TASER and In-Custody Deaths

Cardiac Effects of Conducted Electrical Weapons

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Heart and Vascular Institute

Cleveland Clinic
What is a stun gun?

- A device that delivers rapid electrical impulses that stimulates nerves and muscle rendering the subject incapable of voluntary movement.

- TASER, International is the dominant manufacturer of these devices. The largest users are law enforcement agencies.
TASER X26
Parts of the X26

- AFIDs
- TASER CARTRIDGE
- TASER WIRE
- PROBES
- BLAST DOORS
- LASER SIGHT
- (LIL) LOW INTENSITY LIGHTS (LEDs)
- (DPM) DIGITAL POWER MAGAZINE
- TEXTURED GRIP ZONES
- SAFETY SWITCH
- STAINLESS STEEL SHOCK PLATES
- DPM RELEASE BUTTON
- ILLUMINATION SELECTOR
- HIGH VISIBILITY SIGHTS
Operation

• One pull of the trigger delivers a 5 second series of pulses from the device
• Frequency of pulses is 19/sec (59 ms duty cycle)
• Each pulse is approximately 100 microsec in duration
• The device acts like a constant current generator – i.e. it will try to deliver the same current waveform over a wide range of impedances.
Current Waveform

Kroll and Kroll,
http://www.taser.com/research/Science/Pages/TASERDeviceElectricalDesign.aspx
Demonstration of TASER application

- Police Training video
- Darts are fired into the back
- The single application lasts 5 seconds
- Note total muscular paralysis and rigidity
TASER Use Associated With In-Custody Deaths

• Since 2000, there has been an estimate of 650,000 field uses of TASER
• A public records search has found over 400 deaths associates with the use of TASER*
• An estimate of about 200 deaths occurred within 15 mins of TASER application.*
• Based on these numbers, assuming a causative relationship, the incidence is approximately 3 deaths /10,000 applications or 0.0003.

* Personal Communication, Dr. Charles Swerdlow, UCLA.
Can TASERs Cause Cardiac Arrhythmias?

• The most likely causation candidate for deaths immediately after stunning with TASER is the induction of cardiac arrhythmias.

• TASERs deliver electrical pulses. If these pulses were able to pace the heart at a rapid rate, then arrhythmia induction is a possibility.

• What is the evidence that TASERs can capture the heart?
Physiology of Pacing or Cardiac Capture

The Strength Interval Curve

Current Density

0.1 ms  0.5 ms  2.0 ms

Pulse Width

Voltage Pulse

Cell Transmembrane Voltage Response
Can Tasers Cause Cardiac Arrhythmias?

There are several different ways to approach that question in experimental studies. It was reasonable to expect that proximity of the TASER darts to the heart would be important. And thus, animal studies have concentrated on this approach.
Can Tasers Cause Cardiac Arrhythmias?

One approach to answering this question is to establish a safety margin or a VF inducing threshold for application of TASER pulses near the heart.
Can Tasers Cause Cardiac Arrhythmias?

Taser Safety Factor

McDaniel WC, stratbucker RA, Nerheim M, et al.

Cardiac safety of neuromuscular incapacitating defensive devices.


Single position
Not necessarily the worst case
No intracardiac monitoring
CC Study Inception

- Approached by TASER, International 2005
- Reviewed existing studies
- Reviewed existing case reports of in-custody deaths involving TASER use
- Proposed assessing VF thresholds at different positions of TASER barbs on the body
- Proposed assessing myocardial capture
5 Barb Locations
Study Protocol

- General anesthesia, mechanically ventilated
- ABGs followed to maintain normal respiratory function/acid base balance
- Escalating power of TASER waveforms: Increasing the capacitor size by a multiple of the standard size
- Maximum safe capacitor multiple = 3 consecutive application w/o VF induction
Escalating TASER Waveform

