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Predictors of intraoperative electrosurgery-induced implantable cardioverter defibrillator (ICD) detection

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Abstract
Background In the USA, the number of people needing implantable cardioverter defibrillators (ICDs) has grown dramatically. Many ICD recipients will need to undergo a surgical procedure at some point following ICD implantation. Most surgeries involve the use of electrocautery. Currently, the effects of electrocautery-induced electromagnetic interference (EI-EMI) on ICDs are poorly understood. The aim of this study was to study EI-EMI using prospectively collected clinical data.
Methods We analyzed prospectively collected ICD data from patients undergoing a surgical procedure at Mayo Clinic between 2011 and 2012. Information on clinical, device history, device interrogation pre- and post-surgery, and surgical information were collected for all patients. ICDs were programmed with detections on and therapies off. The patients were then categorized into two groups: those with EI-EMI inappropriate arrhythmia detection and those without detection. The stored electrograms were reviewed. Clinical and device parameters were analyzed to identify predictors of EI-EMI.
Results Of 103 patients studied, bipolar cautery did not induce EI-EMI (0/11 cases), whereas monopolar cautery resulted in noise detection in 11/92 procedures. Among 11 inappropriate episodes of detection, 10 had surgery at chest, neck, and upper extremity sites with cautery current across the ICD lead tip; 1 had abdominal surgery; and none had back or low extremity surgery. On average, the near-field electrogram amplitude values were greater than the far-field amplitude values.
Conclusions EI-EMI does not occur when bipolar cautery or monopolar cautery is used below the hips with the dispersive ground pad applied to the lower extremities. In contrast to external EMI, EI-EMI may be larger on near-field than far-field electrograms.

Keywords Electrocautery · Pacemaker · Implantable cardioverter defibrillator

Abbreviations

ICD	Implantable cardioverter defibrillator
EI-EMI	Electrocautery-induced electromagnetic interference

1 Introduction

Since its application into clinical medicine, the use of the implantable cardioverter defibrillator (ICD) has grown exponentially [1, 2]. Though it is an effective therapy for patients at risk for sudden cardiac death, ICDs have the risk for inappropriate therapy due to interaction with other electrical apparatuses that cause electromagnetic interference (EMI) [3]. Specifically, the effects of EMI in the form of electrocautery during surgery can have potentially negative consequences, including, but not limited to, inappropriate device detection and therapy, device reprogramming, induced atrial fibrillation and ventricular fibrillation, and tissue injury at the lead-tissue interface [4–6]. Therefore, tachyarrhythmia detection or therapies are programmed off before the surgery and reprogrammed to its original settings after the surgery [7, 8]. However, this process can be logistically complex as it requires specialized equipment and highly trained personnel—as such, it is not always an option in hospitals that lack these necessities or during emergency

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situations. Previous studies have shown that the risk of a harmful interaction between the ICD and electrocautery is unlikely [6, 9]; information regarding the actual consequences of EMI on the patient and ICD function when detection does occur remains poorly documented in the literature. In this study, we aim to discern if there is a measurable effect of electrocautery on ICD sensing and function and to identify what predictors indicate increased likelihood of inappropriate detection by ICDs. We hypothesized that electrocautery-induced EMI (EI-EMI) would not impair ICD sensing and function and that the risk of inappropriate detection would depend on the physical relationship between the ICD and cautery electrodes. To test these hypotheses, we performed a single-center prospective observational study in ICD patients who undergo non-cardiac surgery.

2 Methods

2.1 Study subjects

This prospectively designed study included 103 patients who underwent non-cardiac surgery at Mayo Clinic, Rochester, between July 2011 and December 2012. All the subjects had a transvenously placed ICDs. The ICD was interrogated by a pacing nurse before the surgery as per standard clinical practice. The ICD tachyarrhythmia detection was programmed on, but the therapies were deactivated per study protocol. The VT/VF detection was the existing programming for each patient, without a specific detection scheme programmed.

After surgery, the devices were reinterrogated to evaluate ICD and lead function, and tachycardia or EI-EMI detection. If the tachyarrhythmia or EI-EMI was detected, the stored electrogram was retrieved and was manually reviewed by the pacing nurse and an electrophysiologist. The amplitude of EI-EMI when present was reviewed by study personnel (YMC, JVH, and JR). The clinical information was collected from a review of the electronic medical records.

