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Fatal and non-fatal burn injuries with electrical weapons and explosive fumes

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ABSTRACT

Introduction: While generally reducing morbidity and mortality, electrical weapons have risks associated with their usage, including eye injuries and falls. With the presence of explosive fumes or fuels there also exists the possibility of burn injury.
Methods: We searched for cases of fatal and non-fatal major burns with TASER® electrical weapon usage where there was a possibility that the weapon ignited the explosion.
Results: We confirmed 6 cases of fatal burn injury and 4 cases of major non-fatal burns out of 3.17 million field uses. The mean age was 35.5 ± 9.7 years which is consistent with the typical arrest-related death. Moderate, minor, and noninjurious fires — typically due to a cigarette lighters in a pocket, petrol, recreational inhalants, or body spray were also noted.
Conclusions: The use of electrical weapons presents a small but real risk of death from fatal burn injury. It also presents a small risk of major non-fatal burn injury. The ignition of petrol fumes dominates these cases of major fatal and nonfatal burns.

1. Introduction

Death during arrest is a recognized event, for which there are many known causes; sometimes the cause of the death remains unexplained.[1,2] Annually there are about 800 000 arrests in which force is used in the United States and approximately 800 non-firearm ARDs (arrest-related-deaths) yielding a mortality rate of about 1:1000.[3,4] About 80% of resistant subjects have co-morbidities of mental illness, drug abuse, or intoxication; the majority has at least 2 of these.[5,6]

The conducted electrical weapon (CEW) is involved in a minority of ARDs.[2,7] There have been 3.17 million field uses as of Sept 2016. There have also been 2.13 million CEW training exposures for a total of ~5.3 million human CEW exposures.[8]

Prospective studies have found suspect injury rate reductions of about 65% with electronic control[9,10] This is similar to the 2/3 reduction in fatal police shootings where CEW usage is not overly restricted.[11]

Electrical weapons are, after all, weapons, and there are indeed risks associated with their usage, including blinding eye injuries and fatal head and neck injuries from falls.[12,13] They are also electrical and hence present a risk of igniting explosive fumes. The goal of this paper is to summarize the mechanisms and risks of such fires and explosions.

1.1. Burn injury definitions

The American Burn Association (ABA) defines major burn injury as partial thickness burns involving more than 25% of TBSA (total body surface area) in adults (age 11–50) or full thickness burns involving more than 10% TBSA. Any burns involving the face, eyes, ears, hands, feet or perineum that may result in functional or cosmetic impairment are also considered major.

Moderate burn injury includes partial-thickness burns of 15–25% of TBSA in adults (age 11–50) and full–thickness burns involving 2–10% of TBSA. Minor burn injury includes burns involving less than 15% of TBSA in adults (age 11–50) and full-thickness burns involving less than 2% of TBSA.

1.2. Chemistry of a fume explosion

Fresh petrol has a lower explosive limit (LEL) of 1.4%. This means that a mixture that is 98.6% air and 1.4% petrol vapor is explosive.

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Surprisingly, this concentration level (1.4%) is not considered acutely toxicologically dangerous but in the "recreational" intoxication range for petrol sniffers.[14,15] The upper explosive limit (UEL) is 7.6% and thus petrol, *per se*, is not explosive. The minimum ignition energy (MIE) for petrol is 0.24 mJ compared to the ~1 mJ of the popular TASER X26 probe-wire connection and thus the fumes are easily ignited by the arc in the "needle-eye" at the back of the probe with an optimal concentration. See Fig. 1.

There are other liquids that have similar explosive capabilities. Benzene (commonly used for methamphetamine production) has a LEL of 1.34%. Butane (often used to manufacture hash oil) has a higher LEL of 1.81–1.86% in different forms. Its isomer, isobutene, is also present in cigarette lighters.

