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How Do Electrical Weapons Affect the Behaviour of Implantable Pacemakers

Antoni Aguilar Pallarès
Unitat Central d'Informàtica Forense
Mossos d'Esquadra. Policia de Catalunya
Catalonia, Spain
itpg7539@gencat.cat

Juan Francisco Morante Barragán
Unitat Central d'Informàtica Forense
Mossos d'Esquadra. Policia de Catalunya
Catalonia, Spain

Marta Novelle Rodríguez
Unitat Central d'Informàtica Forense
Mossos d'Esquadra. Policia de Catalunya
Catalonia, Spain

Mercè Subirana Domènech
Servei de Patologia Forense
Institut de Medicina Legal de Catalunya
Catalonia, Spain

***Abstract*— Electrical weapons are designed to generate an electric current between electrodes and deliver an electric shock. Their effects are controversial and considered dangerous by some authors because they could cause heart attack and ventricular fibrillation in some cases, but very few studies are related to the effects of the electricity on subcutaneous pacemakers. In order to establish the effects caused on pacemakers several discharges have been made with three electrical weapons on twelve different pacemakers and the behaviour, before and after the discharges, has been recorded. By comparing the results obtained we have arrived to the conclusion that, in most cases, the pacemakers tested are not affected in a significant way by the electrical weapons. This is due to the protection of the electronic circuitry and the electrical insulation provided both by the biocompatible titanium alloy, typically used, of the pacemaker's housing and by the polymer cover of the thin lead.**

Keywords— Forensic science; conducted electrical weapon; nonlethal weapons; TASER®; Stun Gun; electrical discharge

I. INTRODUCTION

The objective of electrical weapons is to temporally incapacitate through electrical discharges aimed at interfere the surface muscular functions causing electrical interruption of the body's normal pulses [1] but they can also be used merely to cause pain.

There are two main types of electrical weapons: the ones you need to make physical contact between the subject and the weapon (Contact Discharge Weapon or CDW) such as Stun Guns, Stun Batons, Electroshock Belts and such like and the ones you shoot projectiles to the subject and the electric shock is administered through a flexible wire (Conducted Electrical Weapon or CEW) such as TASER weapons. They were created as an alternative to conventional hand gun used by law enforcement officers without significant or lasting injuries [2].

When the CDW makes the discharge without being in contact with anyone it produces a distinctive sound and light that has a deterrent effect.

The CEW can work the same way as the CDW or shooting the electrodes from a safe distance. In this way it allows the separation between the agent and the suspect and immobilizes the subject (Neuromuscular Incapacitation or NMI).

Pacemakers are electronic systems that, by producing electrical stimulus, activate the myocardium and keep the cardiac rhythm in the most physiological possible way making the ventricle trigger the systole.

The aim of the present study is to analyse the effects that electrical weapons produce when applied upon pacemakers and, in case they result affected in some way, determine the time they need to get back to normal behaviour.

II. MATERIAL AND METHODS

In order to simulate a wide range of cases, twelve random pacemakers of different types and from different manufacturers are tested, as shown in Tables I and II. To produce the electrical discharge we use three weapons from the two main types, CDW and CEW. Pig's feet are being used to replace the human skin and an oscilloscope displays the results.

Table I. Type of pacemakers

TYPE	I STIMULATED CHAMBER	II SENSED CHAMBER	III SENSING RESPONSE	IV FREQUENCY RESPONSE PROGRAMMING
VDD	Ventricle	Dual	D(I+T)	
VDDR	Ventricle	Dual	D(I+T)	Frequency response
SSIR	Shock in V	Shock in V	Inhibition	Frequency response
DDDR	Dual	Dual	D(I+T)	Frequency response
VVIR/ AAIR	Ventricle /Auricle	Ventricle/ Auricle	Inhibition	Frequency response
SSIR	Shock in V	Shock in V	Inhibition	Frequency response
SSI	Shock in V	Shock in V	Inhibition	
SSIC	Shock in V	Shock in V	Inhibition	Communication

Table II. Pacemakers tested

Number	Model and type	Brand
1	PHILOS II SLR VDD	BIOTRONIK
2	AXIOS SLR VDDR	BIOTRONIK
3	ALTRUA 50 S502 DDDR	BOSTON SCIENTIFIC
4	ALTRUA 50 S502 DDDR	BOSTON SCIENTIFIC
5	INSIGNIA I AVT 1192 SSIR	GUIDANT
6	ESPRIT SR SSIR	SORIN
7	DISCOVERY II 0481 SSI	GUIDANT
8	AFFINITY VDR 5430 VDDR	PACESETTER
9	NEWAY VDR VDDR	SORIN
10	REGENCY SC+ 2402L SSIC	St. JUDE MEDICAL
11	VERITY ADx XL SR 5156 SSIR	St. JUDE MEDICAL
12	PHILOS II SR VVIR/AAIR	BIOTRONIK

The electrical weapons used are: Stun Gun GL2000RB Gallant Lion (CDW), Stun Gun Viper (CDW) and TASER® X26 (CEW)

We make one electrical discharge and we record the pacemaker's behaviour with an Oscilloscope Tektronix TAS 465 before and after the discharge.