The electrocautery information was confirmed by a surgeon that operated for the patient in the study. The type of cautery used, the ground patch location when applicable, and the anatomic location at which cautery was used were collected. In the cases in which device interrogation demonstrated an inappropriate detection of EI-EMI as VT/VF, characteristics of the signal leading to detection were recorded, and post-operative interrogation of the ICD was compared to the pre-operation. The pre- and post-operative interrogations were determined by the temporal proximity to the surgery, using the last full interrogation before and after surgery for data collection. To characterize the noise leading to detection, the voltage amplitude from the ventricular lead tip to ring electrode (near-field signal) was measured, as was the voltage from the shocking coil to the generator (far-field signal). Patients that did not have both pre- and post-surgery ICD interrogations were excluded from the analysis of function of ICD.

2.2 Statistical analysis

Patient demographic information was represented by the population mean and standard deviation. To establish whether there was a significant difference between pre-operative and post-operative functions of the ICD in those ICDs that had EI-EMI detection, a paired student t test was used. All other information comparing the group that had perioperative EI-EMI noise detection vs. the group that did not was determined through an unpaired student t test or chi-squared analysis where applicable. Results were considered statistically significant when $p \leq 0.05$.

3 Results

3.1 Patient baseline characteristics

The baseline characteristics of the 103 study patients are summarized in Table 1. The mean age of the study population was 70 ± 10 years (male 72 %), and the mean body mass index (BMI) was 29.97 ± 6.31 kg/m^2. Forty-six patients had single-chamber, 30 had dual-chamber, and 27 had biventricular ICDs.

3.2 Electrosurgery and ICD system function

The ICD function before and after surgery is summarized in Table 2. Within the group that had EI-EMI detection, the P-wave and R-wave amplitude, and the right atrial and ventricular lead impedance were not significantly changed after the surgery. This held true for the non-EI-EMI group as well. Comparing the two groups between EI-EMI and no EI-EMI detection, there were no statistically significant differences seen at baseline and after surgery (all $p > 0.05$).

Table 1 Baseline characteristics in patients with or without EMI detection

	Overall $N = 103$	No EMI $N = 92$	EMI $N = 11$	p
Age, years	70 ± 10	70 ± 10	69 ± 11	0.996
Male, n (%)	74 (72)	69 (75)	5 (45)	0.022
BMI, kg/m^2	29.97 ± 6.31	30.3 ± 6.4	27.4 ± 4.6	0.193
Hypertension, n (%)	62 (60)	59 (64)	3 (27)	0.087
Diabetes, n (%)	28 (27)	28 (30)	0 (0)	0.062
CAD, n (%)	59 (57)	53 (58)	6 (54)	1
Cardiomyopathy, n (%)	68 (66)	62 (67)	6 (54)	0.665

Table 2 ICD interrogation before and after surgery

	EI-EMI		No EI-EMI		EI-EMI vs. No EI-EMI groups	
	Before surgery	After surgery	Before surgery	After surgery	Before surgery	After surgery
P sensing	2.76 ± 2.05	2.32 ± 1.70	2.47 ± 1.71	2.55 ± 1.39	$p = 0.732$	$p = 0.745$
R sensing	12.3 ± 7.11	12 ± 6.04	10.2 ± 4.87	10.0 ± 5.20	$p = 0.297$	$p = 0.332$
Atrial impedance	471 ± 44.0	471 ± 55.8	451 ± 79.5	438 ± 84.7	$p = 0.584$	$p = 0.408$
Ventricular impedance	472 ± 69.3	466 ± 47.1	520 ± 127	516 ± 166	$p = 0.371$	$p = 0.402$

