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ORIGINAL ARTICLE

Electrical weapons and rhabdomyolysis

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Abstract

It has been suggested that an application of a conducted electrical weapon (CEW) might cause muscle injury such as rhabdomyolysis and an acute inflammatory response. We explored this hypothesis by testing the effects of electrical weapons on circulating markers of inflammation and muscle damage. In a prospective study, 29 volunteers received a full-trunk 5-s TASER® X26(E) CEW exposure. Venous blood samples were taken before, 5 min after, and at 24 h following the discharge. We tested for changes in serum levels of C-reactive protein (CRP), alkaline phosphatase (ALP), myoglobin, albumin, globulin, albumin/globulin ratio, aspartate and alanine aminotransferase, creatine kinase, total protein, bilirubin, and lactic acid dehydrogenase. Uncorrected CRP and myoglobin levels were lower in the immediate post exposure period (CRP levels 1.44 ± 1.39 v 1.43 ± 1.32 mg/L; $p = 0.046$ and myoglobin 36.8 ± 11.9 v 36.1 ± 13.9 μg/L; $p = 0.0019$) but these changes were not significant after correction for multiple comparisons. There were no changes in other biomarkers. At 24 h, CRP levels had decreased by 30% to 1.01 ± 0.80 mg/L ($p = 0.001$ from baseline). ALP was unchanged immediately after the CEW application but was reduced by 5% from baseline (66.2 ± 16.1 to 62.7 ± 16.1 IU/L; $p = 0.0003$) at 24 h. No other biomarkers were different from baseline at 24 h. A full-trunk electrical weapon exposure did not lead to clinically significant changes in the acute phase protein levels or changes in measures of muscle cellular injury. We found no biomarker evidence of rhabdomyolysis.

Keywords CEW · Electrical weapon · C-reactive protein · Lactate dehydrogenase · Myoglobin · Alkaline phosphatase · Rhabdomyolysis · Taser®

Introduction

The handheld conducted electrical weapon (CEW) carried by law enforcement professionals uses compressed nitrogen to deploy 2 small probes at typical distances of up to 7.7 m, [1, 2] allowing the delivery of ultra-short duration (50–100 μs) electrical pulses (19–22 per second) which stimulate Type A-α motor neurons between, and in close proximity to, the probes. Stimulation of these neurons, which control skeletal muscle contraction, typically leads to a loss of regional muscle control and a fall to the ground, facilitating a safe end to a violent confrontation or to gain compliance.

Several series have collated systematically and prospectively collected data on the use of these devices. The MacDonald study covered 12 USA law enforcement agencies and 24,380 uses of force. They found that CEW subject injury was reduced by 65% [3]. Taylor presented data from 13 USA agencies including 16,918 uses of force and described a 78% reduction in injuries requiring medical attention [4]. The CEW reduces all-cause mortality by 59–66% compared to alternative control techniques [5]. The reduction in the non-firearm arrest-related-death (ARD) rate is consistent with the 2/3 reduction in firearm fatalities in agencies where CEW usage was not overly restricted [6].

The CEW does have various well-established and published complications including 16 deaths from traumatic brain

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injury due to CEW-induced falls [7], 6 fatal burns (4 petrol and 2 methane) from CEW ignition [8], and, more recently, 2 additional deaths in men who had petrol on their clothing in suicide threats. These 8 fatal fire deaths out of 3.9 million CEW discharges give a risk of 2.1 per million [95% CI: 1.0–4.0 by Wilson score interval]. As of 2017 there were also 29 reports of penetrating eye injuries out of 3.44 million field uses [9]. These have led to 20 documented cases of complete unilateral blindness or enucleation (risk of 5.1 per million [95% CI: 3.3–7.9] [10].

One further concern following CEW exposure is cellular muscle damage leading to rhabdomyolysis [11–13]. Studies exploring this hypothesis have consistently failed to find clinically significant increases in creatine kinase [14, 15], and one study has described the lack of change in myoglobin levels [16]. In contrast, there are no published human data on other markers for rhabdomyolysis such as aspartate and alanine aminotransferase and lactic acid dehydrogenase. There are also no published human data on CEW effects on acute phase protein levels.

