

## Can Tasers® directly cause ventricular fibrillation?

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**Abstract**— Tasers are battery powered electrical devices used by law enforcement personnel to temporarily incapacitate a suspect. This study is a portion of a larger study to determine the probability of a Taser (X26 and M26) causing ventricular fibrillation (VF) in humans. We determined the distance between a Taser dart and the ventricle (dart-to-heart distance) necessary to trigger VF in an *in-vivo* porcine model, using 10 anesthetized pigs. All experiments were approved by the appropriate IUCUC and adhere to all applicable laws and standards of the NIH and USDA as well as the policies of the APS. To more accurately represent the dart-to-heart distances found in a human, we reflected the skin, subcutaneous fat and muscle over the sternum and placed a thoracic dart into the third intercostal space over the right ventricle. Current flowed to a second dart 15 to 54 cm away on the abdomen. We determined that the distance between the darts makes no significant difference in the current. We directly measured the dart-to-heart distance and confirmed it post mortem. The dart-to-heart distance that causes VF is  $17 \text{ mm} \pm 6.48 \text{ (SD)}$  for the first VF event and  $13.7 \text{ mm} \pm 6.79 \text{ (SD)}$  for the average of the successive VF events. We will combine these data with echocardiographic human anatomic data, police-provided dart landing distribution data, and a finite element method (FEM) model of current density in the human torso to yield a probability of a Taser causing VF in a human.

**Keywords**— electromuscular incapacitating device, Taser, ventricular fibrillation, echocardiography

### I. INTRODUCTION

The use of electromuscular disabling devices (EMDs) such as the Taser has been controversial (also called human electromuscular incapacitation (HEMI) devices). Some suggest that EMDs can kill [1]. If the EMD directly electrocutes the heart, ventricular fibrillation (VF) would cause the heart to stop pumping, the blood pressure to decrease near zero, and the subject to faint almost immediately. However, many deaths following EMD use occur much later and may be caused by drug overdose, positional asphyxia, or other causes [2]. To help answer the question, “Can the EMD directly cause VF?” we have measured dart-to-heart distances that cause VF in pigs for the X26 Taser.

Electromuscular incapacitating devices (EMDs), such as Tasers, deliver high current, short duration pulses that cause

muscular contractions and temporarily incapacitate the human subject. Their risk in causing VF has been studied [3]. The risk of inducing VF for a 60 Hz power source and leakage current of cardiac pacemakers has been widely studied [4–6]. In our previous studies, we used 60 Hz data to examine the Taser [7] and calculated the safety factor for the human body ranging between 24 and 53 for the M26 and between 18 and 39 for the X26 [8]. However, EMDs operate with short duration pulses and 60 Hz power source data may not apply. In this study, to obtain data independent of 60 Hz data, we experimentally measured the dart-to-heart distances causing VF for the X26 Taser on anesthetized pigs, who feel no pain.

We selected medium sized pigs as subjects because they are about the size of humans and have similar physiology. The mass of the ten normal healthy pigs ranged from 53.8 to 74.4 kg. The pigs were anesthetized and intubated. The blood pressure, oxygen saturation, respiration, heart rate and ECG of the animal were monitored throughout the experiment. The thoracic fat and muscle were dissected to expose the sternum and nearby ribs. The X26 Taser current stimulated over the right ventricle, which is the most susceptible region of the heart [9]. The distances between the stimulation electrode dart tip and the right ventricle were applied from long-to-short distances to determine the threshold distance for VF.

### II. METHODS

**EMD device:** The X26 Taser delivered peak current pulses of about 2 A for a duration of about 150  $\mu\text{s}$ . The stimulation lasted about 5 s with 15 to 19 pulses per second.

**Stimulation darts:** In all experiments, the two stimulation darts setup was used to deliver Taser current to pigs. The stimulation darts were made to match the standard Taser probes which were 9 mm long and 0.51 mm in diameter [10].

The heart dart was placed inside a standard French 7 catheter with a conductive lead installed inside to deliver current. One end of the lead was connected to the heart dart and the other end was connected to the X26 Taser. Fig 1 shows that the heart dart in the catheter was attached to a syringe to provide a stable ground for dart-to-heart distance

adjustments. The heart dart was placed inside a virtual tunnel bluntly dissected into the intercostal muscle between the 3rd and 4th ribs above the right ventricle. The plunger of the syringe formed an adjustable stop. It was placed against the ribs next to the virtual tunnel to provide a firm surface to maintain the dart-to-heart distance constant during the vibration caused by the stimulation.