3.3 Electrosurgery and EI-EMI detection

Of the 103 study patients, 11 (10.6 %) episodes of EMI events were identified by post-operative device interrogation. None of the patients had true ventricular arrhythmia developed during surgery. Of the 11 patients who had bipolar cautery, none had EI-EMI detection. Of the 92 patients who had monopolar cautery, 11 had EI-EMI detection. All EI-EMI episodes were all detected in the VF zone. The EI-EMI cycle lengths ranged from 85 to 150 ms. Eight of 11 episodes met the detection duration criteria that would have resulted in ICD therapy. The frequency of EI-EMI detection was similar between two manufactures (Medtronic Inc. 2 of 38 and Boston scientific Inc. 9 of 65, $p = 0.20$). There was no difference on EI-EMI detection between integrated bipolar Boston Scientific leads vs. true bipolar leads (7 out of 54 vs. 4 out of 49, $p = 0.53$). None of the study patients had power on reset. The grounding patches were always placed on the thigh or the buttocks, either at ipsilateral or contralateral side relative to the ICD. All instances of EI-EMI occurred when the cautery was applied in between the lead tip and the grounding patch. Among the group that experienced EI-EMI during surgery, the mean cycle length and duration of the longest episode were 127 ± 19 ms and 18 ± 12 s, respectively. During the EI-EMI detection, the right ventricular lead near- and far-field amplitudes were 21 ± 12 and 15 ± 12 mv ($p = 0.02$). Examples of electrograms are shown in Fig. 1a, b. Note that in the example in the right panel, the near-field noise has greater amplitude than the far-field noise. In 8 of 9 cases in which electrograms were quantitatively measured, there were greater amplitudes for the near-field signal than the far-field signal. The average ratio of the near-field to far-field signal was

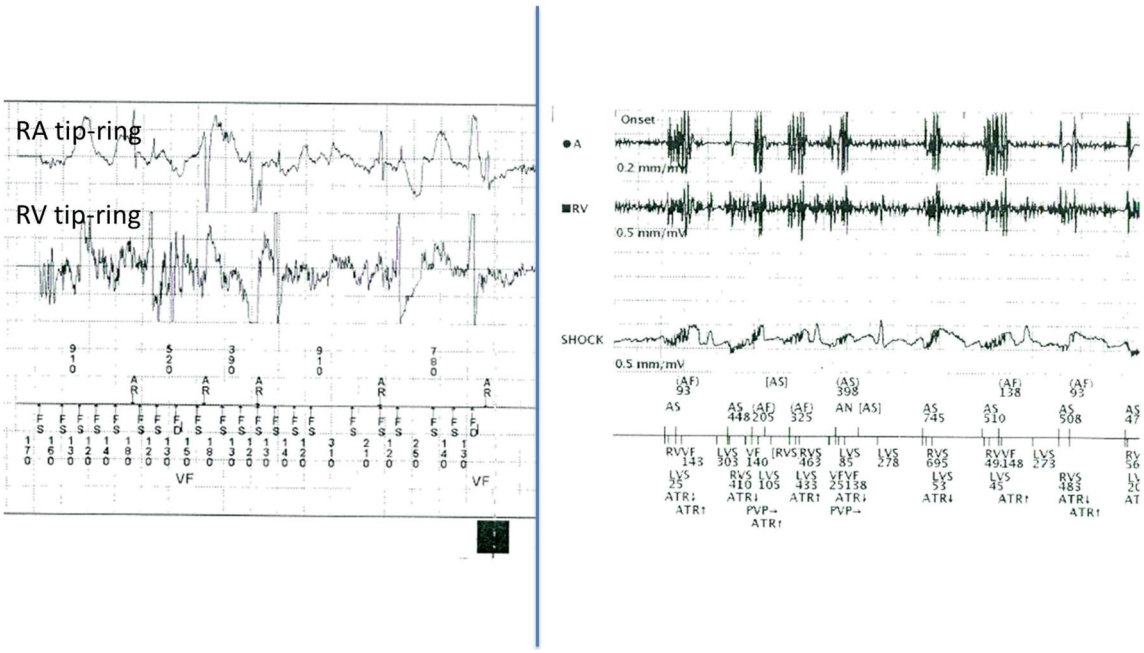

Fig. 1 Examples of EMI that resulted in inappropriate detection (without therapy since therapies had been programmed of) in patients undergoing surgery. **a** Patient undergoing open reduction and internal fixation of a left humerus fracture in the setting of a left-sided ICD system. **b** Tracings from a patient undergoing robotic-assisted tongue base resection and right neck dissection. In both cases, the dispersive cautery pad was applied to the lower extremity. Note that in **b**, the EMI noise amplitude is greater on the near-field than far-field recordings

2.0 ± 1.1. The only episode of EI-EMI that had larger far-field amplitude than the near-field amplitude was a procedure involving the head (Table 3).

3.4 Surgical location and EI-EMI detection

The surgical areas were grouped as neck/head, thorax, shoulder/upper extremity, abdomen, spine/back, and hip/lower extremity as shown in Fig. 2. Among these six areas, the EI-EMI was detected often during neck/head (43 %) or thoracic (50 %) surgery, whereas no EI-EMI event was detected during spine/back or below the hip surgeries (Table 4). Only one patient who underwent abdominal surgery had noise detection; this patient had hemicolectomy involving surgery both above and below the umbilicus. No complications or cardiac arrests that required external defibrillation occurred in this study.

