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TASER Conducted Electrical Weapons and Implanted Pacemakers and Defibrillators

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Abstract—**Introduction: Conducted electrical weapons (CEW) have generated controversy in recent years regarding their effect on heart rhythm and on their suspected interaction with implanted devices such as the pacemakers and ICDs (implantable cardioverter defibrillators). We review the current evidence available on device interactions and pre-sent a new case series of 6 patients. Literature: We used the available case reports and animal studies on TASER or CEW related publications in PubMed. Conclusion: Oversensing of TASER CEW discharges may cause noise reversion pacing in pacemakers and inappropriate detection of VF in ICDs. The nominal 5-second discharge is sufficiently short that neither clinically significant inhibition of bradycardia pacing nor inappropriate ICD shocks have been reported. Current evidence indicates that CEW discharges do not have adverse effects on pacemakers and ICDs.**

Key words: CEW, TASER, Electrophysiology, Pacemakers and ICDs.

I. Introduction

ELECTRICAL current and its effect on heart rhythm and myocardium are well studied and this interaction forms the basis for cardiac pacing and defibrillation. Conducted electrical weapons (CEW) are increasingly used tool by the law enforcing agencies to resolve conflict with a proportionate, lawful, appropriate and necessary use of force [1]-[2]. It is well known that implantable cardiac devices such as pacemakers (PM) and implantable cardioverter defibrillators (ICDs) are susceptible to electromagnetic interference (EMI). This potential interaction between CEWs and implantable cardiac devices is poorly understood and data are limited to anecdotal reports [3]-[5] except for our previous animal study [6].

The most commonly used CEW is the TASER X26 model, which is a pistol shaped device weighing about 205 grams. It has a limited power source (a battery of 2 lithium camera cells) and shoots 2 tethered probes. They deliver 19 very short duration (100 μs) pulses per second, with a typical peak voltage of 1300 V (1000–1500 V), for 5 seconds in a typical burst [7]. The average voltage during the 100-μs duration of the pulse is about 400 volts. The device can also generate an open-circuit voltage of up to 50,000 V to arc through air or across thick clothing but that voltage is never seen in, or ‘‘delivered into” the body. The probe cartridge can be removed and the device used in a ‘‘drive-stun” mode by pushing the front of the weapon into the skin to function as a higher charge stun gun [8].

The electromagnetic environment in which pacemakers and ICD operate has become increasingly complex. The most common device problem associated with external EMI is rapid oversensing, resulting in inhibition of bradycardia pacing or mode switch to a noise-reversion pacing mode. Recent case reports add CEW discharges to this environment [4]-[5]. Our case series describes the effect of CEW devices on the pacemaker and ICD. We also summarize the current literature involving CEWs and cardiac device interactions in both animals and humans.

II. Case reports

We describe 6 patients with either a pacemaker or an ICD who received CEW applications. Table-I provides details. Two patients had pacemakers, and 4 had ICDs. In only 1 patient (Patient#5), the CEW discharge resulted in sufficient rapid oversensing to cause inappropriate detection of a tachyarrhythmia. This patient with an integrated bipolar lead had inappropriate detection of VF, but the shock was aborted because the CEW discharge ended before the capacitor was fully charged. There may have been other intermittent oversensing but it was never sufficient to trigger electrogram storage.

No device had reprogramming, changes in pacing or sensing when evaluated, or other detected interference with device function. No patient had alteration in consciousness during or immediately following CEW discharge, including Patient 4, who had complete heart block. Only patient#5 had sufficient oversensing to detect a tachyarrhythmia. In this case, oversensing resulted in inappropriate detection of VF, but the discharge stopped during capacitor charging, so the shock was aborted.

Table I Summary of clinical and device characteristics in patients with cardiac devices who had CEW applications.