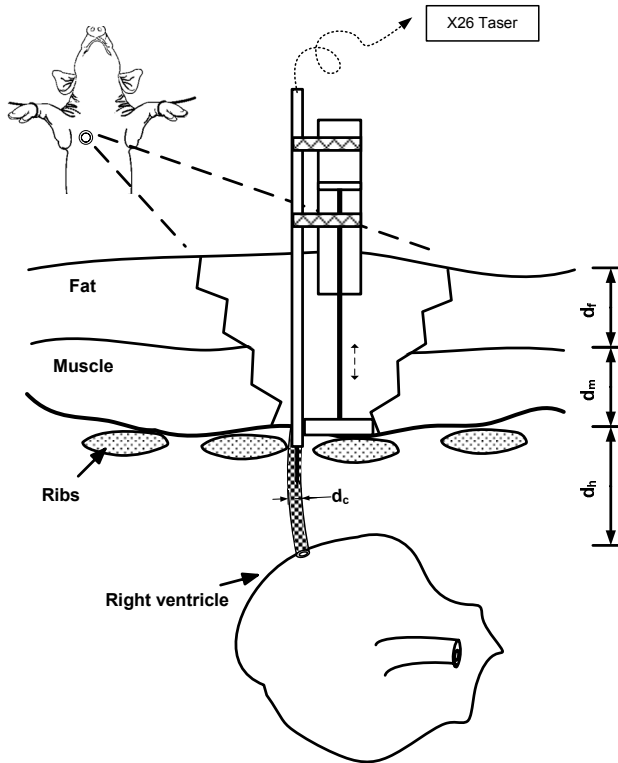


Fig 1 A midsternal dissection exposed the ribs. Above the external intercostal muscles were muscle layers about 30 mm ( $d_m$ ), and fat layers about 20 mm ( $d_f$ ) that were resected to provide the intracostal approach. A 2 mm ( $d_c$ ) slit virtual tunnel contained the heart dart. We held the plunger of the syringe against the external intercostal wall, which was 30 to 35 mm ( $d_h$ ) from the pericardium of the heart.

The remote dart, a standard Taser probe, was placed on the abdominal surface ranging from 15 to 54 cm caudal from the stimulation dart.

**Muscle-impedance matching gel:** The 2 mm virtual tunnel was made by bluntly dissecting tissue between the external intercostal muscle wall and the heart. The opening in the muscle created an air gap inside the virtual tunnel. This air gap between the stimulating electrode and the heart changed the current density distribution due to the higher impedance of the air compared to muscle. In order to maintain a normal electric current distribution, muscle-

impedance matching gel was injected into the virtual tunnel to fill the air gap. The gel was fabricated from NaCl, water and Agar. In order to match the 3.0  $\Omega\cdot\text{m}$  resistance of intercostal muscle [10], the concentration 0.2 % saline was used as electrolyte and consolidated by agar (10 g agar with 500 ml saline).

**Determination of stimulation location:** Once the anesthetic procedures were complete and the animal was in a homeostatic condition, the sternum was exposed up to the intercostal muscle layer. The most sensitive region of the heart for external stimulation has been found to be close to the midpoint of the right ventricle [9]. This region was under the 3rd and 4th ribs. Thus, we placed the heart dart at this region over the right ventricle. The muscle impedance matching gel was injected into the virtual tunnel to fill the air gap.

**Stimulation procedure:** After the dissection, the heart dart setup was inserted into the virtual tunnel and the remote dart was placed caudally on the abdomen surface separated from the stimulation dart setup with the controlled separation ranging from 15 cm to 54 cm. The tunnel distance  $d_h$  from the external intercostal muscle to the heart was measured to determine the dart-to-heart distance. The dart-to-heart distance was the distance from the tip of the heart dart to the heart. We applied current from long-to-short distances to determine the distance threshold of VF. In each experiment, we started the dart-to-heart distance at 20 mm to prevent causing VF immediately. Then we applied Taser current through the heart dart of about 5 s with 15 to 19 pulses per second. The current through a precision resistor was monitored by an oscilloscope.

After the stimulation, the ECG was verified to check if the heart was beating normally. If the heart beating was normally, we decreased the dart-to-heart distance by 2 mm for each step closer to the heart. Then the stimulation current was applied again. The same process was applied until the first VF occurred. Immediately, the defibrillator was used to defibrillate the pig with increasing energy from 100, 200, 300, 400 J. After the defibrillation, a 5 min recovery period was given to return the pig to a homeostatic condition. After the first VF event, the dart-to-heart distance was increased 2 mm to a less hazardous distance. Then the same process was applied to gather at least 3 VF dart-to-heart distances or the pig was euthanized. During the experiment, the impedance matching gel was refilled whenever there appeared to be an air gap in the tunnel.