4 Discussion

4.1 Main findings

This is one of the largest series of prospectively collected perioperative ICD interrogations to investigate the effects of electrosurgery on ICD. We found that (1) cautery does not have adverse effects on device and lead function; (2) with monopolar electrocautery, when grounding pad was placed on the lower extremities, EI-EMI was not detected when the surgery was below the hip, and rarely detected during abdominal surgery; (3) with bipolar cautery, EI-EMI was not detected in the surgery; and (4) in contrast to previous reports that EMI results in larger noise on far-field electrograms than near-field electrograms, we found that either near-field or far-field electrograms could be larger in EI-EMI.

Table 3 EMI magnitude when detected

Area of surgery	Near-field amplitude (mV)	Far-field amplitude (mV)	Amplitude ratio (near-field/far-field)
Neck	65	50	1.3
Head	45	55	0.81
Thorax	65	35	1.9
Thorax	16	10	1.6
Thorax	1.3	Not recorded	N/A
Upper extremity	1.8	Not recorded	N/A
Upper extremity	55	35	1.6
Thorax	18	4	4.5
Abdomen	2	0	∞
Neck	1.2	0.5	2.4
Thorax	1.5	1	1.5

N/A not applicable

4.2 EI-EMI detection during surgery

EI-EMI occurred when the ICD lead electrodes were between the site of cautery and the grounding patch when monopolar cautery was used. When bipolar cautery was used, EMI did not occur, suggesting bipolar cautery is safe when used at least 10 cm from ICD system electrodes. Congruently with previous studies, the use of bipolar cautery in our study minimized the risk of EI-EMI in patients with pacemakers or defibrillators [9, 10].

There was no association between comorbidities or body habitus and abnormal detection of electrocautery. Previous studies have suggested that the likelihood of a perioperative electrosurgery-induced EMI being detected by an ICD is small [5, 9]. Our study found that approximately 11 % surgeries had episodes of noise detection due to cautery. Thoracic surgery had the highest EI-EMI detection rate at 50 %, head/neck surgery as the second, indicating the high likelihood of EI-EMI if the device is within a close proximity to the surgical site and is in the electrical current pathway between surgical site and grounding pad. Only one EI-EMI was observed from abdominal surgery, the operation involved above and below the umbilicus. None of 35 patients who underwent back and low extremity operation had experienced EI-EMI. Our finding is consistent with previous report from Hoyt R et al. [11]; except in our study, one case had EI-EMI detected during a surgery below the diaphragm. In that study, all 53 patients who had surgery below the diaphragm were free of EI-EMI events. Our findings mostly support the HRS/ASA Expert Consensus on Perioperative Management of CIED in general [12]. In the consensus statement, pre-operative CIED reprogramming is recommended if the surgery site is above the umbilicus. However, as we had 1 out of 34 patients who underwent colon surgery and had EI-EMI detection, we recommend pre-operative CIED reprogramming if the surgery site is above the hips in our institution. Some abdominal organs are clearly above the umbilicus such as the liver and spleen; some are below the umbilicus such as the bladder and uterus. Yet it may be difficult to determine whether colon or small intestine surgery is above or below the umbilicus prior to the operation. Therefore, we take a conservative approach in our institution by using the hips as a landmark for pre-operative device programming. We have not encountered any EI-EMI detection and therapy event with this protocol.

4.3 Far-field and near-field EMI signal

The finding of larger near-field electrograms as opposed to far-field electrograms was contradictory to usual characterizations