Oleocapsicum (pepper or OC) spray often uses flammable propellants, such as isopropyl alcohol, ethanol, and methyl isobutyl ketone. A few use nitrogen, which is inherently non-flammable. Many of the OC sprays that are labelled as "non-flammable" actually can be ignited by a CEW.[16] Most of these develop a small flame that is unlikely to produce a severe burn injury. However, the Aerko "Clear Out" OC grenade reportedly will produce a large flame with CEW ignition.[16] TATP (triacetone triperoxide) can be ignited by a CEW discharge.[17]

The probes are deployed at an initial velocity of ~140 fps (43 mps) and the pulse rate is 19 pps. See Fig. 2. Hence the probes travel 2.3 m per pulse. Since the maximum arc is 4 cm, it is unlikely that a probe would ever ignite a gas by arcing from the probe tip as it approached the subject. The probe-wire arcs are the most likely source of the ignition. While each pulse delivers about 100 mJ of energy to the load, the amount of energy delivered to the arc (in each probe) is estimated at ~1 mJ. However, in the event of heavy clothing, or a probe lodged in the clothing on the subject's side there can still be an arcing connection with more energy.

The minimum ignition energy for each substance is given in Table 1. As seen in Fig. 3, the ignition energy goes up rapidly for concentrations either higher or lower than the ideal.[18] This can explain why many electrical weapon probe deployments do not cause an explosion even in the presence of a given fuel.

2. Case reports

Co-author HEW maintains a database of worldwide CEW-proximate arrest-related-deaths. It had 1063 cases (1007 from USA) as of 21 September 2016. This ARD database has been cross-checked with the TASER International, Inc. internal ARD database and is continuously updated with Internet news scans. Autopsies and law-enforcement investigative reports are regularly requested via freedom-of-information letters. The HEW database has been used in previous publications.[13,19] Another author (MWK) did a direct legal and news database search for cases meeting the inclusion criteria.

Fig. 1. Probe conducting to cloth over aluminum foil. Note arcing in the wire-probe connection eye.

For the 6 fatal burn cases, we obtained 5 full autopsy reports or death certificates. We also obtained autopsy summaries from litigation filings, police reports, or news accounts for all fatal cases. We found sufficient incident detail from litigation filings, police reports, a coroner's inquest, or news accounts to support a classification of an electrical-ignited burn for all 10 major burn cases. We excluded 2 additional cases as we judged them to have had an alternative ignition source or an alternative cause of death, respectively.

2.1. *Fatal and non-fatal major burn injury cases*

Cases are listed from earliest incident. See Table 2 for summary.

2.1.1. *Cases #1, #2, and #3*

Two police officers responded to a 911 call to check on the welfare of a man who was depressed and threatening suicide. When the officers arrived, they found the 41-year-old man in his house, and they noticed a strong odor of natural gas inside. The officers entered the house to secure the suspect, but he resisted. To subdue him, an officer discharged his CEW. Immediately, the house exploded into flames with sufficient force to blow down walls and partially collapse the roof. Both of the officers and the suspect received serious burns, and all 3 were transported to a local hospital.

The next day, the suspect died from his injuries. One officer, who was 26 years of age, suffered burns over about 45% of his body. He survived for 33 days before succumbing to his injuries. The other officer, who was 36, received burns over about 35% of his body. He remained hospitalized for 2 weeks, but he recovered from his injuries.

The state fire marshal's office concluded that the evidence was insufficient to determine conclusively the cause of the explosion. Investigators determined that the suspect had turned on the natural gas before officers arrived at his home. The surviving officer said the house exploded as he fired his CEW so we conservatively included this incident as CEW-causal.

2.1.2. *Case #4*

A deputy conducted a routine traffic stop on the suspect, a 52-year-old male. When the officer approached the suspect's van, he suddenly drove away. A short pursuit ensued until the suspect crashed and rolled the van. The suspect emerged from the van and tried to run away, so the deputy applied her CEW. As she did, the suspect's clothes caught fire. The deputy grabbed the suspect, pulled him to the ground, and rolled him into a creek, dousing the flames. Subsequent investigation revealed that the suspect had a fuel container in the van, which splashed him with petrol during the collision. The suspect suffered burns over about 70% of his body. He survived in a hospital for 181 days before he died from complications of the burn injuries.

