblinded study of adult human volunteers recruited at several TASER International training courses in 2007. The institutional review board of Hennepin County Medical Center approved the study. All subjects provided informed consent before enrollment.

Study Setting and Population

This study was performed at TASER ECD training courses using volunteer human subjects attending the training courses. As a voluntary part of their training, they were to receive an ECD exposure from a TASER X26 device. All adult subjects (age > 18 years) who were going to receive this exposure were eligible for enrollment in the study. All volunteers were personnel involved in various aspects of law enforcement. They did not have to participate in the study as a requirement for successful course completion, but declining to participate in the study did not necessarily absolve them from receiving an ECD application as part of the training course. The exclusion criteria were known pregnancy and persons with a known mental illness. Study volunteers were given a TASER X26 ECD on successful completion of the study protocol. The TASERs were donated by TASER International.

Study Protocol

All volunteers completed a medical questionnaire for the purpose of gathering additional medical information for descriptive reporting. The descriptive data points gathered for all subjects included age, gender, body mass index (BMI) parameters, medical history, and current medication use. After completion of the study questionnaire, all volunteers underwent limited echocardiography before, during, and after a 10-second TASER X26 ECD application with preplaced thoracic electrodes. The electrodes were placed in the optimal cardiac axis position per American Heart Association guidelines for emergency transcutaneous cardiac defibrillation or pacing.[9] This position was at the upper right sternum and the cardiac apex as estimated by the palpated point of maximal impulse. Ultrasound images were analyzed using M-mode through the anterior leaflet of the mitral valve for evidence of arrhythmia by a trained ultrasonographic emergency physician (EP). Heart rate (HR) and the presence of sinus rhythm were determined.

The ECD application consisted of a 10-second continuous application (standard application is 5 seconds with each trigger pull) with manually applied skin surface electrodes powered by a factory standard TASER X26 model ECD (Figure 1; TASER International, Scottsdale, AZ). The exposure consisted of manually applying electrodes to the volunteer while they were lying on a padded mat in a supine position. The electrodes were manually placed instead of fired from the ECD, to assure exact placement position on each volunteer.

Figure 1. TASERX26 electronic control device (ECD; cutaway view).

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 PLC is not a standard part of an ECD, but the use of it during this study did not change the characteristic of the electrical waveform. The purpose of the PLC was to enable the ECD current application to be delivered in an objective, reproducible, and controlled fashion. With the exception of this PLC, the ECD was not altered from the factory standard. The PLC was programmed to deliver the ECD discharge for a total of 10 continuous seconds. Upon completion of the application protocol, the electrodes were removed, the attachment points were disinfected, and adhesive bandages were applied if needed.

Echocardiography was used for continuous cardiac monitoring before, during, and after the ECD exposure, so that HR and rhythm could be determined without interruption. A parasternal long-axis view of the heart was obtained by an unblinded, trained EP sonographer, and M-mode was used to record a continuous tracing of the mitral valve (Figure 2). A Sonosite Micromaxx (SonoSite, Inc., Bothell, WA) with a P17 tranducer (5–1 MHz 17-mm broadband phased array) was used to obtain echocardiographic images. An obstetrical preset (machine imaging mode allowing for computer calculated HR) was used, so that HR could be accurately determined by measuring the distance between E and A peaks on the M-mode tracing. Echocardiograms were continuously recorded, for later review, as MPEG-4 videos using Security Spy software (http://www.securityspy.com/) with a direct feed into a MacBook computer. Each M-mode tracing was immediately measured to accurately determine HR before, during, and after ECD exposure. Captured video was later reviewed by the ultrasound physician to determine if sinus rhythm could be demonstrated during ECD