Step Up To VF
1x, 5x, 10x, 20x, 30x, ……, 100x

Step Down By 10x decrements
5x, 3x, 2x, 1x

Standard 5 second duration of pulses
Results

• 13 pigs, Wt = 34.4 ± 6.9 kg
• Variables analyzed:
  – Minimum VF inducing capacitor multiple
  – Maximum safe capacitor multiple
  – Capacitor multiple that generated 3:1 capture (~180 ms CL or 330 bpm)
  – At Position 1 (PMI to sternal notch), average distance of barb tip at PMI to heart was 1.6 ± 0.33 cm
Example of VF Induction

2:1 capture occurring
Example of VF Induction
Example of 3:1 Capture

3:1 capture occurring
Example of 3:1 Capture

ECG

RV

RV activation

TASER pulses

ART
VF Induction Data

Output Multiples

Positions

P1  P2  P3  P4  P5

MinVFIM  VFT  MaxSM
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Ventricular Capture Data

![Graph showing ventricular capture data with positions P1 to P5 and output multiples for 2:1 Capture and 3:1 Capture.](image)
### Ventricular Capture Data

**Capacitor Multiples with 3:1 Capture**

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# Ventricular Capture Data

Capture Data at Standard Output

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Ventricular Capture
At Position 1 With Varying Barb Separation at Standard Output

- After assessing VF induction, the effect of barb separation at position 1 on ventricular capture was assessed at the standard TASER output.
- The separation of the barbs were approximately 15 cm. Thus barb separations of 2.5, 5, 7.5, 10, 12.5 and 15 cm were tested incrementally.
- One barb was fixed at the apex while the other one was moved incrementally towards the sternal notch.
- Then one barb was fixed at the sternal notch and the other barb moved incrementally towards the cardiac apex.
Ventricular Capture
At Position 1 With Varying Barb Separation
at Standard Output

% of Pigs with Capture

Interelectrode distance - cm

PMI towards SN  SN towards PMI
Conclusions

• While VF was not induced at standard output from the TASER, our findings were in contrast to the prior study in pigs which showed an over 15x safety margin for the induction of VF.

• At the most sensitive areas, as low as a 3x capacitor multiple was able to induce VF.

• Location of the dart on the chest and its electrical proximity to the heart plays an important role in whether the TASER pulses capture the.

• Dart separation 3 to 5 cm and above is necessary to optimize depth of TASER current propagation.

• Of significant concern, rapid capture was very common at standard output of the TASER at rates we commonly associate with potential induction of VF.
Controversies

• Should Studies be done in humans instead of Pigs?
• Are pigs inappropriate models of the human heart?
• Modeling studies of the human torso suggest lack of sufficient current from the TASER to capture the heart.
Nanthakumar, et al, University of Toronto

- 6 Pigs, 2 orientations of darts, general anesthesia
- Thoracic – right parasternal and left lateral thorax
- Abdominal – across the abdomen
- Standard TASER discharge of 5 and 15 sec
- Epinephrine infusion to increase HR by 50% for 15 mins

Nanthakumar et al. JACC 2006. Vol. 48, No. 4, 798–804
• 98% of X26 discharges in thoracic configuration had rapid capture of the myocardium

• With one application of 15 sec during Epi infusion, VF was induced

• VF induction was associated with 2:1 capture
Walter et al, TASER ARRHYTHMIAS IN PARALYZED SWINE, Chicago, IL

- 6 experimental pigs
- GA, Sch paralysis
- Echo verification of capture
- 40 sec TASER X26 applications
- Right of sternum to left of Umbilicus

ACADEMIC EMERGENCY MEDICINE, Jan 2008; 15:66–73
Walter et al, TASER ARRHYTHMIAS IN PARALYZED SWINE, Chicago, IL
“Since the fundamental law of electrostimulation estimates that the average minimum pacing threshold is 2.33 times the size of the TASER X26 pulse, the ventricular fibrillation threshold should be approximately 29 times the magnitude of the TASER pulse. This estimate is in good agreement with the experimental study of McDaniel et al, who found that the size of the pulses needed to induce ventricular fibrillation in pigs is a mean of 28 times the size of the TASER pulse. Again, these results are for electrodes located in small regions on the anterior chest; the stimulus strength required to initiate ventricular fibrillation with electrodes at other sites on the body surface should be much higher. Thus, it is unlikely that the TASER X26 will immediately induce ventricular fibrillation.”
What about Human Studies?