Characteristics	Patient#1	Patient#2	Patient#3	Patient#4	Patient#5	Patient#6
Age	25	45	56	61	42	53
Gender	Male	Male	Male	Male	Male	Male
Type of Device	DC-PM	DC-ICD	SC-ICD	SC-PPM	SC-ICD	DC-ICD
Associated Conditions	SSS	DCM	ICM	CHB	DCM	DCM
Mode of CEW Application	Drive Stun	Probes	Probes	Drive Stun	Probes	Probes
No. of Applications	3	2	4	2	1	Unknown
Location of Application	Chest/ Upper Abdomen	Back	Front Chest	Front Chest	Back	Back
Duration of Application (in seconds)	5	5	5	10	5	Unknown
Noise Detection on the Device	No	No	No	No	Yes	No
Noise Reversion Mode	No	No	No	No	No	No
Change in battery status, PT, ST, LI and SI from baseline	No	No	No	No	No	No
Change in battery status, PT, ST, LI and SI from incident interrogation	No	No	No	No	No	No

DC = Dual Chamber, SC = Single Chamber, PM = Pacemaker, ICD = Implantable Cardioverter Defibrillator, SSS = Sick Sinus Syndrome, DCM = Dilated Cardiomyopathy, ICM = Ischemic Cardiomyopathy, CHB = Complete Heart Block, PT = Pacing Threshold, ST = Sensing Threshold, LI = Lead Impedance, SI = Shock Impedance, TB = True Bipolar, IB = Integrated Bipolar.

III. REVIEW OF LITERATURE

Standards for device protection against strong applied electric fields

Pacemakers and ICDs are required by international standard to withstand the 360 Joule shock of an external defibrillator, lasting approximately 10 ms [9], and protection circuits have been incorporated to prevent damage to electronic components from transthoracic shocks. The TASER X26 CEW delivers 0.1 Joule with an interprobe resistance of 600 Ω with a pulse rate of 19 PPS and a pulse width of 100 μs. Thus, pacemaker and ICD protection circuits have ample safety margin to protect against TASER discharges (Table-II). Nevertheless, transthoracic defibrillation shocks can reprogram and occasionally damage pacemakers if a defibrillation electrode is placed directly over the pulse generator. Neither we nor any other investigators have identified reprogramming of or damage to pulse generators because of CEW discharges. Ironically, the very protection circuits that prevent damage to the pacemaker itself can facilitate parasitic pacing as discussed later.

Haegeli et al ICD Case Report

In ICDs, rapid oversensing long enough to fulfill the programmed VF detection duration results in inappropriate detection of ventricular fibrillation (VF). Haegeli et al. reported such a case in a 51 year old female ICD patient with an integrated bipolar lead [5]. Probes struck the woman in the sternum and the pulses were mistaken by the ICD as VF. The device began charging its capacitors to deliver a shock.

By the time the capacitors were charged, the CEW application was over and the ICD then went back to normal monitoring operation without delivering a shock.

Table II. Approximate electrical characteristics of some common sources of high-voltage shocks modified from Nanthakumar et al.[14]

Source	Peak Voltage	Peak Current	Duration	Energy
External Defibrillator	4000 V	40 A	10-20 ms	360 J
ICD	750 V	4-20 A	5-20 ms	35 J
Electroconvulsive Therapy	450 V	900 mA	<1 s	20 J
TASER X26	2000 V	3 A	0.1 ms	0.1 J

V = Volt, A= Ampere, mA =milliampere, s= seconds, ms = milliseconds, J = Joules

If the EMI persists until capacitor is fully charged, an inappropriate shock may be delivered. For CEWs, the likelihood of oversensing depends on three factors: (1) the stimulus amplitude of the CEW pulse, (2) the location and interelectrode distance of the CEW electrodes, and (3) the interelectrode distance of the pacemaker or ICD sensing dipole and its orientation relative to the applied CEW field.

Based on the these considerations, the report by Haegali et al., and our observations, oversensing of CEW pulses probably is more likely when the pulses are delivered by widely-spaced barbed dart electrodes than by closely-spaced drive-stun electrodes and more likely in ICDs with integrated bipolar sensing than true bipolar sensing. Usually, the nominal 5-second CEW discharge is long enough to result in inappropriate detection of VF, but not long enough to result in an inappropriate shock, because it ends before capacitor charging is complete. Thus most CEW-related oversensing episodes would be expected to result in aborted shocks.