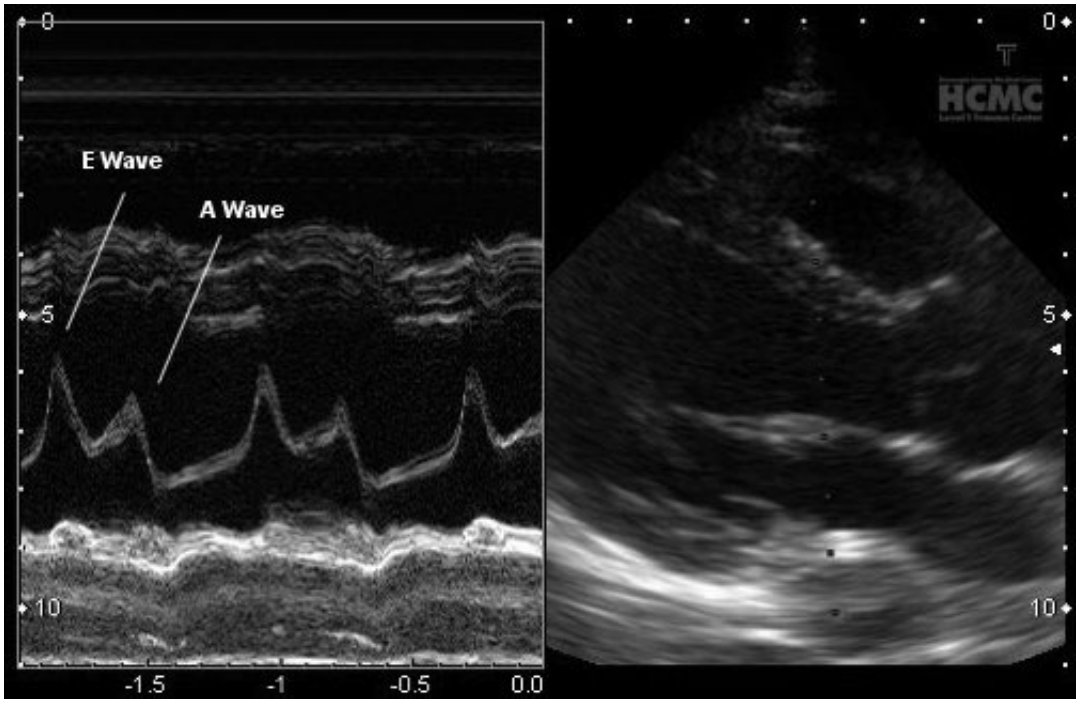

Figure 2. Echocardiographic M-mode image of E-A wave peaks of mitral valve and long-axis parasternal view of the heart.

exposure by the presence of an E/A pattern on M-mode tracing.

Data Analysis

All data were recorded in a spreadsheet format and underwent descriptive statistical analysis.

RESULTS

A total of 33 subjects were enrolled, 100% were male, mean (±standard deviation [SD]) BMI 29.8 (±4.8), mean age 40.5 (±10.5) years, range 28 to 59 years. There were no adverse events reported. The mean HR prior to starting the event was 108.7 beats/min (range 65 to 146 beats/min, 95% CI = 101.0 to 116.4 beats/min).

During the ECD exposure, the mean HR was 120.1 beats/min (range 70 to 158 beats/min, 95% CI = 112.2 to 128.0 beats/min) and a mean of 94.1 beats/min (range 55 to 121 beats/min, 95% CI = 88.4 to 99.7 beats/min) at 1 minute after ECD exposure. Sinus rhythm was clearly demonstrated in 21 (61.7%) subjects during ECD exposure (mean HR 121.4 beats/min; range 75 to 158 beats/min, 95% CI = 111.5 to 131.4 beats/min). Sinus rhythm was not clearly demonstrated in 12 subjects due to movement artifact (mean HR 117.8 beats/min, range 70 to 152 beats/min, 95% CI = 102.8 to 132.8 beats/min). There were no episodes of ventricular tachyarrhythmias noted in 33/33 cases (100%, 95% CI = 89.6% to 100%).

There were 11 volunteers with significant past medical problems requiring controlling medications. There were 6 subjects with hypercholesterolemia on statins, 2 subjects with hypertension on ACE inhibitors, two subjects with diabetes on oral hypoglycemics, and one subject with hypothyroidism on synthroid.

DISCUSSION

TASER is a brand name (acronym for Thomas A. Swift Electric Rifle) of ECD and is manufactured by TASER International, Inc. (Scottsdale, AZ). The terms TASER and ECD are often used interchangeably because, at the time of this writing, the TASER brand of ECD has market product dominance. Currently, TASER International manufactures two law enforcement models (X26 and M26) and four civilian models (C2, X26c, M18, and M18L). The X26 is the latest generation and the most popular model currently in use and was the model used in this study. It is considered to be a nonlethal weapon under the definition set forth by the United States Department of Defense,[10] and it is generally considered to be an intermediate weapon by most law enforcement agencies.

