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Cardiac Effects of Varying Pulse Charge and Polarity of TASER® Conducted Electrical Weapons

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Abstract:
The TASER® CEW (Conducted Electrical Weapon) is rapidly replacing the club in the English-speaking world for assisting in the arrest of resistant subjects and is now used by the majority of law enforcement agencies in the USA, Canada, and the UK. Animal safety studies of the CEW have focused on the risk of VF. We sought to determine the difference in cardiac capture and VF risk between the approximately 102 ± 8 μC of the ubiquitous X26 and a metered 72 μC charge from an experimental device. It is well established from the bidomain theory and experimental data that a pacing electrode will capture the heart with significantly lower charge when the electrode touching the cardiac tissue is a cathode However, experimental data show that there is no difference in the ability of the anode vs the cathode to induce VF. We sought to evaluate the effect of polarity changes on cardiac capture and the induction of VF. Small swine (~ 20.0 kg) were anesthetized and ventilated. The apex of the heart was located via echocardiography and a CEW probe was fully inserted towards the apex. Echocardiography was used to monitor cardiac contractions to determine cardiac capture. Both the X26 and the 72 μC pulses were delivered at both polarities to test for cardiac capture. Higher charge pulses (375 μC) were then delivered with both polarities to test for VF risk. The 72 μC experimental unit was unable to cause cardiac capture even in small swine with fully inserted probes directly over the apex of the heart. We found no polarity effect in the risk of VF in small swine with larger charge (~5x) pulses.

Keywords: TASER, CEW, charge, VF, capture

INTRODUCTION

The TASER® CEW (Conducted Electrical Weapon) is rapidly replacing the club in the English-speaking world for assisting in the arrest of resistant subjects.[1-8] It is now used by the majority of law enforcement agencies in the USA, Canada, and the UK. Suspect and officer arrest-related injuries are reduced by an average of 63% in agencies adopting the CEW.[9] As of July 2009 the total human applications are estimated to be over 1.74 million with about 940,000 of these training applications (mostly to the back) and 800,000 field uses.[9] In 19% of field applications there is a probe deployment to the chest.[8] This gives an estimate of 152,000 human chest exposures. Some swine studies have reported the induction of VF (ventricular fibrillation) from the TASER X26™ CEW. However, human studies have not found VF in human chest applications in either clinical[10-12] or prospective field studies.[8,13] Cardiac capture (the induction of at least an extra heartbeat by electrical stimulation) requires far less charge than the induction of VF. The induction of VF typically requires 12 times as much charge as does cardiac capture.[14] While VF is clearly an undesirable outcome, cardiac capture is not necessarily a negative outcome. With rapid cardiac capture, the blood pressure would fall, the suspect would cease fighting and the CEW could be turned off without suspect injury. We elected to monitor for both capture and VF in this study.

The most critical design parameter of a CEW pulse is the delivered pulse charge. It has been estimated that a pulse charge of 64 μC (microcoulombs) is the minimum to achieve sufficient muscle control in a human to cause the required fall.[15] On the other extreme, pulses with a charge of 20,000 μC are estimated to be likely to cause VF with a chest application.[16] We sought to determine the difference in capture and VF risk between the 102 ± 8 μC of the X26 and a metered 72 μC charge from an experimental device.

It is well established from the bidomain theory and experimental data that a pacing electrode will capture (pace) the heart with significantly lower charge when the electrode touching the cardiac tissue is a cathode (negative polarity).[17,18] However, experimental data show that there is no difference in the ability of the anode vs the cathode to induce VF.[17] We sought to evaluate the effect of polarity changes on cardiac capture and the induction of VF.

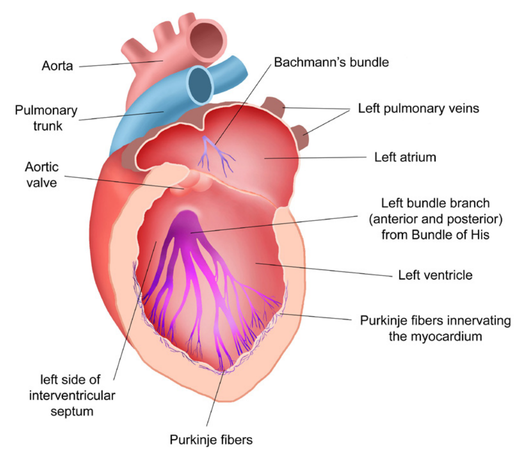

Fig. 1. Human Purkinje fibers are endocardial.

