

# Output of Electronic Muscle Stimulators: Physical Therapy and Police Models Compared

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## Abstract:

**Introduction:** Both physical therapists and police officers use electrical muscle stimulation. The typical physical therapist unit is attached with adhesive patches while the police models use needle-based electrodes to penetrate clothing. There have been very few papers describing the outputs of these physical therapy EMS (electrical muscle stimulator) units.

**Methods:** We purchased 6 TENS/EMS units at retail and tested them with loads of 500  $\Omega$ , 2 k $\Omega$ , and 10 k $\Omega$ .

**Results:** For the typical impedance of 500  $\Omega$ , the EMS units delivered the most current followed by the electrical weapons; TENS units delivered the least current. At higher impedances (> 2 k $\Omega$ ) the electrical weapons delivered more current than the EMS units, which is explained by the higher voltage-compliance of their circuits. Some multi-channel EMS units deliver more calculated muscle stimulation than the multi-channel weapons.

**Conclusion:** Present therapeutic electrical muscle stimulators can deliver more current than present law-enforcement muscle stimulators.

## I. INTRODUCTION\*

Physical therapists, trainers, athletes, and police officers use electrical muscle stimulation.[1-7] The typical training unit is attached with adhesive patches while the police models use dart-based electrodes to penetrate clothing due to the uncooperative nature of the situation. The outputs of the related TENS (transcutaneous electronic nerve stimulators) have been published and several papers have documented the outputs of the CEW (conducted electrical weapon) used by the police for muscle stimulation and control.[8-11] However, we were unable to find papers describing the outputs of physical therapy EMS (electrical muscle stimulator) units and there are no published data comparing the outputs of CEWs with the therapeutic stimulators.

It is a common misconception that the police CEW units are designed to cause both pain and a muscular spasm. Pain is irrelevant since 80-90% of the people resisting officers' actions have a highly elevated pain

threshold due to legal and illegal intoxicants or psychotic break.[12] Moreover, the strength of the contraction induced is < 50% of the voluntary maximal contraction since the primary effect is merely to cause the subject to lose voluntary control of the affected muscles.[13, 14]

In addition, a CEW, used by police in semi-controlled environments, should appropriately have more limited capacity focusing on a brief loss of function, than clinical devices where, in medically controlled circumstances the aim for example might be to stimulate denervated quadriceps to elicit functional leg movement leading to muscle training. Modern CEWs, by contrast, are designed as indirect muscle stimulators.

Thus, in developing supportive evidence for the safety of the muscle stimulators used by police we were interested in making comparisons only between police CEWs and the athletic muscle stimulators that are available online, without a prescription, and used unsupervised in the home environment.

## II. METHODS

We purchased 6 TENS/EMS units at retail (Table 1) and tested the outputs at nominal values using the standard resistive loads of 500, 2 k $\Omega$ , and 10 k $\Omega$  in keeping with the original FDA guidance on TENS testing. (The new AAMI/ANSI standard only requires the use of 500  $\Omega$ ).[15] None of the units acquired were designed for true *direct* muscle stimulation (ie for denervated muscles) as those thresholds are usually  $\approx$  10 times higher than those of healthy muscles stimulated indirectly via the nodes of Ranvier in the motor neurons.

The load resistances were made up from Ohmite model MOX-3N noninductive ceramic resistors rated for 30 kV pulses. All resistance values were verified to be within 1% of the desired values by measurement by a Flexzion VC8145 5-digit meter which was in turn calibrated to a Vishay (0.1% 500  $\Omega$  precision resistor). Voltage values were recorded by a Siglent SDS1202X digital storage oscilloscope sampling at 1 ns intervals and current calculated by Ohm's law.

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The EMS 7500, iStim A6, and iStim EV-805 allow direct adjustment of the pulse duration and pulse rate; these were set at 300  $\mu\text{s}$  and 70 PPS respectively. Amplitudes were set at the maximum. If the unit delivered a biphasic wave, measurements were made of the 1st phase as that was always the larger phase. For the other 3 units the program setting that gave the largest duration and pulse rate was selected. These were “#1”, “Leg”, and “Kneading 4” as listed in Table 1.