2.1.3. *Case #5*

Officers received a 911 call of a man pouring petrol around his house and threatening to set it on fire. The suspect, a 47-year-old male, had a history of domestic disturbances with his family. According to family members, he had for months threatened to set fire to himself and his house. When officers arrived, they found the man outside in his car. He was holding a cigarette lighter as he poured petrol on himself and threatened to set himself on fire. He also claimed to have a bomb in the house. When he started to walk into the house carrying a container of petrol and the cigarette lighter, one officer tried to subdue him with pepper spray, but that

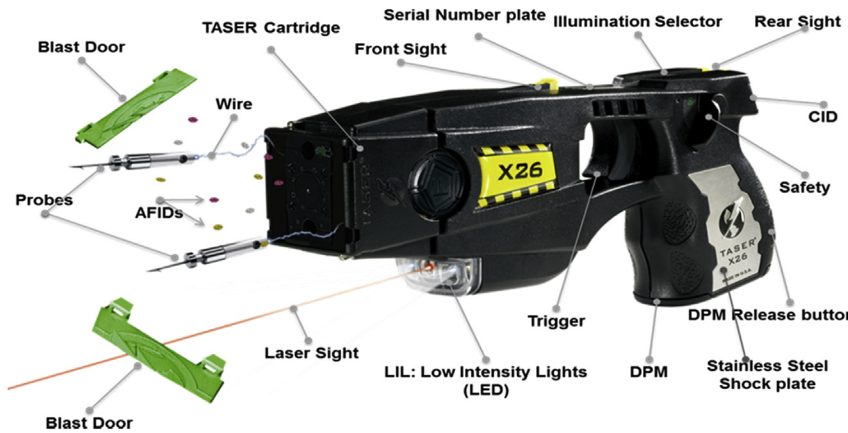

Fig. 2. X26 CEW during probe launch.

Table 1
Relevant flammable substances.

Substance	Lower Explosive Limit	Upper Explosive Limit	Minimum Ignition Energy (mJ)	Major Burn Cases	Source or Usage
Petrol	1.4%	7.6%	0.24	7	Motor vehicles, arson, suicide, sniffing
Methane	5%	15%	0.21	3	Natural Gas
Isobutane	1.8%	9.5%	0.009	0	Spray-paint propellant, lighter fluid
Ethanol	3.3%	19%	0.23	0	Spray-paint propellant, OC spray propellant
Isopropyl Alcohol	2%	12%	0.65	0	OC spray propellant
Methyl Isobutyl Ketone	1%	8%	0.21–0.53[a]	0	OC spray propellant
1,1-difluoro-ethane	3.7%	18%	UNK	0	Refrigerant aka “Dust-off” sometimes sniffed recreationally
TATP	NA	NA	NA	0	Explosive

[a] Published values for methyl *ethyl* ketone. UNK = No published values found.

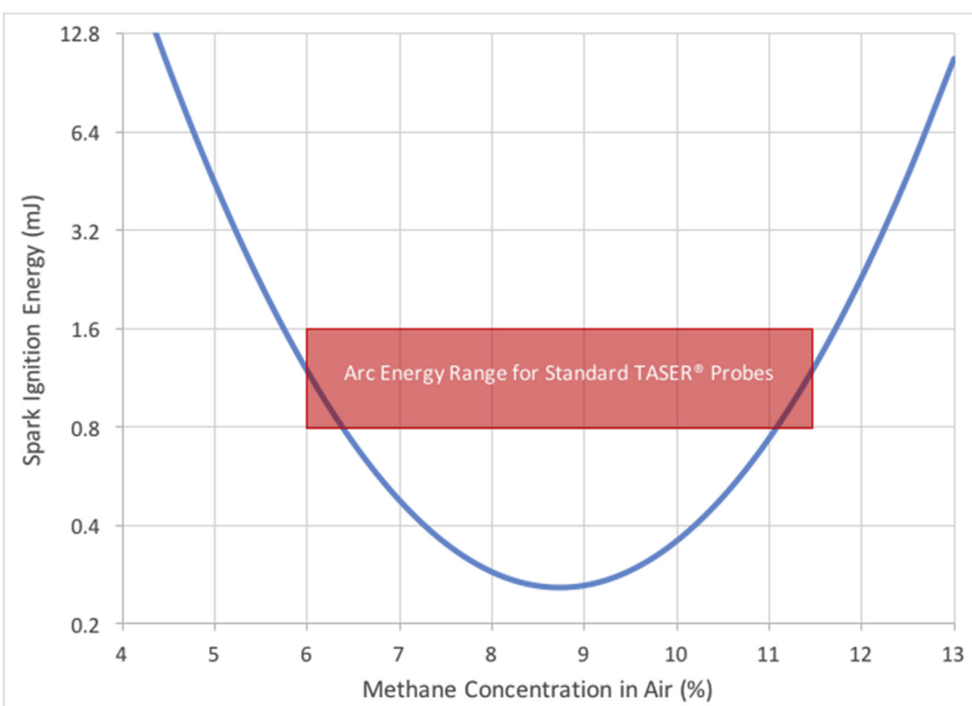

Fig. 3. Arc ignition energy for methane vs. air concentration.