With the pacemaker located between the skin and the meat of the pig's foot and the wires in contact with the meat the following discharges have been made:

TASER® X26 weapon

1. Direct contact of the electrodes on the skin for 1 second, working as a CDW.
2. Direct contact of the electrodes on the skin for 5 seconds, working as a CDW.
3. Discharge with the dart-like electrodes placed 14 cm one from the other for 1 second, working as a CEW.
4. Discharge with the dart-like electrodes placed 14 cm one from the other for 5 seconds, working as a CEW.

Stun Gun type weapons

1. Direct contact of the electrodes on the skin with Viper weapon for 2 seconds.
2. Direct contact of the electrodes on the skin with Gallant Lion weapon for 2 seconds.
3. Direct discharge (without pig's feet) on the pacemaker with Gallant Lion weapon for 2 seconds.

The TASER® X26 can make an electrical discharge in three different lengths. The standard one is a five seconds discharge which is done by simply pulling and releasing the trigger. Then, you can either make it shorter, by activating the safety switch, or longer keeping the trigger pulled. These lengths depend entirely on the agent using the weapon and we have chosen the standard of five seconds and one shorter of one second as these are the most usual lengths used.

When it comes to Stun Guns this is very different. The length of the discharge depends on the person receiving this discharge because he or she, not being immobilized by the CDW, can escape so this length will be very short. We have chosen a discharge of two seconds long.

The pacemaker's behaviour has been recorded before and after each discharge.

In the cases that the pacemaker has two wires we have connected to the auricle wire an ECG signal simulating circuit and we have recorded the ventricle wire signal.

III. RESULTS

The response of a pacemaker is an electrical signal characterized by four parameters: Amplitude (Volts), negative return (Volts), duration (microseconds) and frequency (beats per minute) as seen in Figure 1.

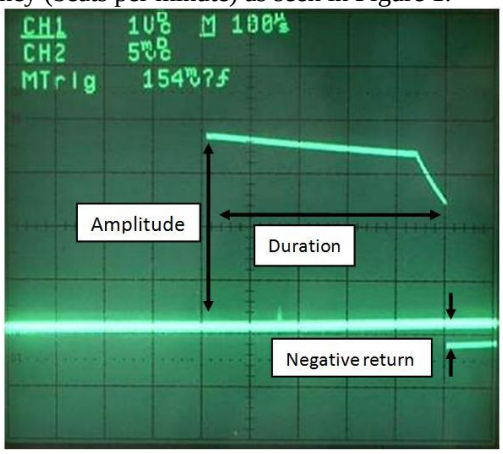

Fig. 1. Measured parameters with Tektronix TAS 465 oscilloscope. Amplitude is the difference, in Volts, between the reference value of zero Volts and the highest value of the signal. Duration is the time, in microseconds, that the pulse value is bigger than zero Volts. Negative return is the difference between the reference value, in Volts, and the most negative value of the signal when the pulse finishes

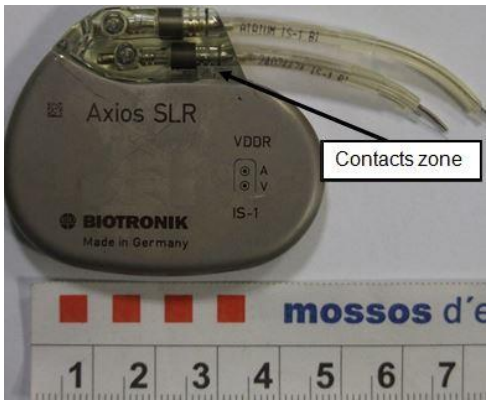

Fig. 2. Contacts zone is the area where the wires enter the housing of the pacemaker

Table III shows, as an example, the results measured before and after each discharge of a PHILOS II SLR VDDR pacemaker. As we can see, in this case, the pacemaker barely is affected by the test. Before the discharges we had an amplitude of 3,7 V, a negative return of 0,4 V and a duration of 500 microseconds, the same we measured at the end of the study. After a discharge from the TASER with the electrodes placed 14 cm one from the other for 1 second the amplitude and negative return varied 0,1 V and the duration 20 microseconds. For the frequency results, we begin with 60 bpm and finish with 58 bpm with a maximum variation of only 4 microseconds, that is to say only 0,000004 seconds.

