Cardiac and Physiologic Effects of Taser Application: Real World Implications

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Objectives

- Cardiac electrophysiology and lethal arrhythmias
- Theoretical evidence
- Animal evidence
- Human evidence
- Real world evidence
- Conclusions
- Recommendations
Normal Cardiac Electricity

*Defining the Electrocardiogram (ECG)*

- **P**: Atrial contraction
- **QRS**: Ventricular contraction
- **QT**: Period of repolarization
  - Electrical recovery of ventricle
- **T**: Peak of “vulnerable period” (~3% ECG cycle)
Ventricular Arrhythmias

- Ventricular fibrillation (VF): fatal cardiac rhythm causing no coordinated cardiac output

- Ventricular tachycardia (VT): potentially fatal rapid cardiac rhythm that produces uncoordinated contraction, low cardiac output and can degenerate into VF, a medical emergency
Induction of VF with T shock

Heart Function and Electric Shock

- Normal Heart Function
- Ventricular Fibrillation

ECG
- Blood Pressure

Electric Shock

- 400 ms
- mm Hg
VF induction

Commotio cordis:
Low energy chest wall trauma
--> VF
Resuscitation from VF
Resuscitation from VF

- Time to defibrillation is key for survival:

![Graph showing survival rate over time to defibrillation.](Callans DJ. Engl J Med 2004; 351:632.)
Increased Vulnerability for VT/VF

• Underlying cardiac disease
  – Previous myocardial infarction (heart attack)
  – Heart failure
• High adrenergic tone (adrenaline)
  – Cardiac arrests most common early in AM when adrenaline highest
  – Cardiac arrests surge with stressful events: earthquakes, disasters
• Illicit drugs: cocaine, methamphetamines
• Acidosis
• Electrolyte disturbances: potassium, magnesium
• Inherited genetic cardiac electrical diseases
  – HCM, Brugada, LQTS
Taser Electrical Outputs

- High-voltage discharge, short pulse durations
- Initial 3 microsecond electric pulse, followed by longer 100 microsec pulses
- Current flows across a low-impedance pathway across propelled barbs

<table>
<thead>
<tr>
<th>Source</th>
<th>Peak voltage</th>
<th>Peak current</th>
<th>Duration</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightning</td>
<td>1 GV</td>
<td>40 kA</td>
<td>0.12 ms</td>
<td>500 MJ</td>
</tr>
<tr>
<td>Internal defibrillator</td>
<td>750 V</td>
<td>4-20 A</td>
<td>7-30 ms</td>
<td>35 J</td>
</tr>
<tr>
<td>Electrostatic discharge</td>
<td>15-20 KV</td>
<td>30 A</td>
<td>0.1 μs</td>
<td>60 mJ</td>
</tr>
<tr>
<td>Shock from line voltage</td>
<td>120 V</td>
<td>80-100 mA</td>
<td>&lt; 1 s</td>
<td>10 J</td>
</tr>
<tr>
<td>Shock from electroconvulsive therapy</td>
<td>450 V</td>
<td>900 mA</td>
<td>&lt; 1 s</td>
<td>20 J</td>
</tr>
<tr>
<td>TASER X26</td>
<td>1200 V</td>
<td>3 A</td>
<td>0.1 ms</td>
<td>0.1 J</td>
</tr>
</tbody>
</table>
Physiologic Effects of Taser Application

- Effects increase with duration of application
- Inhibits voluntary function of skeletal muscles ("locked muscles")
  - Electrically overwhelming voluntary control of muscles
- Dazed, immobilized, weak for 5-15 min after application
- Eye injury, miscarriage, rhabdomyolysis, brain penetration
- Intense pain
- Can be no autopsy findings for sudden arrhythmic death
- Metabolic acidosis
- ECG changes: QT interval
- Risk for cardiac arrhythmias
  - Immediate: cardiac capture $\rightarrow$ VT, or T shock $\rightarrow$ VF
  - Late: pain, adrenaline, acidosis, QT changes
- Possibility for additive risk of death from “excited delirium”
Theoretical Constructs

Capture (electrostimulation) of heart:
- Inverse relation between duration and current of pulse
- If pulse duration is short, higher current is required
- Theoretical analyses suggest Taser cannot capture heart
- Assumptions:
  - Only 4-10% of current that reaches chest wall will affect heart
  - High pacing threshold from body surface
  - Long recovery period of cardiac tissue
  - Short duration of Taser pulses
- Theoretical calculations do not allow for “worst case” scenario
Animal Studies


Conclusions:
- Stun guns did not cause VF in swine model
- Safety margin of 15-42x
- Safety margin inversely correlated with weight

Caveats:
- Funded by Taser grant (Taser authors)
- Stun gun simulator (not Taser) to specify safety margin, different electrode spacing than field use
- General anesthesia
Animal Studies

Conclusions:
- Stun guns did not cause VF in swine model
- Cocaine infusion increased safety margin by 50-100%
Caveats:
- Funded by Taser grant
- Stun gun simulator (not Taser) to specify safety margin, different electrode spacing
- General anesthesia
- Pulses did influence heart rate during shock if they formed a vector crossing the heart
Animal Studies

Nanthakumar et al (JACC 2006; 48:798-804)
- Arterial blood pressure recordings, intracardiac recordings
- Taser X26 and M26
- Anesthetized swine model
- CIHR funding
- No blood pressure during Taser shock: pumping of heart stopped
- Arrhythmia induced or heart stimulated so rapidly that it was not capable of cardiac output
- 74/150 (49%) shocks in 6 pigs captured myocardium
- Dependent on vector of barbs (most vulnerable across heart)
- 74/94 (79%) shocks across heart captured myocardium
- 0/56 (0%) shocks away from chest captured myocardium
- X26 model higher risk than M26
Animal Studies