Ho, et al: Echocardiographic Evaluation of a TASER-X26 Application in the Ideal Human Cardiac Axis


- Manually applied surface electrodes
- Standard Taser output attached to the patches
- M-mode echo at the MV used to determine HR
- 33 subjects
- 21 subjects had SR during TASER application mild increase in HR
- 12 subject – could not tell due to poor M mode
- No VT noted

Electrodes placed in standard defibrillation position
Where is the closest skin to heart distance in humans?

In the transverse axis, it is a small area just behind and slightly to the left of the sternum. It is the area where the right ventricle is in contact with the anterior chest wall.

The best electrical conductive path is just to the left of the sternum in the intercostal space where muscle can conduct the impulse.
Where is the closest skin to heart distance in humans?

In the sagittal axis, it is a small area just behind the lower sternum where the zyphoid process joins the sternum. It is an area where the right ventricle is in contact with the anterior chest wall.

The best electrical conductive path is just to the left of the sternum in the intercostal space where muscle can conduct the impulse.
Relationship of Body Mass Index (BMI) to Minimum Distance from Skin Surface to Myocardium: Implications for Neuromuscular Incapacitating Devices (NMID)

Gregory G. Bashian, Gabriel A. Wagner, Donald Wallick, Patrick J. Tchou

- 3M and 5F Cardiac CT scans
- Minimum Skin-to-heart distances ranged from 1.8 cm to 5.7 cm.
- Location of minimum distance was to the left of mid sternum (2.1 ± 2.2cm) and slightly inferior (0.5 ± 1.6cm) to the lowest left rib sternal insertion.
- The area of myocardial contact with the anterior chest wall averaged 50 ± 24 cm².
Relationship of Body Mass Index (BMI) to Minimum Distance from Skin Surface to Myocardium: Implications for Neuromuscular Incapacitating Devices (NMID)

Gregory G. Bashian, Gabriel A. Wagner, Donald Wallick, Patrick J. Tchou

$r = 0.77$
$F = 47.4$
$p < 0.0000001$
Taser-Induced Rapid Ventricular Myocardial Capture Demonstrated by Pacemaker Intracardiac Electrograms

MICHAEL CAO, M.D., JEROLD S. SHINBANE, M.D., JEFFREY M. GILLBERG, M.S., LESLIE A. SAXON, M.D.

55 yo male
Medtronic Dual Chamber Pacer
Taser barbs struck the right chest

J Cardiovasc Electrophysiol, Vol. 18, pp. 876-879, August 2007
Taser-Induced Rapid Ventricular Myocardial Capture Demonstrated by Pacemaker Intracardiac Electrograms

MICHAEL CAO, M.D., JEROLD S. SHINBANE, M.D., JEFFREY M. GILLBERG, M.S., LESLIE A. SAXON, M.D.
Cardiac Arrest After TASER, How Often Does it Happen?
Presenting Rhythm in Sudden Deaths Temporally Proximate to Discharge of TASER Conducted Electrical Weapons

Charles D. Swerdlow, MD, Michael C. Fishbein, MD, Linda Chaman, MPH, Dhanunjaya R. Lakireddy, MD, and Patrick Tchou, MD
Presenting Cardiac Arrest Rhythm as Classified by EMS

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<td>VF or Shockable Rhythm</td>
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The Four VF Rhythms

1) 25 yo male, immediate collapse, Police AED showed VF when applied within 3-5 mins

2) 41 yo male, collapsed prior to CEW application. Drive stun was applied to thigh to assess subject responsiveness. Police AED showed shockable rhythm

3) 54 yo male, collapsed while under EMS care, 8 mins after last CEW discharge. EMS monitor showed VF.