Cao Pacemaker Case Report

Cao et al reported a case of CEW cardiac capture in which the CEW discharge was delivered directly over a pacemaker pulse generator [4]. The specific pacemaker involved had the typical overvoltage protection circuitry (see Figure 1) that passes negative potentials from the pacemaker housing ("can") to the intracardiac bipolar ring electrode which can cause unipolar cathodal pacing. A 53-year-old male had a dual-chamber pacemaker implanted subcutaneously on the left chest (Medtronic Kappa, model KDR901). The subject received a CEW barb mode application to his chest immediately over the pulse generator. This was reported to cause cardiac capture for the duration of the CEW pulse, but had no lasting effects as seen in Figure 2. Finite element modeling in this case indicates that the CEW field at the heart was much weaker than the stimulation threshold, but the field at the pulse generator was likely sufficient (5 – 10 V) to permit capture with the ring and tip electrodes [10]. This current pathway has the potential for ventricular proarrhythmia, but the level of risk is not known.

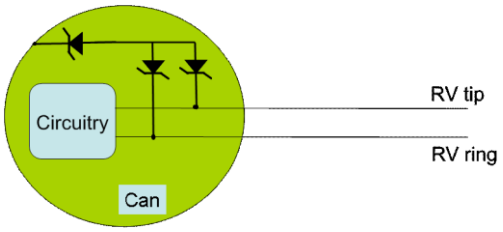

Figure 1: Typical pacemaker protection circuitry allows the shunting of negative voltages from the housing ("can") to the endocardial leads.

The presence of an implantable cardiac device may facilitate cardiac capture by EMI. Perhaps the best-studied example is that of electromagnetic radiation associated with magnetic resonance imaging (MRI). This may induce current in electrode loops, potentially resulting in cardiac capture or tissue heating at electrode myocardial interface. In swine, CEW discharges delivered close to the heart have resulted in direct cardiac capture [11]-[12]. However, cardiac capture has not been seen in humans (without implanted cardiac devices) even when electrodes were oriented across the cardiac axis [13]. However, as described previously, pacemakers may facilitate cardiac capture from CEW pulses under extremely unusual conditions: The CEW electrode needs to be extremely close to the pacemaker, and the pacemaker must function in the unipolar mode during the CEW discharge. It is important to note the distinction between the typical protection circuits in pacemakers vs. ICDs. While pacemakers use shunt protection circuits, ICDs use series switches to open in the presence of high voltages. This is necessary to prevent the shunting of the high voltage shocks developed by the ICD itself. This distinction suggests that ICDs should not conduct CEW-induced currents into the right ventricle.

Animal Studies

Our group studied the interaction between CEW discharges and implanted pacemakers and ICD [6]. In our study, an anesthetized pig model was prepared with insertion of 2 probes at the sternal notch and with maximum cardiac impulse separated by 1.5 cm from the epicardial surface. A prepectoral pocket positioned between the probes was created to place a device generator that was connected to either a defibrillator lead or to a pace-sense lead placed at the right ventricle apex (Figure 3).