Table 2
Fatal and non-fatal major (ABA class) burn cases.

Case#	Age	Race	State	Month of Incident	Month of Death	Fuel
1	41	W	MO	Aug-04	Aug-04	Methane
2	26	W	MO	Aug-04	Sep-04	Methane
3	36	W	MO	Aug-04	Survived	Methane
4	52	B	NC	Oct-05	Apr-06	Petrol
5	47	H	TX	Jun-07	Jun-07	Petrol
6	UNK	UNK	PA	Aug-08	Survived	Petrol
7	36	O	WA, AUS	Jul-09	Survived	Petrol
8	24	W	CA	Mar-12	Mar-12	Petrol
9	32	W	Devon, UK	Mar-13	Apr-13	Petrol
10	26	W	VA	Feb-15	Survived	Petrol

effort was unsuccessful. When the suspect tried to splash another officer with petrol, both officers simultaneously deployed their CEWs. Contemporaneous with the application of the CEWs, the suspect's clothing burst into flames. Officers extinguished the flames, and paramedics rushed the suspect to the hospital. The suspect received burns over his entire body, with the exception of a small area on the back of his head. He died from his injuries the next day.

2.1.4. Case #6

A state trooper observed a man on an expressway driving a motor scooter with no license plate. The trooper initiated a traffic stop, and, at first, the suspect complied and pulled to a stop. When the trooper got out of his cruiser to speak with the suspect, he drove away, and a low-speed pursuit ensued. The suspect eventually tried to pull into the parking lot of an apartment complex, but he crashed when he struck a cable that was blocking the entrance. The scooter began leaking petrol that coated the suspect's clothes. The suspect ignored the trooper's commands to stay on the ground, and a struggle ensued between the suspect and the trooper. The trooper unsuccessfully tried electronic control several times, and these applications did not ignite any fumes. Another trooper arrived and applied his CEW igniting gasoline fumes and the subject's clothing. The suspect fell to the ground, and officers used fire extinguishers to put out the flames. Once the troopers extinguished the flames, the suspect rose and again threatened the troopers. They used the CEW once more to secure the suspect. The suspect survived, but he suffered burns over about 1/3 of his body.

2.1.5. Case #7

When police arrived in response to a report of people sniffing petrol, a 36-year-old man, known to be violent toward the police, ran from a house at police officers while carrying a cigarette lighter and a container believed to contain fuel. The suspect ignored orders to stop and continued to charge the officer, who fired a CEW. When he did, the suspect's clothes, which had apparently been soaked in petrol, caught fire. The officer threw the suspect to the ground and smothered the flames with his hands. The suspect suffered 3° burns over 10% of his body, including his head, neck, and chest. Total burn coverage was 20%. The officer received burns to both hands. The suspect is listed as a single case in Table 2 and the officer is listed in Table 3.

2.1.6. Case #8

A federal agent attempted to stop a vehicle driving on the wrong side of an interstate highway. The suspect, a 24-year-old male, initially refused to stop, but he stopped after running over a tire deflation strip. Agents approached the vehicle, but the suspect refused to get out or unlock the doors. When an agent saw the suspect reach toward the center console, he broke out the passenger door window and discharged his CEW into the vehicle. When he did, the vehicle violently erupted in flames. The suspect was engulfed in flames and died in the vehicle. The agent suffered burns and lacerations of the face, but he survived and recovered from his injuries. Subsequent investigation suggested that the suspect had a quantity of exposed petrol in his vehicle — from earlier petty arson activity — that had vaporized and exploded with the spark from the CEW. Dash camera video clearly shows that the explosion was initiated by the CEW. The suspect is listed in Table 2 and the officer in Table 3.