Intermediate weapons (those devices that generally can induce subject compliance due to pain or incapacitation and are a level above empty hand control techniques but less than deadly force) are available for law enforcement, military, and civilian applications. Examples of intermediate weapons include devices such as aerosolized chemical irritants, impact batons, projectile beanbags, and ECDs. The ECD has received some favor by law enforcement officials because it appears to offer a force alternative that effectively decreases suspect and officer injuries.[11,12]

The TASER X26 ECD is programmed to deliver a roughly rectangular pulse of approximately 100 μsec duration with about 100 μC of charge at 19 pulses per second for 5 seconds.[13] The peak voltage across the body is approximately 1200 Volts, but the weapon also develops an open circuit arc of 50,000 Volts to traverse clothing in cases where no direct contact is made. The

average current is approximately 2.1 milliamperes. It uses compressed nitrogen to fire two metallic darts up to a maximum of 35 feet with a predetermined angled rate of spread. It is capable of transmitting an electrical impulse through two cumulative inches of clothing. When it makes adequate contact and the darts are of adequate separation (approximately 4 inches or greater), 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. Additionally, the TASER device has electrical contact points at its tip that are approximately 1.5 inches apart. These contact points may be touched to a subject during discharge of the weapon and are also considered a pain compliance technique, as the separation is not adequate to cause a full, involuntary contraction of muscles.

A prior human study has utilized a 5-second ECD exposure time that is generally accepted as equivalent to a single ECD exposure.[3] In this current study, we extended the single ECD application time from 5 seconds to 10 continuous seconds. We believe that this prolonged time may more accurately reflect some field-usage patterns, since some agitated subjects require more than a single ECD application. A single ECD application is considered to be a single depression of the trigger that would result in a 5-second discharge from the device. Alternatively, the ECD trigger could be depressed continuously, resulting in a ECD discharge for as long as the trigger is depressed. Current information from the manufacturer suggests that the majority of ECD exposures in the field are for 5 seconds or less (S. Tuttle, personal communication, April 17, 2007). Another reason that we studied prolonged application times was to increase the chance of uncovering an adverse effect, if one were to be found.

The placement of the electrodes in our study deserves some discussion. The American Heart Association guidelines for emergency transcutaneous cardiac pacing/defibrillation electrode placement recommend either sternal–apical, biaxillary, or apical-back positioning as optimal (class IIa: therapeutic option for which the weight of evidence is in favor of its usefulness and efficacy) for delivery of electrical current to the myocardium.[9] Each of these positions has been evaluated and found to have equivalent ability to deliver myocardial current as measured by transthoracic impedance.[14] We elected to use only the sternal–apical positioning (Figure 3); the other two positions described cannot be achieved during realistic field use of an ECD, since deployed ECD probes (fired simultaneously) can only contact a subject on the same side of the body.

Our sternal–apical positioning is similar to the electrode placement used by Dennis et al.[7] and Walter et al.[8] in their recent swine studies of ECDs. In their studies, descriptions of tachyarrhythmias to 300 beats/min with each exposure and some cases of VF are described. We have conducted multiple human ECD research trials with well over 400 subjects to date with probe positions in numerous configurations on the thorax and had never experienced any findings concerning for tachyarrhythmia induction (such as syncope, palpitations, electrocardiogram changes, etc.). We were therefore curious to examine the differences between human and swine modeling in ECD research. In the current study, we were unable to reproduce in humans the findings of Dennis et al.[7] and Walter et al.[8]

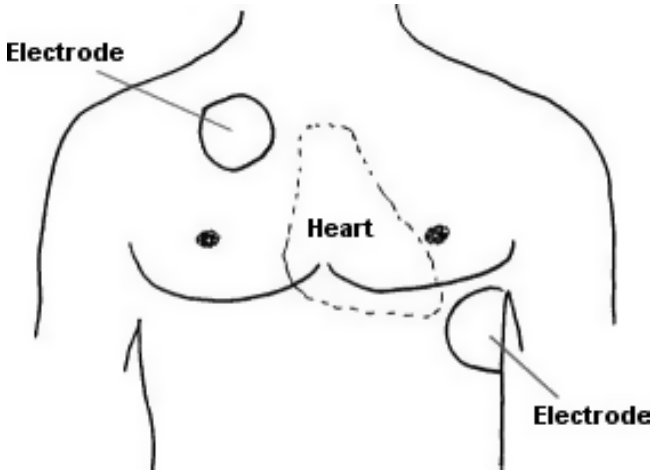

Figure 3. Sternal–apical electrode positioning.