Ten animal tests were performed to study the VF dart-to-heart distance of X26 Taser through the two stimulation darts configuration. Except for pigs 1 and 3, the separation of two stimulation darts was fixed at 54 cm in all other tests.

### III. RESULTS

We recorded the dart-to-heart distances of all stimulations including VF and no VF events. Figure 2 shows the experimental record of pig 1. The first VF dart-to-heart distance was 18 mm. A total of nine VF distances were recorded for this animal, with average distance 15 mm  $\pm$  1.22 (SD).

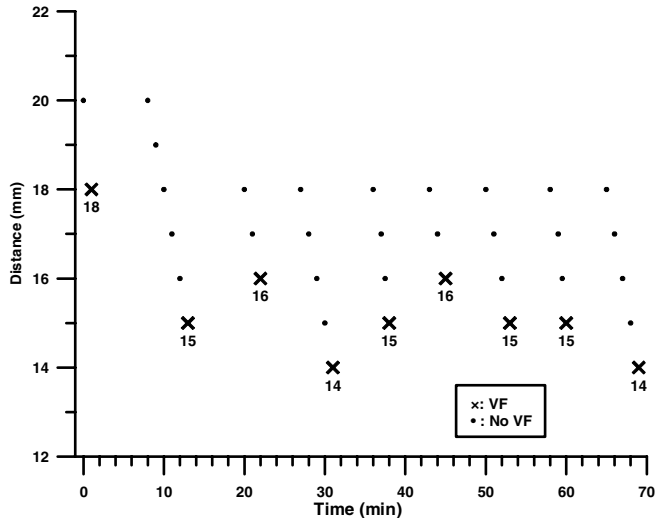


Fig 2 Experimental record of pig 1. The first VF dart-to-heart distance was 18 mm. The average VF dart-to-heart distance was 15.33 mm  $\pm$  1.22 (SD).

The first VF distance ranges from 14 to 24 cm except for pig 2. The average first VF distance is 17 mm  $\pm$  6.48 (SD). The overall average VF distance for each experiment ranges from 9.3 to 21 mm except for pig 2. The overall average is 15.16 mm  $\pm$  5.25 (SD). Table 1 summarizes VF distances of all experiments.

All animals remained physiologically stable throughout the experimental procedures; however, blood pressures were depressed after the first episode of VF. Generally, the first VF dart-to-heart distances were longer than the following VF distances.

Among 10 experiments, we observed very different VF behavior in pig 2 and pig 10. Pig 2 was less susceptible to the stimulation current than the other pigs. The first VF distance of pig 2 was 0 mm with average VF distance 4 mm  $\pm$  2.83 (SD). For pig 10, the first VF distance was 24 mm. However, after the first VF event, pig 10 became less susceptible to the stimulation current and the following two VF distances were shortened to 2 mm.

Table 1 Summary of VF dart-to-heart distances. The average first VF distance was 17 (mm)  $\pm$  6.48 (SD) which was shorter than the average distance of the successive distances 13.7 (mm)  $\pm$  6.79 (SD).

Pig	First VF distance (mm)	All VF ave dist (mm)
1	18	15 $\pm$ 1.22 (SD)
2	0	4 $\pm$ 2.83 (SD)
3	14	12 $\pm$ 2.31 (SD)
4	20	17 $\pm$ 2.58 (SD)
5	18	21 $\pm$ 2.58 (SD)
6	20	19.3 $\pm$ 1.15 (SD)
7	18	18 $\pm$ 0 (SD)
8	18	18 $\pm$ 0 (SD)
9	20	18 $\pm$ 2 (SD)
10	24	9.3 $\pm$ 12.7 (SD)
Ave	17 $\pm$ 6.48 (SD)	15.1 $\pm$ 5.28 (SD)

Our finite element method (FEM) simulation determined that the current density at the ventricle 16 mm under the dart tip remains the same when the dart separation is longer than 15 cm. According to the Taser cartridge specification the average spread of two probes by the standard Taser Cartridge 15' (model 34200) at the deployment distance from 0 to 0.9 m is from 4.8 to 20 cm [11]. Therefore, as long as the Taser darts are deployed at a distance farther than 0.9 m, then the separation of two darts will be larger than the minimum separation of darts that affects the current density distribution around the dart. Since the current density distribution around the dart and the current delivered by the X26 Taser are the same regardless of the separation of the darts, we can conclude that as long as the heart is very close to the heart, the separation of the remote dart will not affect the VF risk. Thus, the VF dart-to-heart distance remains the same regardless of the separation of the two stimulation darts (at separations greater than 15 cm).