2.1.7. Case #9

Police were called to a home where the 32-year-old suspect had been involved in a disturbance. When officers arrived, they found the suspect in the garden behind the house drenched in petrol and holding a lit match. One officer, trying to prevent the suspect from setting himself on fire, discharged his CEW. The suspect was instantly engulfed in flames. Officers smothered the flames, and the suspect was taken to a hospital where, 5 days later, he died from his injuries. A forensic scientist testified to a coroner's jury that, in his opinion as an experienced fire investigator, it was the CEW that ignited the petrol-soaked victim and not the lit match. A coroner's inquest jury agreed that the likely source of ignition was a spark from the CEW.

2.1.8. Case #10

Police conducted a traffic stop on a drunk-driving suspect, a 26-year-old-male, who initially stopped, but then fled. A pursuit ensued that ended when the suspect wrecked his vehicle, rolling it over several times. At first, the suspect was trapped in the vehicle. However, once emergency workers freed him, he began struggling with officers. One officer discharged his CEW, and the suspect's clothing, which was apparently covered in petrol, burst into flames. Firefighters extinguished the flames, and the suspect survived, but he received severe burns over about 85% of his body.

2.1.9. Excluded cases

We found 2 other fatality cases where a CEW had been used and the subject had some petrol on his clothing. In the first case, the subject appears to have doused himself in petrol — and ignited it with his cigarette lighter — only after the electronic control attempt. In the other case, the subject died of a myocardial infarction 5 days after experiencing probable minor burn injuries from a very brief fire. A post-arrest photo shows the subject walking with no apparent injuries.

3. Results

We found 10 major burn cases by the ABA criteria (6 fatal and 4 nonfatal). Our searches also found 2 moderate burn injury cases. We found 11 cases of CEW-induced fires with minor to zero injury (2 officers and 9 suspects). The 11 cases were comprised of 6 from

Table 3
Non-major burn injury cases.

#	Age	Race	State	Year	Fuel	Burn Injury	Victim
1			AZ	2005	Lighter fluid	None	S
2			OH	2005	Probable lighter	Presumed minor to zero injury.[a]	S
3	28	B	WI	2005	Ethanol OC Spray	Minor (neck and face)	S
4	53	W	FL	2006	Isobutane: Lighter fluid	Moderate (upper body)[b]	S
5			ON, CAN	2006	AXE body spray	Minor	S
6	31		CA	2009	Petrol from spilled motorcycle.	Minor (singed hair)	S
7	UNK	W	WA, AUS	2009	Petrol	Officer burned hands in major case#7	O
8	31	W	OH	2009	1,1-difluoro-ethane Refrigerant	Minor (chest & R arm)	S
9	44		WA, AUS	2010	Petrol	Moderate	S
10	24	H	CA	2012	Petrol	Minor (Officer has facial flash burns in major case#8	O
11		W	GA	2012	Spray paint	Minor	S
12	47	B	OH	2015	AXE body spray	Minor	S
13		B	LA	UNK	Lighter fluid	None	S

Note: All victims were male. AXE body spray has Isobutane and ethanol as fuels.
O = Officer, S = Suspect.
[a] Subject fled the scene.
[b] Partial thickness (2°) burns to 15% just at the cutoff from minor to moderate by ABA. This was the most severe injury from a pocket cigarette lighter.

our searches and 5 from a survey of 507 CEW instructors (with 128 full responses).

We estimated a risk of 3.2 per million of major burns (CI [1.7–5.8] by the Wilson score interval). For fatalities, the estimated risk was 1.9 per million CI [0.9–4.1] and for non-fatal major burns the risk was 1.3 per million CI [0.5–3.2]. The mean age was 35.5 ± 9.7 years which is consistent with the typical arrest-related death.[7,20,21] These estimates must be read in the context of the major limitation of the study being the way in which we were forced to find the data — through online and database searches. We focus on the rarity of the event, without claiming precision in its measurement.