There are several possible explanations for these differences. Animal models for this type of study are always artificially manipulated as a result of sedation and anesthesia required by ethical research boundaries. It is not known what cardiac effect could result from the introduction of exogenous medications prior to ECD exposure. It is likely that sedation, anesthesia, and supine positioning of a quadruped may affect the response to an applied ECD. This has been suggested by previous ECD studies. For example, Jauchem et al.[15] showed that a swine model fails to breathe during ECD application. A study by Ho et al. in 2007[16] demonstrated that this does not occur when nonsedated, unanesthetized human subjects are used. The study by Jauchem et al. initially led many to believe that ECDs might be causally linked to induction of sudden death due to asphyxia. However, other studies have failed to demonstrate this.

Animal size may also account for differences in our findings. Dennis et al.[7] used animals between 22 and 46 kilograms, and Walter et al.[8] used animals between 25 and 71 kilograms. The Centers for Disease Control and Prevention reported that the average weight for an adult male in the United States is 86.5 kilograms.[17] Since human males are the usual intended ECD targets, it is likely to be more valid to use an adult human male model for this type of research than a swine model. In our study, the mean weight of our subjects was 96.0 (±14.6) kilograms, which is at least on par with the average American male adult. Additionally, there have been instances when persons of small stature have experienced a ECD deployment without evidence of sudden death or disability.[18,19] Collectively, this human data do not support the theory of an ECD-induced fatal arrhythmia.

It is also possible that the swine model may simply be a poor model for simulating human exposure to

ECDs. In 2007, Ideker and Dosdall[20] reviewed animal data to make assumptions about the ability of the TASER X26 to induce cardiac arrythmias in humans. They determined that less than 0.4% of adults would have an ectopic beat induced by a TASER, even when the electrodes were placed in a worst-case scenario location for pacing. The stimulus required to cause VF is higher than that needed to cause an ectopic beat, and again using animal data, they concluded that the pulse needed to induce VF would have to be 30 times greater than the TASER X26 pulse. These results are in agreement with our findings in the human model. However, several investigators using swine models have found that tachyarrhythmias, and in certain cases, VF can be induced.[6–8] These concerning findings using swine models are not consistent with the data reported from human study and experience, where there have been no reports of collapse, syncope, or death that would be expected with high capture rates during discharge.[2,3,5] Also, the findings of previous studies using a swine model are not supported by our current findings from humans.

In our study, 12 subjects had movement artifact, and the ultrasonic view of the mitral valve was not maintained during the full ECD exposure; however, visualization of the posterior wall of the left ventricle was. Because the mitral valve view was lost, sinus rhythm could not be assured with complete certainty in this group. However, the posterior ventricular wall view allowed for accurate measurement of the rate of cardiac contraction and this did not rise greater than 152 beats/min in any of these subjects. This data are in contradistinction to a previous animal model findings of cardiac capture reporting rates of 300 beats/min.[7]

Although some sudden, unexpected, custodial deaths have occurred temporally proximate to an ECD application, a causal link between the two has not been established. Critics of ECD technology believe that animal research findings, as described above, may point in the direction of potential causation. However, these types of sudden custodial deaths have been documented well before the invention of this technology.[21] A similar theory of causal relationships occurred when oleoresin capsicum irritant spray was first introduced into the law enforcement market.[22] Eventually, it was determined that this irritant spray was not the cause of custodial deaths.[23,24] It appears that ECD technology may now also be going through this type of societal scrutiny.

Although the possibility of ECD-induced arrhythmias has been examined previously,[2,3] it had not been done in human subjects using an ideal cardiac axis electrode placement. Additionally, prior cardiac evaluation studies in humans have always used a before/after methodology with electrocardiography. The electrical artifact generated by the ECD application made real-time electrocardiography impossible. Our use of real-time echocardiography has allowed simultaneous delivery of ECD current and monitoring of HR and rhythm, which eliminates any uncertainty of arrhythmia induction at the time of exposure.