Nanthakumar et al (JACC 2006; 48:798-804)
Animal Studies

Nanthakumar et al (JACC 2006; 48:798-804)

- Simulated excited state with adrenaline infusion
- 13/16 (81%) Taser shocks captured myocardium
- Both mechanisms for lethal arrhythmia demonstrated:
  - VT (capture)
  - VF (T shock)
Animal Studies

Dennis AJ et al (J Trauma 2007; 63:581-90)
Walter et al (AED 2008; 1:66-73)
- Anesthetized swine model
- University funding
- All animals demonstrated myocardial capture with Taser
- 2 fatal VF episodes
- Vector critical
Human Studies

- Anatomic, electrophysiologic differences exist between pigs and humans
- Lower safety margin for VT/VF in pigs
- Rested, healthy police volunteers
- No drugs, low heart rate, not exercising
- Vector across back
Human Studies

Ho J et al (AEM 2006; 13: 589-95)

Conclusions:
- No cardiac effects in 66 resting adult volunteers
- No potassium or bicarbonate disturbances: no acidosis

Caveats:
- Taser funding
- Vector across back
- Single 5 sec Taser application
- ECG in only 32 of 66 subjects
  - Before and after but not during
  - ECG intervals were not reported: QT
- pH not reported, time points not reported
Vilke GM et al (AJEM 2008; 26: 1-4)

Conclusions:
- No cardiac effects in 32 resting adult volunteers
- No cardiac arrhythmias
- No “clinically relevant ECG changes”

Caveats:
- Funding not reported
- 32 healthy volunteers
- Vector over back or not reported
- Single 5 sec Taser application
- QT interval shortened and lengthened: clinically relevant
- Lower pH immediately after Taser
Human Studies

Levine et al (JEM 2007; 33: 113-7)

Conclusions:
- QT interval shortening and lengthening in 105 healthy police volunteers

Caveats:
- Funding not reported
- Vector across back
- Single 5 sec Taser application
- Even with vector across back, not capturing heart -- stress of Taser shock causes increased HR and ECG changes increasing vulnerability
Human Studies

- Taser-induced rapid ventricular myocardial capture demonstrated by pacemaker
- University funding
- Vector across chest
- Myocardial capture at >240 bpm
- Risk for inappropriate shock in ICD patients
Real-World Studies

Ordog GJ et al (AEM 1987, 16: 73-78)
• 218 individuals subdued by police with firearm vs. Taser
• 1.4% mortality in Taser group vs. 50% in firearm group
• 3 fatalities in Taser group were due to cardiac arrest

Swerdlow (HRS 2008)
• 2 cases of VF in sudden in-custody deaths after Taser use
Real-World Studies

- Case series of Taser-related deaths (Strote, *Prehosp Emerg Care*, 2006)
  - Of 75 cases identified, 37 (49%) had autopsy reports available for review
  - All male, 18 to 50 years
  - Cardiac disease in 54%
  - >80% on illicit drugs
  - 76% of deaths attributed to “excited delirium”
  - Use of a Taser potential or contributory cause of death in 27%
“Excited Delirium”

- Sudden death while being restrained: “excited to death”
- “Overdose of adrenaline”
- Agitation, excitability, paranoia, aggression, great strength, and numbness to pain, racing heart rate, fever
- Often associated with cocaine or methamphetamine
- Not recognized by AMA or APA as medical or psychiatric disease
- Recognized by National Association of Medical Examiners, often cited as cause of death in autopsies
- Taser funds the Institute for Prevention of In-Custody Deaths which raises awareness of sudden death from excited delirium
- Evidence for increased risk for sudden death due to excited delirium:
  - Pain, acidosis (QT, racing heart rate)
Real World Studies

- No studies have examined true impact of Taser on real world outcomes of incidence of in-custody sudden deaths (cardiac or excited delirium)
Conclusions

- Low absolute risk for sudden death, but not non-lethal
- Definitive risk for both mechanisms of lethal arrhythmias in animal models: VT and VF
- Definitive demonstration of myocardial capture during Taser shock in humans
- Adrenaline increases vulnerability for Taser-induced VT/VF
- Tolerability in healthy volunteers under optimal conditions does not mean safety
- Human studies do not approximate real world uses with higher risk:
  - Underlying heart disease
  - Multiple shocks
  - Concomitant illicit drug use
  - Adrenaline
  - Acidosis
  - Additive effect on risk of “excited delirium”
Conclusions

- Vector critically important
- No findings on autopsy supports Taser-related arrhythmic death
- Finding of underlying cardiac disease does not exclude Taser as a contributory cause, in fact may make Taser more likely
- Temporal association of sudden collapse almost certainly means Taser-induced VT/VF
- Delayed sudden death after Taser shock does not mean that Taser did not increase the intrinsic risk for arrhythmia:
  - QT changes
  - Acidosis
  - Pain/adrenaline
Recommendations

Research

• Open issues of the true effect on outcomes of in-custody sudden deaths and additive risk for excited delirium deaths by Tasers in the real world
• We can do all the theoretical calculations and experimental studies we can think of in healthy volunteers, shot in the back, in anesthetized pigs, etc. but we can't know the answer until we examine real-world outcomes
• Cities and jurisdictions should be transparent with outcome statistics for expert review in an objective scientific manner
Recommendations

Policy

- There may be a useful role for Tasers in law enforcement, but the public should be aware of Taser risks and policy should be crafted with knowledge of these risks.
- Due the possible direct and additive risk for lethal events, Tasers should only be deployed for situations in which subjects are in imminent threat of significant harm to self or others.
- Avoid vector across chest.
- Avoid repeated shocks which may cause rapid VT capture and VF induction.
- Mandate AED availability with Taser use.