4. Discussion

We believe that this paper represents the first methodical analysis of the risk of major burn injury from electronic control. Clark and Andrews reported that they had found 6 cases of fatal burn injuries but did not provide details.[22] They did perform an excellent series of experiments on the nature of the petrol-fume explosion from a CEW spark. Gerber demonstrated that TATP could be ignited by a CEW, and Myers showed that many brands of OC spray could be ignited by a CEW.[16,17]

The warnings of the largest CEW manufacturer appear to be consistent with our results. They warn against usage around “explosive or flammable clothing or materials, liquids, fumes, gases, or vapors.” They give examples of “petrol, vapor or gas found in sewer lines or methamphetamine labs, butane-type lighters, flammable hair gels or some self-defense sprays.” With hindsight, we could say that strictly following these warnings could have prevented these burn injury cases. Such utopian reasoning, of course, does not suggest a viable control option for the officer at the time of the incident. For example, in case #8 there was not enough time for the officer to smell the petrol and react. This was also the only case where the inside of the car had a dangerous level of petrol fumes.

Spray paint and body spray are not explicitly listed, by the weapon manufacturer as risks. These items have explosive or flammable fuels and are hence covered by the broader warnings. We also note that these cases only resulted in minor burns. We found 4 cases where the probe punctured a plastic cigarette lighter starting a fire; there was a single burn injury. There were also 3 such cases with no fire. See Table 4 for a summary of minor and non-injury cases with and without fires.

While much stress is placed on the risk of OC spray, this interaction has never led to a serious injury beyond the face and neck minor burn in case #3 of Table 3. The survey also found 6 cases of concomitant OC spray application all without any fire as seen in Table 4. Whether the lack of major burn injuries — with OC spray — is due to the low flammability of OC spray versus the training emphasis is difficult to ascertain. We also note that a popular OC propellant, isopropyl alcohol, has a fairly high minimum ignition energy of 0.65 mJ.

It has been previously reported that the risk of a fatal head or neck injury exceeds the hypothetical risk of electrocution.[13,23] The risk of a fatal burn also appears to exceed that of the hypothesized electrocution.[24]

5. Limitations

A prospective experimental study would generate superior data compared to our retrospective data. However, a relevant experiment would have difficulty obtaining ethical approvals.

There is no national database that records data in such incidents, so secondary sources are the only sources of information available to identify the relevant cases. When primary sources of data, such

Table 4
Minor burn or non-injury fire case summary.

Fuel	Source	Reason for Involvement	Cases With Fire	Case With Burns	Cases With No Fire
Petrol	Applied as liquid	Suicide, arson, or motor vehicle accident	4	4	4
Isobutane	Cigarette lighter	Pocket location.	4	1	3
Isobutane & Ethanol	AXE® body spray	Pocket location.	2	1	0
Ethanol	OC spray	Use of force	1	1	6*
1,1-difluoroethane	Dust-Off®	Recreational inhalation	1	1	0
Unknown (probably Isopropyl Alcohol or Methyl Isobutyl Ketone)	Spray paint	Recreational inhalation, graffiti	1	0	0

* Many brands of OC spray do not use ethanol.

as autopsy reports, were available, we used them. However, autopsy and police reports are not available in all states and countries, depending on their public information laws. Police reports, autopsy reports, and news accounts are also subject to bias.

Due to the extensive media coverage of any arrest-related-death, we are confident that we have missed few — if any — fatal burns cases. For the less-severe burns cases, our confidence decreases with the decreasing burn severity.

We also note that the sampling frame is less rigorous than we would prefer. However, there is no practical alternative. We spent significant time searching open records sources trying to identify cases for this study. We focused our examination on those cases when the electrical weapon caused a fire, and that fire resulted in a fatal or nonfatal major burn. Those instances are rare, but they are critically important to understanding the risks of using such weapons. Medical records are not available to us to study the effects of this force on people who suffered minor or zero injuries, and the effects on people who had no fire ignited add nothing to the understanding of the risks of fatal fires once the rate is calculated, as we did.

6. Conclusions

The use of electrical weapons presents a small but real risk of death from fatal burn injury. It also presents a small risk of major non-fatal burn injury. The ignition of petrol fumes dominates these cases of major fatal and nonfatal burns.

Conflict of interest statement

MWK has been an expert witness in law-enforcement litigation (and specifically in case #8) and is a member of the Axon (fka TASER) corporate and scientific advisory board who partially funded this work. HEW is a retired Police Chief and has been an expert in law-enforcement litigation and a coroner's inquest. MBR reports no conflicts.

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