Table 1. TENS/EMS Models Tested

Model	Duration (Setting)	Pulses Per Second (Measured)
Accumed	#1 Program	59.9
EMS 7500	300 $\mu\text{s}$	68.6
iStim A6	300 $\mu\text{s}$	70.2
iStim EV-805	300 $\mu\text{s}$	70.1
Obovov R-C4D	Leg	79.6
TechCare + 24C	Kneading 4	100.3

The integration function was used on the Siglent SDS1202X digital storage oscilloscope to calculate the charge in the 1st phase. The oscilloscope has an intelligent function to calculate “Vtop” representing the maximum voltage while ignoring spikes and overshoots. For example, as seen in Figure 1, with a 10 k $\Omega$  load, the EMS 7500 had a peak voltage of 142 V but Vtop was calculated as 122 V.

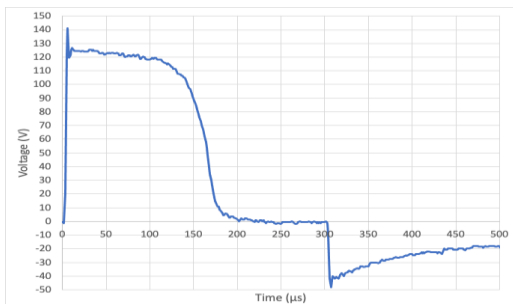


Figure 1. Output of EMS 7500 with 300  $\mu\text{s}$  setting and 10 k $\Omega$  load

We were also provided raw test data for 10 each of the popular Axon Enterprise, Inc. (Axon) CEW models TASER<sup>®</sup> X2, X26P, and T7. They were tested with non-inductive high-voltage resistor assemblies of 400, 600, 1k, 1.5k, 2.5k, 3.5k, 5k, and 10 k $\Omega$ . A Stangenese “0.5-1.0 W” model high-frequency 0.5% accuracy current transformer was used to record the outputs with a Tektronix model DPO3034 oscilloscope. The mean charge value for each CEW model was used for comparison.

We did not test the EMPI<sup>®</sup> Select<sup>™</sup> unit which delivers up to 4.5 mA of aggregate current according to the published specifications. TENS units have been used for treating angina with the electrodes placed across the cardiac silhouette, suggesting that there is no cardiac risk with these devices.[16-18]

Whole-body electro-myostimulation is an emerging athletic-training technique.[19] The subject strips naked and then dons an electrode jacket as shown in Figure 3 and Figure 4. Additional electrodes are placed on the

legs. We did not test the multi-electrode Miha Bodytec system shown in Figure 3 and Figure 4. However, their output specifications are available from the FDA 510k clearance K182519.[20] Their pulse charge is reported as “< 32  $\mu\text{C}$ ” so the charge and current values shown should be considered as an upper limit. We also compared the E-Fit EF-1289 and Katalyst Mark 1 Model 2 based on FDA 510k clearance documents.[21, 22]

### III. RESULTS

The results are given in Table 2. The aggregate current was calculated by multiplying the charge by the pulse rate.[23, 24] As seen in Figure 1, with higher load resistance, a higher-output device, the EMS 7500, began shortening its pulses. We speculate that this was due to a loss of compliance due to the discharge of the main output supply capacitor. Note the charge balanced waveform which is truncated at 500  $\mu\text{s}$ .

The outputs of the TENS and EMS units are compared with the electrical-weapon muscle stimulators as seen in Figure 2. In the typical impedance range of around 500  $\Omega$ , the EMS units delivered the most current followed by the CEWs (T7, X2, and X26P). TENS units delivered the least current.

Table 2. Measured outputs of the TENS/EMS units.

Model	Load ( $\Omega$ )	Vtop	d ( $\mu\text{s}$ )	Charge ( $\mu\text{C}$ )	Iagg (mA)
Accumed	500	46	120	10.80	0.65
Accumed	2k	88	119	5.20	0.31
Accumed	10k	142	118	1.70	0.10
EMS 7500	500	40	301	23.60	1.62
EMS 7500	2k	98	190	9.20	0.63
EMS 7500	10k	122	162	1.94	0.13
iStim A6	500	48	130	9.92	0.70
iStim A6	2k	55	130	2.84	0.20
iStim A6	10k	55	130	0.59	0.04
iStim EV-805	500	36	305	21.76	1.53
iStim EV-805	2k	92	264	10.88	0.76
iStim EV-805	10k	150	209	2.48	0.17
Obovov R-C4D	500	58	210	24.60	1.96
Obovov R-C4D	2k	99	210	10.65	0.85
Obovov R-C4D	10k	122	210	2.67	0.21
TechCare +24C	500	18	100	5.92	0.59
TechCare +24C	2k	36	100	3.28	0.33
TechCare +24C	10k	72	100	1.38	0.14