METHODS

It has been known since 1936 that swine are unusually sensitive to the electrical induction of VF.[19] In dogs and humans the Purkinje fibers are confined to a very thin endocardial layer as shown in Fig. 1.[20] In swine they cross the entire ventricular wall as seen in Fig. 2.[21]

It has been recently demonstrated that the electrical activation in swine proceeds from the epicardium to the endocardium while in dogs and human it proceeds in the reverse direction.[22] Thus, swine are much more sensitive to external electrical currents. Swine hearts are literally wired "inside out" compared to humans.

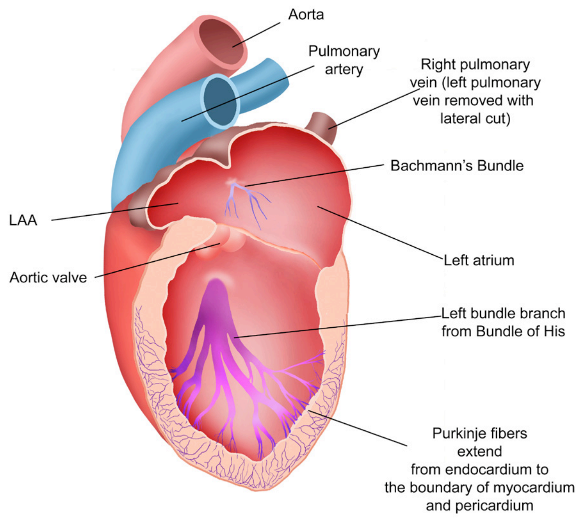

Fig. 2. Swine Purkinje fibers are transmural to initiate cardiac activation at the epicardium.

In addition, swine are extremely sensitive to higher frequency electrical currents. Ventricular ablation with radio frequencies is routinely done in human beings without problems yet will typically result in VF in swine.[23] A possible cause (beyond the transmural Purkinje fibers) for this observation lies with significant ion channel differences.[24]

In spite of the fact that swine are more sensitive to electrical currents it is appropriate to use them for relative within-species comparisons. For example, it is scientifically valid to use swine to study the differential effects of cocaine versus no cocaine, on the CEW safety margin, such as done by the Cleveland Clinic.[25] Similarly, swine can be used to study the effects of varying body weight on the ECD safety margin.[26]

Small swine (19.5 and 20.0 kg) were anesthetized and ventilated. The apex of the heart was located via echocardiography and a CEW probe was fully inserted towards the apex. Skin-to-epicardium distances were 12.4 and 16.9 mm respectively in subjects 1 and 2. With the fully inserted 9 mm probe, the probe tip-to-heart distances were 3.4 and 7.9 mm. A second CEW probe was fully inserted in the abdominal region. Continuous echocardiography was used to monitor cardiac contractions to detect any cardiac capture.

Both the X26 and the 72 μC pulses (19 PPS for 15 seconds) were delivered at each polarity to test for cardiac capture. Anodal stimulation was defined as the delivery of a positive (anodal) pulse to the probe over the apex of the heart. (The top probe of the TASER X26 CEW is the anode.) Higher charge pulses (375 μC) were then delivered (by adding capacitors in parallel) with both polarities to test for VF risk.

RESULTS

Cardiac capture results are given in Table 1. There was no cardiac capture (0/15) with the metered 72 μC experimental device. This was different from the X26 device (16/21) with strong statistical significance (p = 0.000006). There was no difference between the cathodal or anodal capture rates. There was no difference in the capture rates for either device between the 2 subjects.

Table 1. Cardiac Capture Results

CEW	Charge (μC)	Cardiac Capture with Cathode	Cardiac Capture with Anode	χ^2 p value
X26	~100	11/13	5/8	NS (.25)
Exp	72	0/11	0/4	NS
χ^2 p		0.000034	0.038	

The charge was gradually increased to 375 μC in order to test the effects of polarity on the electrical threshold of VF. There was no induction of VF at pulse charges up to 300 μC. Pulse charges of 340-375 μC were then applied. The VF induction rate was 3/7 for cathodal stimulation vs. 0/3 for anodal stimulation which was not significant (p = .18 by χ^2).