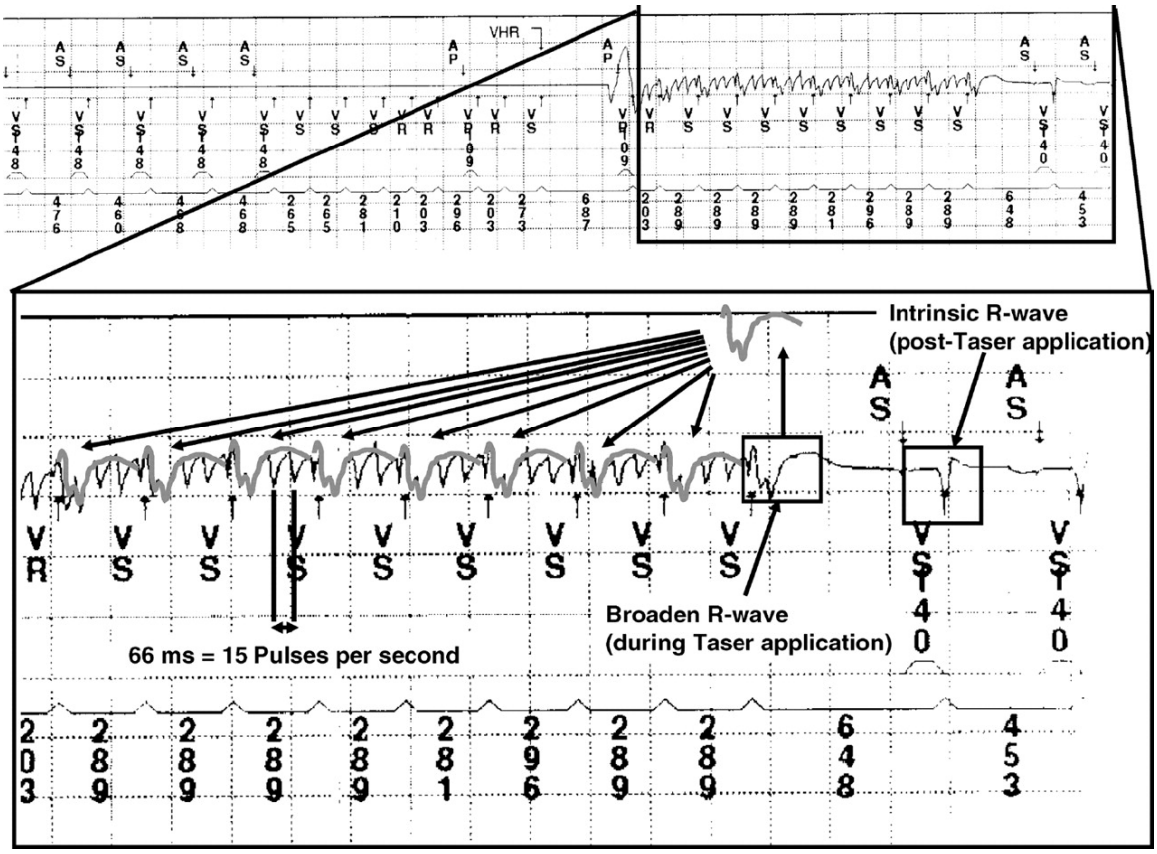

Figure 2 Electrograms during CEW show the modulation of the signal by a repeating R wave with morphology different than the intrinsic R wave (with permission from Cao et al).

Pacemakers and ICDs were programmed to detect and shock at maximum energy levels appropriately respectively. The animal was exposed 3 times with a standard CEW discharge of 5-second duration with each device being tested. A total of 7 ICDs and 9 pacemakers were checked in the same animal (Table III). Before and after each discharge, lead and generator functions were assessed with a device interrogator specific to the manufacturer. Pacing and sensing thresholds as well as pacing and shocking coil impedances were determined before and after each of the 3 CEW discharges and results were analyzed using the average of 3 post discharge values.

Analysis of the experiment results showed that there was no significant difference between the pre- and post-shock device values and no evidence of device malfunction. Thus the short-term functional integrity of implantable devices is not affected by standard CEW applications even when exposure is such that the generator is directly between the CEW probes.

Telemetry monitoring of the devices showed a consistent electrical artifact during the 5-second period of CEW shock as seen in Figure 4. All ICDs sensed the electrical activity and started capacitor charging. Mean cycle length of the artifact detected by ICDs varied among devices due to as different blanking periods.

VT or VF did not occur after the exposure to the CEW discharge, and no ICD delivered an inappropriate shock in response to a standard 5-second CEW exposure. The minimum charge time to shock delivery for all ICDs used in this study was >5 seconds, and this probably explains the detection, charge, and aborted therapy sequence seen in all models of ICDs.