We recommend only using data from the first VF event because each successive defibrillation damages the heart muscle and changes the VF threshold (see Fig. 2). If we use standard Taser probes to stimulate a pig, it won't cause VF because the normal skin-to-heart distance of pigs is 70 to 80 mm, which is much farther than the sum of the maximum (most dangerous) VF threshold distance 24 mm and the probe dart length 9 mm. However, if we assume the human heart is as vulnerable as the pig's heart, it is more dangerous for human subjects than pig subjects due to the shorter human skin-to-heart distance. McDaniel et al. [3] were unable to cause VF when applying the Taser to the skin of pigs. However pigs have a layer of fat (~20 mm) plus a layer of muscle (~30 mm) over the sternum whereas most humans do not. This causes a lower cardiac current density in the

pig than in the human. Thus we sought to determine the dart-to-heart distance that causes VF in pigs. We will apply this dart-to-heart distance to estimate the probability of Tasers directly causing VF in humans.

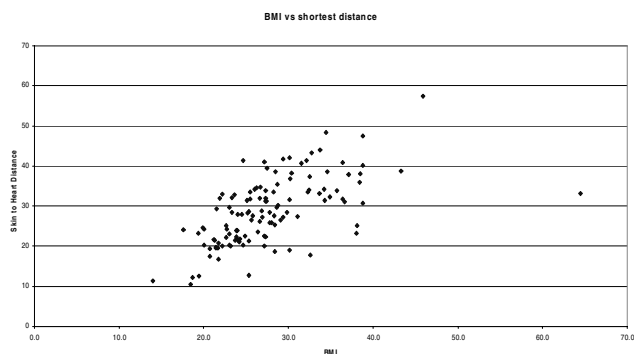


Fig. 3 Ultrasonography of erect humans yields skin-to-heart distances from 10 to 58 mm (from P. S. Rahko)

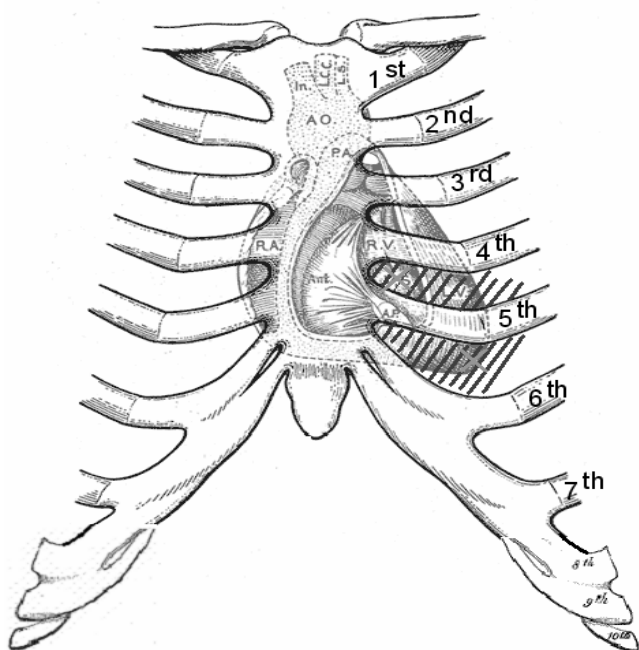


Fig. 4 The shaded area over the heart yields a VF probability = 1 in a thin human. Remote areas yield a VF probability = 0. X is the place between the 4<sup>th</sup> and 5<sup>th</sup> ribs with the minimal skin-to-heart distance.

We will (1) determine the range of skin-to-heart distances for erect humans (from echocardiography, See Fig. 3), (2) the cardiac current density for all possible dart locations (from FEM computer models of pathways of electric current through the human thorax), and (3) human dart landing location data (from police reports). From these data, we will estimate the probability of Tasers causing direct electrocution of the human heart (see Fig 4). Results should

help law enforcement jurisdictions decide whether or not to use Tasers (which have a low probability of death) or bullets (which have a high probability of death) when apprehending violent offenders. Also, during training, it would seem advisable to avoid having the dart landing on the front of the thorax.

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