DISCUSSION

Classical stimulation theory and data have clearly demonstrated that the stimulation capability of a short pulse is best measured by its charge.[15,52,53] This is consistent with our results as the metered 72 μC experimental device had less cardiac stimulation than the X26 CEW with a typical ~100 μC of charge. It is notable that the 72 μC charges *never* caused cardiac capture even in very small swine (20 kg) with a fully inserted probe *directly* over the heart apex.

Our results are consistent with the findings of Valentino *et al* which found VF occurred equally with either polarity in small swine with the X26 CEW.[42] We did not find a difference in the cardiac capture abilities of anodal vs. cathodal stimulation. This is different from the predictions of the bidomain model.[18] However, our probes — while close to the epicardium — were not in *direct* contact.

The CEW has dramatically reduced both suspect and officer injuries. The CEW has also significantly reduced officer-involved firearm shootings.[13] The experience of the Portland, Oregon, Police Department (PPD) provides an unusual opportunity for a dose-response analysis as they implemented their CEW deployment in 3 stages. As they moved from 0 to 360 CEWs the officer-involved shooting rate fell from a mean of 9.3 per year to below 4 per year as seen in Fig. 3. This was highly statistically significant (p = 0.014). The linear regression relationship was:

Shooting rate = 9.28 – 0.016 * CEWs

Every 63 CEWs (1/0.016) prevented a shooting per year.

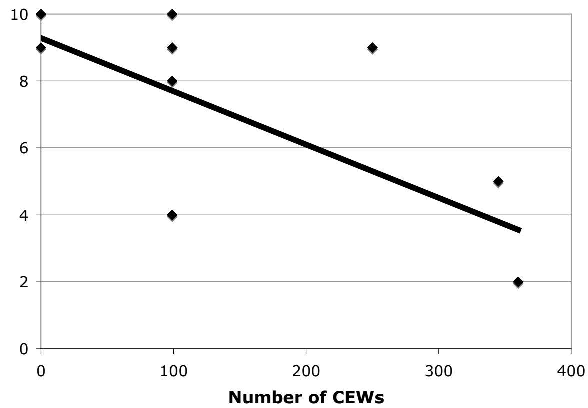

Fig. 3. PPD saw a dramatic reduction in officer-involved firearms shootings with deployment of CEWs.

The annual arrest-related death rate is around 800 for North America.[27] A CEW is used in less than 10% of these cases.[28,29] However, news media attention focuses on the less common CEW-present deaths. Whether this is due to lay ignorance of electricity or the novelty of CEWs is not clear. Similar concerns were expressed when OC (Oleoresin Capsicum or "pepper") spray was introduced.[30-35] The cause of death from application of electrical currents (outside of massive currents such as those from lightning strikes or power lines) is the induction of VF.[36-39] For this reason CEW animal safety studies have focused on the risk of VF.[40-44]

Nevertheless, VF is rarely seen with custodial deaths in which a TASER CEW was involved.[45] This suggests that electrical causation is very rarely, if ever, involved in custodial deaths. A century of experience with electrical accidents and safety studies have found no dangers from currents on the level of the TASER CEW.[46,47]

The TASER ECD satisfies the UL (Underwriters Laboratory) standards for electric fences.[48] If the pulses from a TASER ECD were dangerous then there would have been 1000s of deaths from the ubiquitous electric fences. TASER ECDs deliver less current than many models of TENS (Transcutaneous Electronic Nerve Stimulator) units. For example, the popular EMPI Select unit delivers up to 4.5 mA of average current which is twice that of the TASER X26. It is popular in Europe to use TENS units for treating angina with the electrodes placed across the cardiac silhouette.[49-51] No deaths have been reported.

CONCLUSIONS

A 72 µC experimental unit was unable to cause cardiac capture even in small swine with fully inserted probes directly over the apex of the heart.

We found no polarity effect in the risk of VF in small swine with larger charge (~5x) pulses. There is no benefit of using one polarity over another for CEW safety.

DISCLOSURES

Dr. Kroll sits on the corporate and advisory board of TASER Intl, Inc. Dr. Panescu is a paid consultant to TASER.

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