Methods

This was a prospective, cohort study exploring the effects of a single CEW exposure on multiple clinically relevant endpoints. The present report explores the circulating levels of acute phase proteins and markers of skeletal muscle damage specifically describing rhabdomyolysis.

Participants were cadets from the Austin (Texas) Police Academy. All participants gave informed consent. The medical monitor of the study interviewed each consenting volunteer to exclude any subjects with recent illness, musculoskeletal injury, pregnancy, lactation or with any known cardiovascular, pulmonary, or hematological condition. The CEW exposure was performed by trained Academy staff according to the standard operating procedures of the device. The study was approved by the Institutional Review Board of Texas A&M University.

Each subject was positioned face-down on a narrow, slightly raised padded mat (approximately 60 cm wide × 180 cm long × 30 cm high) such that the torso and legs were supported by the mat.

Alligator clips were placed on the skin of the participant's shoulder (clamped to the shirt in the mid-scapula region of right shoulder) and waist (clamped to the upper edge of waistband mid-way from spine to right margin). These locations were chosen to achieve maximal CEW-induced control of the subject's upper and lower extremities by simulating a 45–60 cm CEW-probe spread [17]. The goal was to obtain the highest level of muscle contraction within the training-authorized 5 s discharge in order to increase the likelihood of detecting a change in biomarkers. The alligator-clipped electrodes were applied manually to ensure consistency of lead placement throughout data collection. A standard X26(E) CEW was triggered by an instructor. Electrical current delivery lasted for a duration of a standard 5-s cycle (single pull of the trigger), as used in training and in the field.

Serum biomarker protocol

A 20 mL venous blood sample was taken before, 5 min after, and at 24 h following the CEW exposure. All phlebotomies were performed by certified emergency medical technicians using routine venipuncture practices, wherein a sterilized intravenous catheter was placed in the vein of the anterior forearm for ease and repeatability. All drawn blood specimens were labeled, collected and transported to an off-site facility by an independent laboratory organization (Laboratory Corporation of America, Austin, TX). Samples were analyzed for serum levels of C-reactive protein (CRP), alkaline phosphatase (ALP), albumin, globulin, albumin/globulin ratio, aspartate and alanine aminotransferase, total protein, bilirubin, creatine kinase, myoglobin, and lactic acid dehydrogenase.

All statistical comparisons were by a Wilcoxon signed-rank test for differences between baseline and immediately following discharge and between baseline and 24-h following discharge. Post-hoc analysis demonstrated that the study was powered to detect differences of 1 standard deviation with a 99% likelihood. The Holm-Bonferroni adjustment was used to correct for multiple comparisons.

Results

A total of 29 subjects (26 male and 3 female) participated and provided blood samples before and 5 min and 24 h following the CEW exposure. Subject ages ranged from 21 to 55 years and all were healthy with no co-morbidities or regular medication. The CRP, creatine kinase, myoglobin, and lactate dehydrogenase results for one subject were not available thus the present report includes the results of 28 subjects (Table 1).

The CEW discharge led to a slight immediate reduction in CRP which although unilaterally significant ($p = 0.046$) was insignificant after correction for multiple comparisons by Holm-Bonferroni (Fig. 1) and of doubtful clinical significance. Similarly, myoglobin was decreased by 2% post exposure ($p = 0.019$) but this was insignificant after correction for multiple comparisons. (Fig. 2) There were no changes in other biomarkers.

At 24 h, CRP levels decreased by 30% to 1.01 ± 0.80 mg/L ($p = .001$) compared with baseline. ALP was unchanged immediately after the CEW application but was reduced by 5% ($p = 0.0003$) from baseline at 24 h (Fig. 3). No other biomarkers were different from baseline at 24 h.