Table III. Results obtained with a PHILOS II SLR VDDR pacemaker from Biotronik

Discharge type	Amplitude	Negative return	Duration	Frequency
Before	3,7	0,4	500	60
TASER Contact 1 s	3,7	0,4	500	60
TASER Contact 5 s	3,6	0,4	500	57
Separated electrodes 1 s	3,6	0,3	480	56
Separated electrodes 5s	3,7	0,4	500	59
Viper weapon	3,7	0,4	490	58
Gallant Lion weapon	3,7	0,4	500	58
Direct discharge	3,7	0,4	500	58

The following table, Table IV, is a summary of all the results obtained.

Table IV. Summary with the main results obtained: Initial value (Ini), final value (Fin) and variation between the maximum and minimum measured (Max). Shown in underlined bold is pacemaker #9, the one that stopped working permanently

PACEMAKER (see Table II)	AMPLITUDE			NEGATIVE RETURN			DURATION			FREQUENCY		
	Ini	Fin	Max	Ini	Fin	Max	Ini	Fin	Max	Ini	Fin	Max
1	3.7	3.7	0.1	0.4	0.4	0.1	500	500	20	60	58	4
2	2.5	4.2	1.8	0.4	1	0.8	480	610	130	43	55	13
3	3.8	3.8	0.1	0.4	0.4	0.1	420	430	10	70	70	11
4	2.4	2.5	0.3	0.6	0.7	0.2	440	430	20	72	60	21
5	3.6	3.6	0.1	0.7	0.7	0.1	430	420	10	51	51	4
6	3.2	3.2	0.1	1.9	1.9	0.2	1000	1000	50	69	71	11
7	2.2	2.2	0.2	0.8	0.8	0.3	1000	950	100	49	45	7
8	4.1	4.9	0.9	0.8	1.1	0.4	500	650	150	57	67	14
9	**3.1**	**0**	**7.6**	**0**	**0**	**0.4**	**400**	**0**	**400**	**48**	**0**	**52**
10	4	4	0	0.8	0.8	0	1900	1900	0	60	60	0
11	3.2	2.9	0.5	0.4	0.5	0.3	610	610	10	67	67	4
12	4.7	4.6	0.2	0.8	1	0.3	1100	700	420	60	60	2

Pacemakers number 9 and 10 were only tested with the Taser® weapon.

To check the viability of this study two of the pacemakers were the subject of previous tests and the behaviour of one of them was affected by the discharge of the Gallant Lion weapon, reason why they were kept in the study. These are the results of these previous tests:

Pacemaker number 11: Before the discharge we measured a voltage between 2.5 and 2.7 V. During these early tests the pacemaker stopped working for a period of eighteen minutes after which it continued working normally. After a direct discharge on the pacemaker's wires tips with the Gallant Lion weapon we measured 3.7 V. The rest of the testing didn't affect the pacemaker's behaviour.

Pacemaker number 12 was: Before the discharge we measured a voltage between 2.44 and 2.52 V with an approximated frequency of 60 bpm. After a direct discharge on the pacemaker's wires tips with the Viper weapon we measured 4.75 V with no frequency variation. The rest of the testing didn't affect the pacemaker's behaviour.

IV. Discusion

It is well known that direct stimulations on the heart can cause fatal cardiac arrhythmia and ventricular fibrillation [3]. Although electronic devices are considered by some a safer alternative to firearms, concern has been raised about potential adverse cardiac effects of neuromuscular incapacitating and they have been associated with some sudden in-custody deaths [4] and even with torture [5]. This subject is controversial and some authors report the absence of electrocardiographic change after prolonged application of a conducted electrical weapon in physically exhausted adults. [6]. Another fact is that in custody-deaths we cannot ignore the effects of excited delirium [5 7].

Electromagnetic interference has long been recognized as a problem in the management of patients with pacemakers and implantable cardioverter-defibrillators [8] but there is a lack of knowledge about the effects of electronic weapons on pacemakers and there are few references of the effects on implantable cardioverter-defibrillators [9 10 11].

From our study we can summarize that ten pacemakers didn't show any significant variation. One pacemaker though, NEWAY VDR VDDR, had an anomalous behaviour showing variations in the amplitude after each discharge and stopped working permanently when a direct discharge on the contacts zone with the TASER® was made. Two months later it was tested again and continued broken-down. This behaviour may be due to the pacemaker being broken before the study or to the effects of the electrical discharges made.