Table III. List of pacemakers and ICDs tested

Pacemaker		ICD	
Manufacturer	**Model**	**Manufacturer**	**Model**
St. Jude	Enpulse	St. Jude	Atlas DR
St. Jude	Identity DR	St. Jude	Photon VR
St. Jude	Affinity DR	Medtronic	7273
St. Jude	Integrity AF	Guidant	Vitality DS
St. Jude	Affinity DR	Guidant	Ventak MS
Medtronic	Insync 2.77	Guidant	Vitality DS
Medtronic	Insync 2.95	Guidant	Ventak DR
Guidant	Meridian		
Guidant	Pulsar max		

Another important potential interaction of devices with electrical energy is switching into reset mode or other alteration of device parameters. It is very well known that external or internal defibrillation sometimes results in activation of reset mode or elective replacement indicator, or transient elevation of capture and sensing thresholds, primarily in older unipolar systems. We did not discern this type of interference in our study. With the delivery of this small amount of energy over 5-seconds and rapid cooling effects of blood with quick dissipation, significant cardiac tissue alteration which would change device threshold parameters is unlikely. Our study was done using the TASER-X26 CEW and probably can be generalized to other CEW models since the X26 has the highest net delivered charge.

In a porcine Calton et al model reported that a 15-second CEW discharge resulted in inappropriate detection of EMI as VF followed by inappropriate shocks [3]. A 5-second exposure to the CEW pulse terminated before the reconfirmation of VF which resulted in aborting the planned shock. We have clearly shown in our animal study that the electrical artifact created by TASER CEW current enables ICD detection and if it persists beyond charge and redetect timings may result in an ICD shock despite no true myocardial capture.

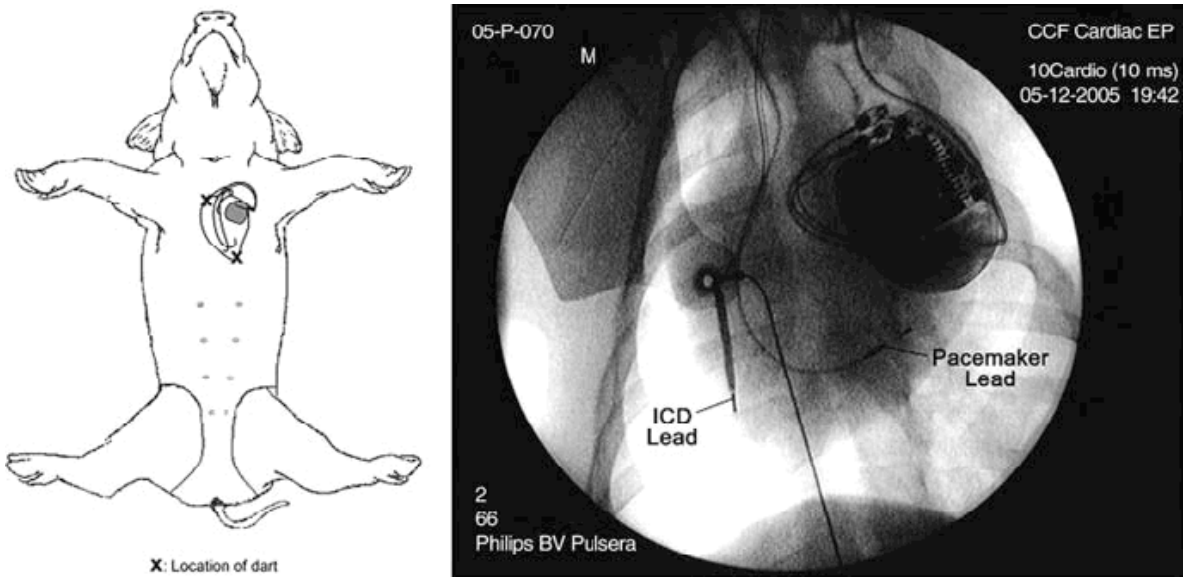

Figure 3: Location of the probes and device with leads in the study of Lakkireddy et al with permission.[15]