Table 1 Biomarker values

Biomarker	Units	n	Baseline	Post	*p* value	24 Hour	*p* value	HB limit
Alkaline phosphatase	IU/L	29	66.2 ± 16.1	68.8 ± 20.6	0.29	**62.7 ± 16.1**	**0.0003**	0.0042
C-reactive protein	mg/L	28	1.44 ± 1.39	1.43 ± 1.32	0.046	**1.01 ± 0.80**	**0.0012**	0.0045
Albumin	g/dL	29	4.68 ± 0.25	4.61 ± 0.29	0.21	4.60 ± 0.26	0.15	0.0050
Creatine kinase	U/L	28	318 ± 234	309 ± 221	0.15	335 ± 185	0.17	0.0056
Protein, total	g/dL	29	7.30 ± 0.38	7.26 ± 0.35	0.68	7.23 ± 0.43	0.21	0.0063
AST (SGOT)	IU/L	29	28.6 ± 9.4	28.7 ± 9.7	0.60	27.6 ± 7.0	0.25	0.0071
Myoglobin	μg/L	28	36.8 ± 11.9	36.1 ± 13.9	0.019	38.7 ± 13.9	0.26	0.0083
A/G ratio		29	1.80 ± 0.25	1.76 ± 0.22	0.3	1.78 ± 0.22	0.37	0.010
ALT (SGPT)	IU/L	29	28.7 ± 10.4	28.2 ± 11.1	0.6	28.1 ± 9.9	0.40	0.013
Bilirubin, total	mg/dL	29	0.66 ± 0.27	0.64 ± 0.25	0.23	0.65 ± 0.27	0.63	0.017
LDH	IU/L	28	207 ± 44	206 ± 41	0.87	211 ± 33	0.64	0.025
Globulin, total	g/dL	29	2.62 ± 0.30	2.64 ± 0.25	0.61	2.63 ± 0.31	0.87	0.05

HB Holm-Bonferonni. *Bolded values are significantly different from baseline

Discussion

We believe that this is the first publication of the effects of modern electrical weapons in humans on C-reactive protein, alkaline phosphatase (ALP), albumin, globulin, albumin/globulin ratio, aspartate (AST) and alanine aminotransferase (ALT), total protein, bilirubin, and lactate dehydrogenase (LDH). Our data suggest no clinically relevant adverse changes in acute phase proteins or markers of muscle damage that might lead to rhabdomyolysis.

Previous studies have reported on the effects of the TASER X26(E) on total serum protein, CRP, and LDH in swine. One extreme model by Jauchem tested a protocol where anesthetized swine had the ventilator was turned off during a total of 126 s of exposure [18]. Total LDH was 705 ± 111 IU/L before and 791 ± 159 IU/L afterwards (NS by pooled T-test). In another study, with 60 s of total exposure, Jauchem reported no statistically significant changes in either total protein or CRP [19].

Elevated AST is a highly sensitive marker for rhabdomyolysis being found in 95% of cases [20], and although an elevated ALT is less sensitive (75% sensitivity), the absence of any increase in either AST or ALT is consistent with the existing literature showing only nominal increases of CK with a CEW exposure [14, 15]. The lack of change in LDH is also consistent with a lack of rhabdomyolysis [21]. The only previous paper reporting myoglobin levels was by Ho [16], and reported a minor increase in myoglobin after a 5 s exposure (from 32.4 ± 15.1 ng/ml to 45.5 ± 27.1 and 51.3 ± 29.8 at