4) 18 yo male, collapsed 5 mins after last CEW discharge. EMS monitor showed VF.

• In one of the 4 documented VF rhythms did collapse occur immediately following CEW application and could temporally be associated with it. The other 3 either collapsed prior to CEW application or 5-8 minutes after.

• Of the 56 cases where some form of presenting rhythm assessment was available, only one case could be potentially related to direct induction of VF by the stimulation of the CEW.

“The time sequence and electrode location are both consistent with electrically induced VF in one subject (subject 1), and neither drug use nor cardiac disease provides alternative explanations. To the best of our knowledge, this is the first reported fatality suggestive of CEW-induced VF.”

“Electrode locations in subject 3 and 4 could have placed the heart in the current pathway, but delays from CEW discharge to collapse exclude direct electrical induction of VR. Electrical induction of an intermediate arrhythmia such as ventricular tachycardia (VT) or atrial fibrillation, is possible.”

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<th>Weight</th>
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<th>Response to ECD shock</th>
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<td>6'0''</td>
<td>155 lbs</td>
<td>5, 5, 5</td>
<td>LOC toward end of last ECD cycle</td>
<td>Several minutes</td>
<td>VT/VF</td>
<td>BAC 0.35gm/100 ml, THC present</td>
<td>Survived with memory impairment; normal echocardiogram</td>
<td>Five AED shocks, IV epinephrine, and lidocaine eventually restored a perfusing rhythm.</td>
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<tr>
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<td>17</td>
<td>5'7''</td>
<td>170 lbs</td>
<td>37, 5</td>
<td>LOC toward end of 37 sec cycle</td>
<td>&gt;4.5 min</td>
<td>VF</td>
<td>Negative</td>
<td>410 gms; focal atherosclerosis; Plaintiff pathologist: normal Defense pathologist: HCM</td>
<td>Three defibrillating shocks, and an additional three shocks from a second AED at least nine minutes after the collapse, failed to resuscitate.</td>
</tr>
<tr>
<td>3</td>
<td>17</td>
<td>5'8''</td>
<td>115 lbs</td>
<td>5</td>
<td>ILOC</td>
<td>&gt;5 min</td>
<td>VF</td>
<td>BAC 0.25 gm/100ml, THC present</td>
<td>270 gms; normal heart</td>
<td>Asystole developed after the AED shock and then pulseless electrical activity (PEA). Subsequently, VF recurred, a second AED shock delivered, followed by asystole/PEA and could not be resuscitated.</td>
</tr>
<tr>
<td>4</td>
<td>24</td>
<td>5'10''</td>
<td>176 lbs</td>
<td>11</td>
<td>ILOC</td>
<td>About 10 min</td>
<td>AED: &quot;shockable rhythm&quot;; asystole after shock; no recordings available.</td>
<td>BAC 0.319 gm/100ml</td>
<td>400 gms; Plaintiff pathologist: no specific pathology Defense pathologist: lymphocytic myocarditis</td>
<td>Said to be breathing initially with a weak radial pulse. Resuscitated in hospital; life support withdrawn after 3 days due to anoxic encephalopathy.</td>
</tr>
<tr>
<td>5</td>
<td>33</td>
<td>6'2''</td>
<td>220 lbs</td>
<td>13 shocks totaling 62 sec in &lt;3 min</td>
<td>LOC toward end of multiple shocks</td>
<td>About 13 min</td>
<td>Fine VF vs. asystole</td>
<td>Gabapentin 31μg/ml</td>
<td>470 gms; 10-20% narrowing LAD; normal histology</td>
<td>Gabapentin taken for seizure disorder.</td>
</tr>
<tr>
<td>6</td>
<td>24</td>
<td>5'6''</td>
<td>144 lbs</td>
<td>49.5</td>
<td>LOC toward end of 49 sec shock</td>
<td>About 10 min</td>
<td>VT/VF</td>
<td>Negative</td>
<td>366.5 gms; normal gross and microscopic findings</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>16</td>
<td>5'3''</td>
<td>130 lbs</td>
<td>5</td>
<td>ILOC</td>
<td>About 10 min</td>
<td>VT/VF</td>
<td>THC</td>
<td>380 gms; Medical Examiner diagnosis: RV arcardiomyopathy, disputed by plaintiff’s expert</td>
<td>Six AED shocks for VT/VF resulted in asystole/PEA. Could not be resuscitated.</td>
</tr>
<tr>
<td>8</td>
<td>23</td>
<td>5'9''</td>
<td>173 lbs</td>
<td>21, 7, 3</td>
<td>LOC toward end of 21 sec shock</td>
<td>About 30 min</td>
<td>Asystole</td>
<td>BAC 0.111 gm/100ml</td>
<td>400 gms; mild interstitial fibrosis of compact AV node, interstitial fibrosis, atrophy, and vacuolization of penetrating and branching bundle</td>
<td>Said to be breathing with pulse, initially. Could not be resuscitated. Cardiac pathologist could not determine whether changes contributed to death.</td>
</tr>
</tbody>
</table>

