C18 Theoretical Considerations Regarding the Cardiac Safety of Law Enforcement Electronic Control Devices

Mark W. Kroll, PhD, Cal Poly University, 493 Sinaloa Road, Simi Valley, CA 93065; James Sweeney, PhD, Arizona State University, Box 872303, Tempe, AZ 85287; and Charles D. Swerdlow, MD, Cedars Sinai Hospital, 8700 Beverly Boulevard, Los Angeles, CA 90048*

Attendees of this presentation will learn the biophysical basis for the safety of TASER-type weapons.

This presentation will impact the forensic community and/or humanity by providing a better understanding of the risk of ventricular fib- rillation with in-custody-deaths in which a TASER type electrical weapon was used during the arrest process. This would be ideal for the session being chaired by Peter Alexander.

Introduction: The high-voltage, low duration pulses applied by the latest generations of electrical weapons are intended to stimulate α-motor neurons, which innervate skeletal muscle contraction, but not to stimulate cardiac muscle. Three types of factors contribute to the cardiac safety of these weapons: anatomic, the strength-duration relationship, and the rela- tionship between cardiac thresholds for pacing and fatal ventricular fibril- lation (VF).

Anatomic: The heart is located deep within the torso. In contrast, skeletal muscle and its stimulating α-motor neurons comprise much of the superficial layers. Even transcutaneous pulses delivered through large, antero-posterior electrodes for optimal cardiac stimulation send only 4% of their current through the heart. A much smaller fraction is delivered by small dart electrodes used for skeletal muscular incapacitation when delivered on the same side of the abdomen, thorax, or lower extremities.

The Strength-Duration Relationship: Nerve and cardiac electrical stimulation is accurately described by the strength-duration curve applied to average current. The threshold for stimulation is at a minimum ("rheobase") for pulses of infinite duration. The threshold for shorter pulses then rises up from the rheobase as the pulse is shortened. The duration at which the required stimulus strength doubles is called the chronaxie (d_c). Pulses with duration near the chronaxie are most efficient for stimulation.

The rheobase for α-motor neurons is approximately 1 A with a chronaxie of 100 μs. In contrast, the cardiac chronaxie is 3-5 ms for transcutaneous stimulation which is 30 - 50 times longer.

The most widely sold electrical weapon is the X26 (TASER International, Scottsdale, Arizona). It delivers a pulse with a complex "shaped" waveform of 50 - 100 μs in duration. The pulse repetition rate of 19 times per second causes loss of local muscle control. Note that the pulse duration approximates the chronaxie of α-motor neurons, making it an efficient stimulus for skeletal muscle but an inefficient stimulus for cardiac muscle.

The safety margin for cardiac stimulation can be estimated from the strength duration curve. The typical threshold for transcutaneous pacing is about 70 mA with 20 ms wide pulses, assuming the electrodes are applied for optimized cardiac stimulation. From this one can calculate the minimum charge required with extremely short pulses. Assuming a tran- scutaneous chronaxie of 4 ms:

$I = I_r (1+d_c /d)$

$Id = I_r d + I_r d_c = Q$

$70\ mA = I_r (1+4ms/20ms)\ I_r = 58.3\ mA$

$Q_0 = 233\ \mu C = 4\ ms * 58.3\ mA$

The X26 delivers about 80 μC in about 70 μs. The required charge to pace for a 70 μs pulse is given by:

$Q = dI_d = I_r d + I_r d_c$

$= I_r d + Q_0$

$= 58.3\ mA * 70\ \mu s + 233\ \mu C$

$= 237\ \mu C$

Thus theoretically the X26 pulse is insufficient to pace the heart by a 3:1 safety margin, even if delivered through large electrodes optimally placed for cardiac stimulation.

Pacing threshold vs. fibrillation threshold: The ratio between the current required to pace the heart and that required to induce fatal VF depends on the duration of stimulation and pulse repetition rate. It ranges from 4 - 6 in published animal studies. Combining the theoretical 3:1 safety margin from the strength-duration analysis with a 5:1 estimate for the fibrillation-to-pacing threshold gives a theoretical estimate of a 15:1 safety margin, even if X26 pulses were delivered through electrodes opti- mized for cardiac stimulation. As noted above, anatomic considerations show that X26 electrodes are too small for optimal cardiac stimulation, and their location is usually suboptimal. Thus, one would expect a larger safety margin in actual use.

Experimental data: Peleska demonstrated a minimum transthoracic charge of 5 mC was required to induce VF in dogs. This divided by the 80 μC of the X26 gives an estimated safety margin of 62:1. Published experimental data using the X26 waveform indicate a safety margin of 30-40:1 for VF. Thus, the published

 ** Presenting Author*

experimental data supports this theoretical analysis.

Summary: The TASER X26 electrical weapon appears to have a sound theoretical basis for its large cardiac safety margin.

TASER, Cardiac, Fibrillation

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