The AAMI/ANSI standard for TENS units has an absolute limit of 75  $\mu\text{C}$  per pulse.[15] However, this standard is silent on the role of the pulse rate and aggregate current. Apparently, the standard-drafters did not appreciate that ventricular fibrillation is usually induced by 1-2 seconds of repetitive current and rarely by a single strong pulse.[23, 25]

We also calculated the total muscle stimulation capability according to ANSI CPLSO-17.[26] This standard requires that the raw charge be adjusted for the pulse duration since longer pulses are less charge efficient for stimulation.[27-29] The normalized charge is normalized to a standard 100  $\mu\text{s}$  duration and given by:

$$Q_n = \frac{140 \mu\text{s} + 100 \mu\text{s}}{140 \mu\text{s} + d}$$

where d is the duration of the pulse and 140 μs is the typical chronaxie for skeletal muscle stimulation.[30-33] For example, the EMS 7500 has a pulse duration of 301 μs so it's raw charge of 23.6 μC is multiplied by a normalization factor of 0.54 to give a normalized charge of 12.8 μC. See Table 3.

That normalized charge is then multiplied by the pulse rate to give the normalized aggregate current per the ANSI standard. The total normalized aggregate current is then given by the product of that current and the pulse rate as shown in the last column of Table 3.

The highest calculated muscle stimulation capability was with the iStim EV-805 with its 4 channels and a total current of 3.29 mA. The next highest was the TASER T7 with 2 channels and 3.13 mA.

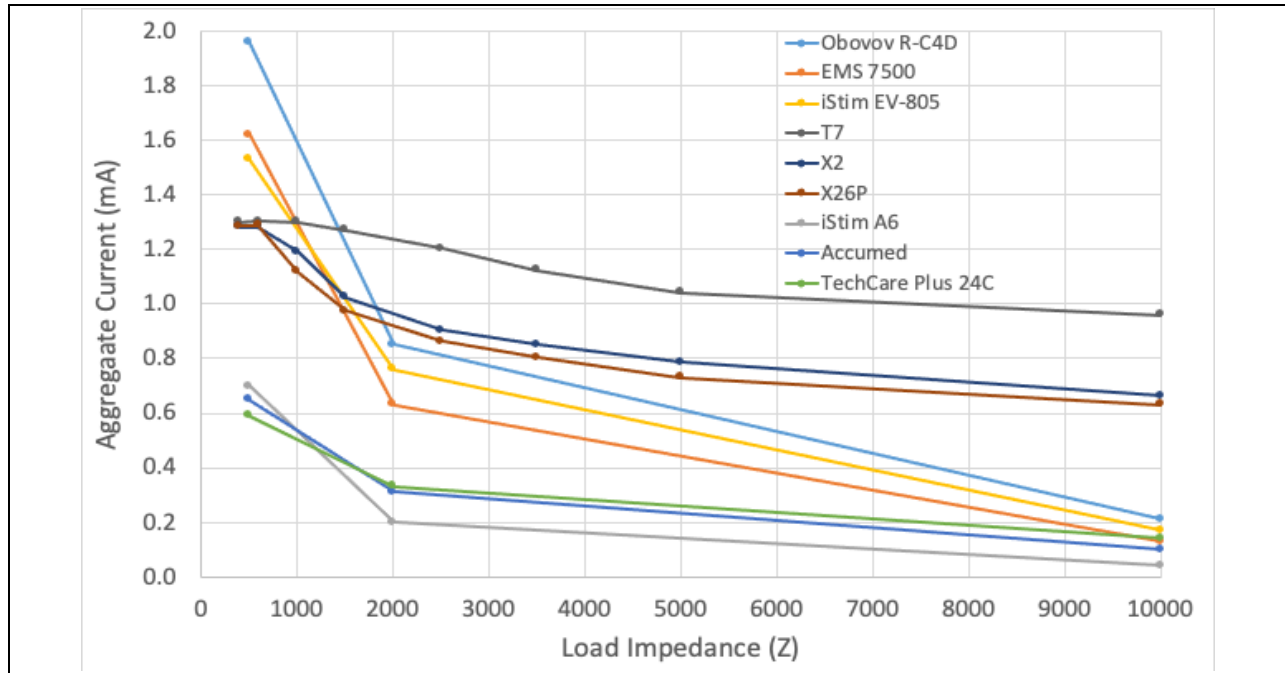


Figure 2. Aggregate current vs. load impedance.