ILOC = immediate loss of consciousness during/following initial shock; lbs = pounds; gms = heart weight in grams; LAD = left anterior descending coronary artery; VT = ventricular tachycardia; VF = ventricular fibrillation; AED = automated external defibrillator; BAC = blood alcohol concentration; THC = tetrahydrocannabinol, positive screen for marijuana; gabapentin = Neurontin

Zipes DP. Circulation, Online April 30, 2012
So, what is the denominator?
Why is Sudden Death from TASER Application So Infrequent?

• Current density is quite high at the tip of the TASER darts, but rapidly diminishes with distance from the tip.
• There are relatively small areas of the chest where a dart hit can potentially generate high enough current density at the myocardial surface to generate rapid capture.
• Skin and bones have high impedance and would resist current propagation towards the heart.
• Thus, unless a dart penetrates the skin and avoids hitting a bony area of the chest directly over the heart, current may not penetrate enough to affect the heart.
• The second dart must also land in such a fashion to direct the current in a direction that brackets the heart.
What Is the Best Approach to a Human Study?

• Due to low probability of cardiac capture, the study should be directed at the “worst case scenario”.

• Location of one dart at a chest site closest to the heart: left parasternal, intercostal, and penetrating the skin to the maximum depth (9 mm).

• Location of the second dart on opposite side of the sternum, at least 10 cm away.
Challenges

• Ethics of doing a study in human volunteers where induction of VF is a realistic possibility
• Painfulness of the stimulation
• Monitoring ventricular capture
The Ideal Human Study

- Subjects would feel no pain with the TASER application
- Subjects undergoing testing where induction of VF would be otherwise routine
- Subjects would already have means of recording intracardiac electrograms to document cardiac capture

ICD implant population
Proposed Study

- Volunteers undergoing ICD implant or generator replacement procedure
- Echo prior to procedure to define optimal sites of TASER darts
- When sedated for ICD defibrillation testing, sterile TASER darts inserted through skin at predefined positions
- TASER output applied for standard 5 sec. while sedated
- If VF induced, then proceed with ICD test. If not, use standard VF induction protocol.
- ECG, intracardiac recordings to be obtained
- Current, protocol under IRB review
Summary

- Animal studies do suggest that rapid myocardial capture can occur when the TASER barbs land near the heart.
- VF induction has been seen in occasional animal applications.
- The optimal human study has not been performed yet.
- Myocardial capture has been seen in one case report in a man with a pacemaker.
- Predictions by modeling studies should be verified in experimental studies.