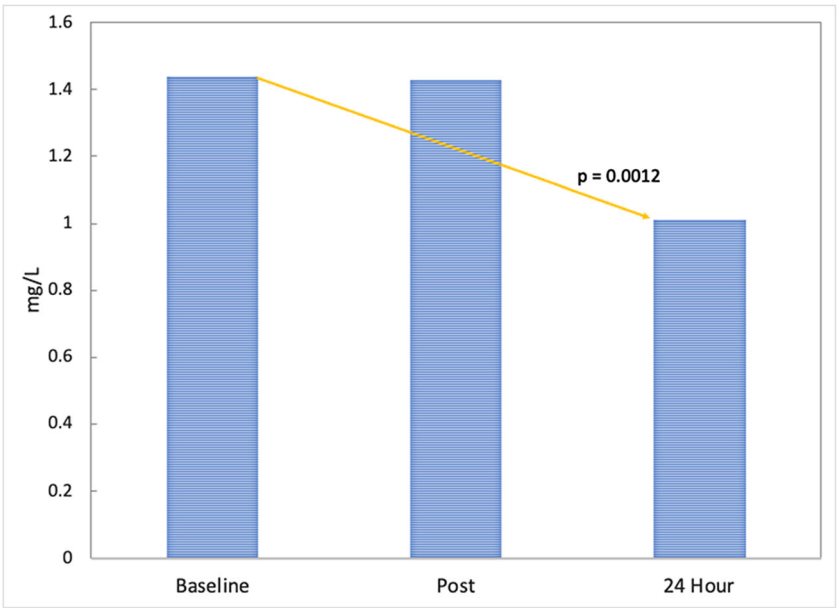

Fig. 1 C-reactive protein levels

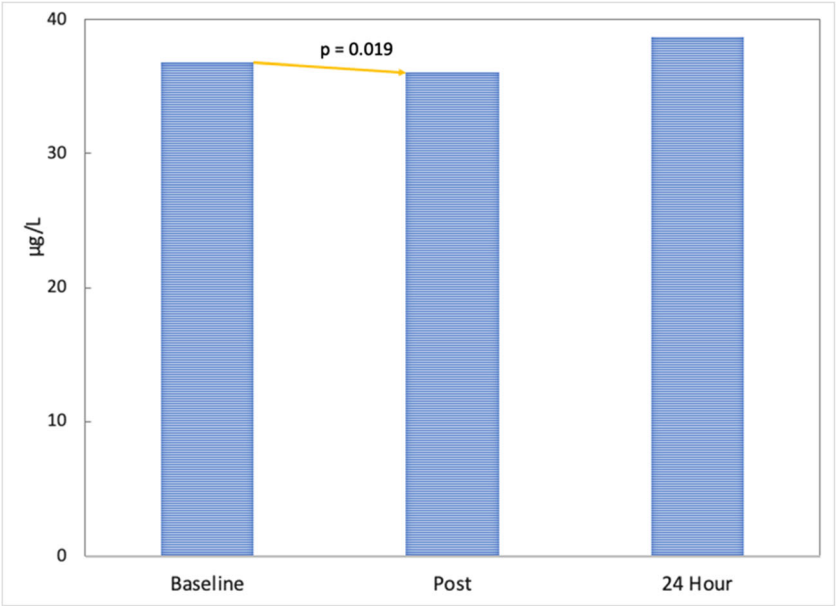

Fig. 2 Myoglobin levels

24 h). That study involved probes deployed from 2 m away into the subject's back (vs. our alligator clips) and thus the impact and penetration trauma may have raised the myoglobin levels rather than the electrical stimulation.

One issue to discuss is the apparent decrease in CRP and ALP, at 24 h. These values are slightly above each subject's normal values before the CEW exposure. The study was conducted during officer cadet training and our protocol did not forbid physical training in advance of the CEW discharge. Exercise can briefly raise ALP and CRP [22, 23], and the baseline CK level of 317.6 ± 234.2 U/L is therefore consistent with physical training before the CEW exposure. Emotional stress can also raise CRP [24]. Such stress is common with officers when faced with a mandatory CEW training exposure that they know will be briefly painful. The relief following the completion is typically accompanied by a more vagal tone. This is thought to also explain the previously described drop in blood pressure (systolic reduced by 3.6 mmHg and diastolic by 3.0 mmHg) immediately after a CEW exposure [25].