Table 3. Total muscle stimulation capability

Model	d (μs)	Raw Charge (μC)	Normalization Factor	Normalized Charge (μC)	Pulse Rate (PPS)	Iagg Normalized (mA)	Channels	Total Iagg (mA)
Accumed	120	10.8	0.92	10.0	59.9	0.60	1	0.60
EMS 7500	301	23.6	0.54	12.8	68.6	0.88	2	1.76
iStim A6	130	9.9	0.89	8.8	70.2	0.62	2	1.24
iStim EV-805	305	21.8	0.54	11.7	70.1	0.82	4	3.29
Obovov R-C4D	210	24.6	0.69	16.9	79.6	1.34	2	2.69
TechCare +24C	100	5.9	1.00	5.9	100.3	0.59	1	0.59
X2 CEW	71.2	65.3	1.14	74.2	19.6	1.45	2	2.91
X26P CEW	98.6	65.7	1.01	66.1	19.6	1.30	1	1.30
T7 CEW	60.0	59.2	1.20	71.0	22.0	1.56	2	3.13

For the body-suits, we calculated the aggregate currents, for each channel and for all channels combined, from the output specifications available from their FDA 510k filings.[20-22] The results are given in Table 4.



Figure 3. Subject using Miha Bodytec system.

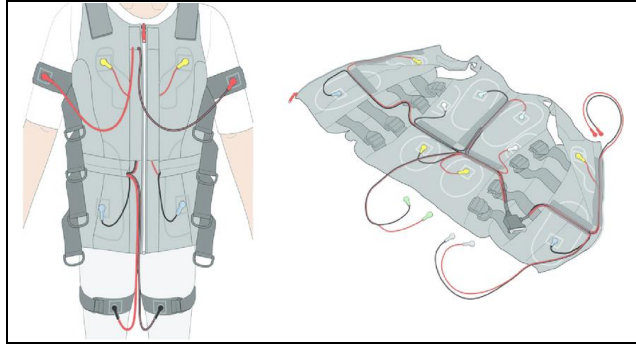


Figure 4. Miha Bodytec WB-EMS electrode vest.

Table 4. Comparison of full-body muscle stimulators to X2 CEW.

	Bodytec	E-fit	Katalyst	X2
Channels	10	12	10	2
Max Pulse rate (PPS)	150	120	85	19.6
Pulse duration ( $\mu$ s)	50-400	100-500	175	71
Typical duration (s)	1200	1800	1200	10
Pulse charge ( $\mu$ C)	32	36	21	65
Agg. current (mA)	4.8	4.3	1.8	1.3
Agg. current all channels (mA)	48.0	51.8	17.9	2.6

### III. DISCUSSION

We believe that this is the first paper to directly compare the outputs of TENS units, therapeutic electronic muscle stimulators, and law-enforcement CEWs. We found that consistent with their design goal of stimulating skeletal muscle, the electrical weapons delivered currents comparable to the EMS units. At maximum output, the EMS units deliver more current with a typical  $500 \Omega$  load. On the other hand, the electrical weapons do not have a user-adjustable output. The TENS units delivered about 1/2 of the current of the electrical weapons and about 1/3 of the current of the EMS units. At higher impedances ( $> 2 \text{ k}\Omega$ ) the electrical weapons delivered more current than the EMS units, which is explained by the higher voltage-compliance of the CEW circuits.

The X2 CEW has 4 possible electrodes. If all were in contact with the body there would be 2 channels for current delivery. This is compared to the whole-body systems in Table 4.

### IV. LIMITATIONS

For the CEWs we only tested those manufactured by Axon. Other CEW models are manufactured internationally. Some appear to deliver significantly more current, primarily due to pulse rates as high as 80 PPS.[34] This paper does not deal with domestic electro-shock protection products, electro-shock psychiatric therapy and none of the other many historic therapies using high voltage, such electrical acne removal. We did not test clinical stimulators which use much larger charges needed, for example, to stimulate denervated quadriceps to elicit functional leg movement.

### V. CONCLUSIONS

Therapeutic electrical muscle stimulators that can be purchased by non-professionals are capable of delivering more current than currently available law-enforcement muscle stimulators (CEWs). Some multi-channel EMS units deliver more calculated muscle stimulation than the multi-channel weapons. Whole body stimulation suits deliver far more total current than present electrical weapons.

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