The most controversial result was that another pacemaker, VERITY ADx XL SR 5156 SSIR, stopped working for eighteen minutes and continued working with normality afterwards. If a person were pacemaker dependant some alterations in the heart behaviour or even cardiac arrest could be produced.

Some pacemakers showed increases of amplitude values but this should not have clinical repercussions because they provide more energy so the pacemaker continues doing its task. Also, these increases are detected after a direct discharge which is not a usual situation.

In our study the fact that one pacemaker stops working permanently as a consequence of a direct discharge is a situation that is impossible that it happens in real life since the pacemaker will always be implanted subcutaneously. We must keep in mind that this discharge was made as the most unfavourable, and irreproducible in a non-experimental situation, event. The same can be said of a discharge over the wires' tips.

All the above said seems to confirm that the protection of the electronic circuitry and the electrical insulation provided both by the biocompatible titanium alloy of the pacemaker's housing and by the polymer cover of the lead is sufficient to ensure a good performance in front of any electric interference.

One aspect to have in consideration, not being the aim of this study, is that the electrical discharge may be taken as a heartbeat by the pacemaker and, depending on the pacemaker's programming, affect its behaviour.

V. Conclusions

In this study the electrical weapons didn't affect in a significant way the behaviour of most of the implantable pacemakers.

However, according to Marine, 2006 [12] emergency and law enforcement personnel should be aware of the potential interaction between neuromuscular incapacitating devices and implanted cardiac devices and these weapons should be avoided, if possible, on individuals known to have pacemakers or implanted cardiac devices. Jauchem, 2010 considers that factors other than electronic control devices themselves may be more important when death occurs after the use of them [13], so our main conclusion is that more research is needed in order to establish the effects of these weapons in humans.

Conflict of interest: The authors declare that they have no conflict of interest.

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References

[1] Kunz SN, Zinka B, Fieseler S, Graw M, Peschel O (2012). Functioning and effectiveness of electronic control devices such as the TASER® M- and X-series: a review of the current literature. J Forensic Sci. 57(6):1591-4.

[2] Ordog GJ, Wasserberger J, Schlater T, Balasubramanium S (1987). Electronic gun (Taser) injuries. Ann Emerg Med. 16(1):73-8.

[3] Reilly JP (1998). Cardiac sensitivity to electrical stimulation. In: Reilly JP, editor. Applied bioelectricity: from electrical stimulation to electropathology. New York, NY: Springer, 194-249

[4] Lee BK, Vittinghoff E, Whiteman D, Park M, Lau LL, Tseng ZH (2009). Relation of Taser (electrical stun gun) deployment to increase in in-custody sudden deaths. Am J Cardiol.103(6):877-80.

[5] Nugent K, Cevik C (2013). Use and safety of conducted electronic devices: what is known? East Mediterr Health J. 19(6):576-9.

[6] Ho JD, Dawes DM, Heegaard WG, Calkins HG, Moscati RM, Miner JR (2011). Absence of electrocardiographic change after prolonged application of a conducted electrical weapon in physically exhausted adults. J Emerg Med.41(5):466-72.

[7] Jauchem JR (2011). Pathophysiologic changes due to TASER® devices versus excited delirium: potential relevance to deaths-in-custody? J Forensic Leg Med.18(4):145-53.

[8] Pinski SL, Trohman RG (2002). Interference in implanted cardiac devices, Part I. Pacing Clin Electrophysiol. 25(9):1367-81.

[9] Leitgeb N, Niedermayr F, Neubauer R (2012). Interference of implanted cardiac pacemakers with TASER X26 dart mode application. Biomed Tech (Berl). 57(3):201-6.

[10] Vanga SR, Bommana S, Kroll MW, Swerdlow C, Lakkireddy D (2009). TASER conducted electrical weapons and implanted pacemakers and defibrillators. Conf Proc IEEE Eng Med Biol Soc. 2009:3199-204.

[11] Lakkireddy D, Khasnis A, Antenacci J, Ryshcon K, Chung MK, Wallick D, Kowalewski W, Patel D, Mlcochova H, Kondur A, Vacek J, Martin D, Natale A, Tchou P (2007). Do electrical stun guns (TASER-X26) affect the functional integrity of implantable pacemakers and defibrillators? Europace. 9(7):551-6.

[12] Marine JE (2006). Stun guns: a new source of electromagnetic interference for implanted cardiac devices. Heart Rhythm.3(3):342-4.

[13] Jauchem JR (2010). Deaths in custody: are some due to electronic control devices (including TASER devices) or excited delirium? J Forensic Leg Med. 17(1):1-7