All present TASER brand CEWs deliver less than 2 W which is far less than the 5–7 W allowed by the Underwriters Laboratories (UL) electric fence standard [26], such that CEW-induced complications are not expected. Modern CEWs satisfy the conservative IEC (International Electrotechnical Commission) and European (Cenelec) 2.5 W limit for electric fences [27–29]. There is also an electrical standard designed

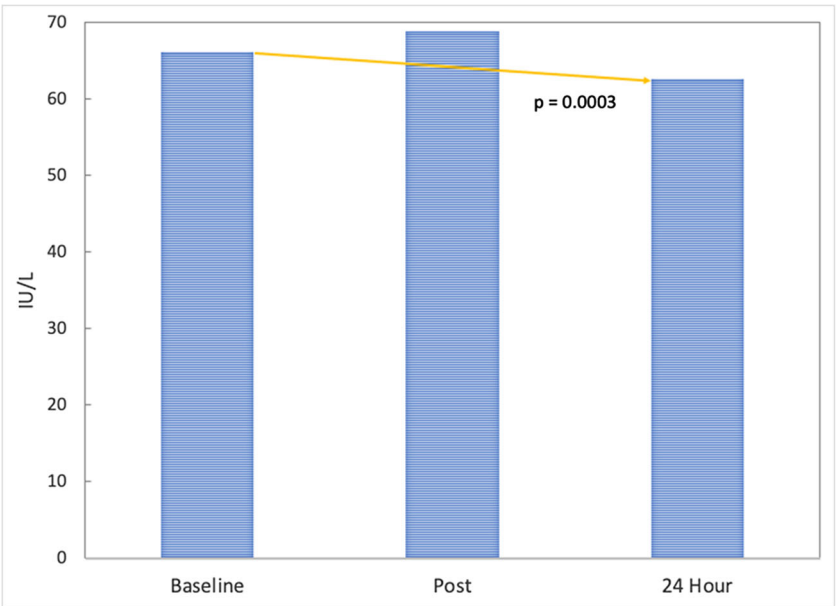

Fig. 3 Alkaline phosphatase levels

specifically for the CEW: ANSI CPLSO-17. It requires certain minimum outputs for effectiveness and has maximum limits for safety [30, 31]. All TASER brand CEWs satisfy this standard and thus injury is not expected.

Limitations

We did not require exercise abstinence during our study, and this may have confounded our results. However, our data showed a lowering of CRP and myoglobin shortly following the exposure; these findings do not therefore counter our hypothesis. There was no control group (with no CEW exposure) for comparison.

Our exposure time of 5 s was less than that of some field uses, which would theoretically increase the risk of rhabdomyolysis. In a study of real-world CEW uses, over 4% had at least 20 s of probe-mode application [32, 33]. However, our exposure vector was maximized and thus the total mass of contracted muscle was greater than that seen in normal field applications [17]. In addition, the only biomarker with an increase was myoglobin (+2 μg/L at 24 h) and that increase would still be clinically trivial even if multiplied by 4 or 40.

Conclusions

A full-trunk electrical weapon exposure did not lead to clinically significant changes in the proteins or enzymes tested. C-reactive protein and alkaline phosphatase were decreased at 24 h. We found no evidence of a potential risk of rhabdomyolysis.

Key points

1. Electrical weapon exposure does not make clinically significant changes in serum protein or enzyme levels.
2. C-reactive protein and alkaline phosphatase are decreased at 24 h.
3. Aspartate aminotransferase was slightly decreased at 24 h.
4. No biomarker evidence for rhabdomyolysis was seen.

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Compliance with ethical standards

Potential conflicts of interest MWK is a member of the Axon [né TASER] Scientific and Medical Advisory Board (SMAB) and corporate board. RML is a SMAB member and consultant to Axon. SNK is a SMAB member. KKW, MBR, and JCC declare no conflicts. MWK and RML have served as litigation or inquest experts in multiple countries.

Informed consent Informed consent was obtained from all participants included in the study.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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