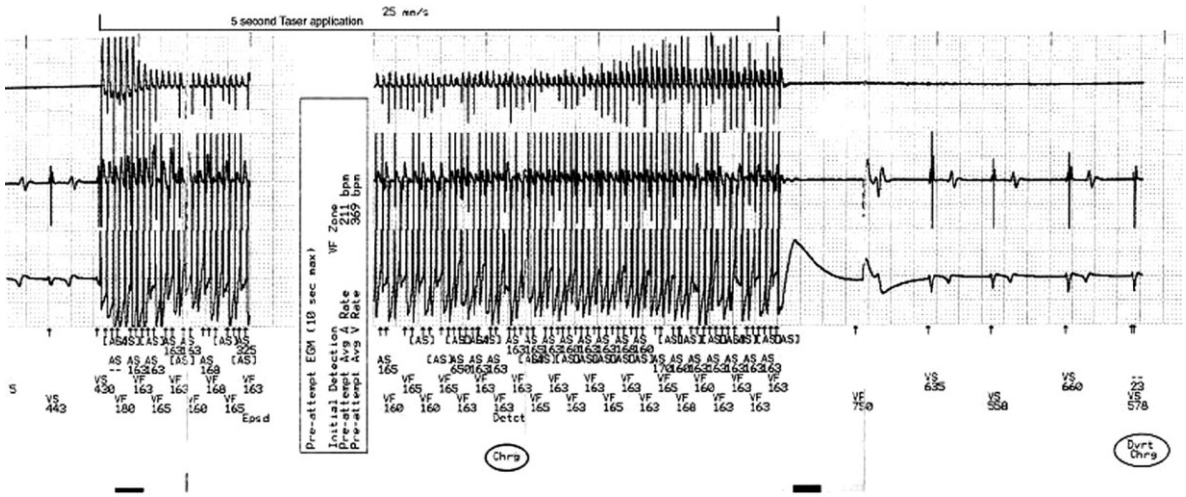

Figure 4: ICD memory record of CEW discharge. The interrogated electrogram after the CEW application showing onset of rapid rate detection with initiation of the application with a detected cycle length corresponding best to the detected CEW pulses rather than the ventricular electrograms even though accelerated ventricular capture can be appreciated visually at cycle lengths around 240 ms. From Lakkireddy et al with permission. [15]

We believe that the same explanation may explain the ICD shocks in the case reported by Haegeli et al [5]. Development of better noise reduction algorithms may help in differentiating the extracardiac from cardiac electrical activity and prevent inappropriate shocks.

IV. DISCUSSION

CEW interactions with pacemakers and ICDs are infrequent due to the significant differences in the demographics between the typical resisting subject requiring CEW control methods (30 ± 10 years) [1] and pacemaker patients (first implant 75.3 ± 11.1 years) [16]. TASER brand CEWs have been used an estimated 700 000 times in the field [17] with only a handful of reported pacemaker and ICD patients as the recipients of the application.

The most common device-device interaction is detection of the CEW pulses as rapid oversensing, which should put the pacemaker into noise reversion DOO, or VOO mode for the duration of the application. This should prevent syncope in the pacemaker-dependent patient. For an ICD patient, oversensing of CEW pulses may result in inappropriate detection of VF. There is a risk of an ensuing shock delivery, but as discussed earlier, this is unlikely because the typical CEW application is shorter than typical the ICD detection and capacitor charge times.

V. CONCLUSION

CEWs represent a new, uncommon source of device-device for pacemakers and ICDs that may result in rapid oversensing, resulting in noise reversion bradycardia pacing or inappropriate detection of VF by ICDs. The likelihood of oversensing is greatest when the CEW is discharged through widely-spaced probe electrodes near the heart and the sensing dipole is wide (unipolar sensing in pacemakers, integrated bipolar sensing in ICDs). The nominal 5-second duration of CEW discharges is too short to result in inappropriate shocks in most ICD patients. CEW discharges do not damage cardiac devices, alter programming, or change pacing thresholds. CEW discharges delivered directly over a pacemaker housing may facilitate rapid pacing and capture for the duration of the discharge.

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