If an ECD is capable of causing an arrhythmic death in humans, one would expect that nearly any induction of arrhythmia would be immediate and result in instantaneous collapse. We acknowledge that the possibility of electrically induced ventricular tachycardia that degenerates to VF could occur over several seconds, but this is rare and is almost never seen in humans without significant underlying heart disease.[20,25,26] In a surveillance of 8 months of sudden and unexpected custodial death events in the United States, only 27% of these events were associated with occurrence proximal to application of a ECD, and none of the subjects collapsed immediately after the application.[27] In addition, an even more compelling set of data comes from the training classes conducted by the ECD manufacturer TASER International. These classes have delivered over 700,000 ECD applications to participants with no reported collapses, cardiac arrests, or fatalities.[28] When these data sets are both considered, the possibility of an ECD induced arrhythmia seems extremely unlikely.

There has been a single report in a letter to the editor of a case of VF found after exposure to a ECD that merits some mention.[29] The paramedic field report for this case (that was not part of the letter) indicated that the subject received an ECD application because of apparent threatening behavior toward a police officer during a prolonged, agitated state. The subject was successfully subdued, but found to be in cardiorespiratory arrest approximately 15 minutes after the ECD application. We believe that this case is very similar to every other described in the literature in which the cardiopulmonary arrest event occurs proximal to ECD exposure, but collapse is not instantaneous. We also believe that the facts of this case report do not support an electrically induced arrhythmic event.

LIMITATIONS

A potential limitation of our study is the duration of time that the ECD was applied. The studies by Dennis et al.[7] and Walter et al.[8] both used two 40-second ECD applications. It is possible that if we had used similar time applications, we may have seen similar results, although Nanthakumar et al.[6] demonstrated ventricular capture and inducement of VF in swine with single 5- to 15-second ECD exposures. We elected to study 10-second exposures because of the discomfort involved with the ECD application, and the fact that two continuous 40-second exposures is an extremely atypical, and likely unrealistic, application of an ECD under normal field-use conditions. We believe that a 10-second continuous application more closely approximates the way that ECDs might typically be used in the field.

We recognize that our small sample size of 33 limits our ability to detect all concerning events. Also, it is possible that the study subjects we enrolled may have body habitus characteristics that could raise their transthoracic impedance above that of a typical American adult. Our study subjects were exclusively male law enforcement officers. Had they been asthenic females with little breast tissue, we may have found a different result. However, previous research indicates that our study population closely mimics the population at highest risk for sudden custodial death when gender, age, and BMI are taken into account.[30,31]

Although there is a perception that using law enforcement personnel as our test population might introduce a ''healthy'' population bias, we believe this to be of minimal influence. Our mean volunteer age was 40.5 years, with a mean BMI of 29.8. This indicates that our typical volunteer is not a young academy recruit and has borderline obesity by federal standards. In addition, 11/33 (33.3%) of our volunteers had significant health problems requiring controlling medication. Based on these findings, we believe that our volunteer population likely reflects an average American citizen and not necessarily a person of exceptional fitness.

Finally, we recognize that we are not fully simulating real-world field conditions of ECD exposure. Because ECDs are often used on subjects with illegal drug intoxication, heightened sympathetic tone, and underlying heart diseases in the field, it is possible that our study conclusions are limited by the absence of these factors. Because of the illegal and unethical nature of performing a human study that would fully explore this, we realize that this question may not be able to be answered by an experimental model.

CONCLUSIONS

A 10-second ECD exposure in volunteer human subjects, applied in an ideal cardiac axis application, did not induce any concerning tachyarrhythmias. This finding supports prior human research. Our study suggests that a swine model has limitations in the study of ECD technology that may lead to inaccurate conclusions. We recommend further human study in this area to validate our findings, as well as further comparative studies involving swine models to determine which aspect of the established swine experimental technique is leading to the observed differences.

The authors acknowledge the valuable assistance of Mr. Mark Johnson, Mr. Andrew Hinz, and Mr. Matthew Carver with this project. Without their help, this study would not have been able to be completed.

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