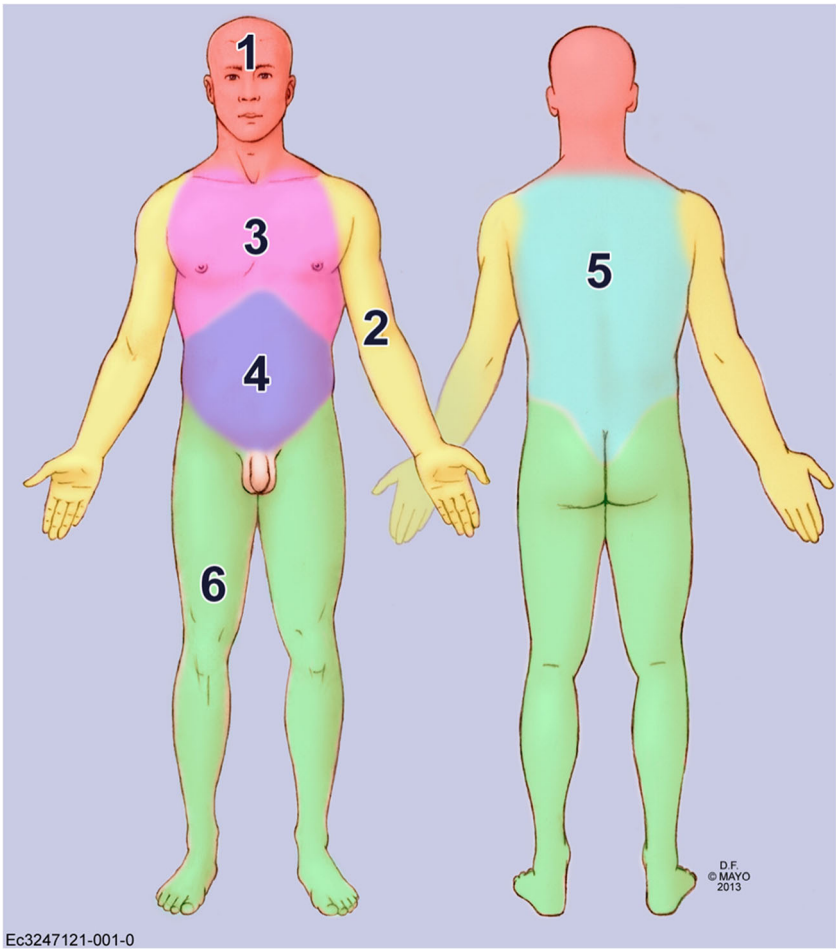

Fig. 2 Surgical regions and electrocautery-induced EMI risk, grouped as neck/head (*1*), thorax (*3*), shoulder/upper extremity (*2*), abdomen (*4*), spine/back (*5*), and hip/lower extremity (*6*)

of EMI-induced noise in which the far-field amplitude is greater than that of the near-field. However, to our knowledge, no prior study has evaluated the magnitude of near-field vs. far-field electrogram detection in EI-EMI. One potential explanation is that cautery is very close to the dedicated bipolar electrodes between the lead tip and grounding patch. The close proximity of cautery to the close-spaced bipolar electrodes may be detected as a larger near-field signal than the far-field signal. Alternatively, the phenomenon of near-field noise amplitude larger than the far-field noise amplitude caused by EI-EMI is different from other source of EMI caused by electromagnetic waves (e.g., from arc welding or anti-theft detectors), in which the far-field electrograms are greater than near-field electrograms, due to their greater antenna effect. The larger surface area and greater separation of the far-field recording electrodes results in their greater susceptibility to external EMI. EI-EMI, on the other hand, is the result of a current passing through the body (a conductor), which can thus be larger on the near-field signal if it is closer to the current pathway.

Table 4 Surgery location and EMI detection

Surgical areas	Number	ICD detection, *n* (%)
Head, neck	7	3 (43)
Shoulder/upper extremity	23	2 (9)
Thoracic (non-cardiac surgery)	10	5 (50)
Abdomen, pelvic	34	1 (3)
Back, spine	5	0 (0)
Hip, lower extremity	24	0 (0)
Total	103	11 (11)

Dispersive grounding pad applied to lower extremities in all cases

4.4 EI-EMI and device function

There was no apparent ICD malfunction detected in this study including those cases that had EI-EMI detected during surgery. This is reassuring the low likelihood of lead and generator malfunction caused by electrocautery.

4.5 Study limitations

The patient population of those who experienced noise detection was significantly smaller than that of the control group. This difference may have affected the statistical power

comparing the two groups. Data on precise distance between electrocautery and the leads in human study were not available, limiting further analysis and calculations. We did not record the cautery duration, which may impact on EI-EMI detection. In addition, due to the study sample size or limited study power, serious EI-EMI complications to the generator or lead may not be adequately assessed. The number of patients is insufficient to draw conclusions for zone 5; additional careful study is needed to determine if there is a specific level of the spine that is safe from EI-EMI.

5 Conclusions and clinical implication

EI-EMI does not occur with bipolar cautery for surgery or when monopolar cautery is used below the hips with the dispersive ground pad applied to the lower extremities. Device reprogramming is not needed when a low extremity surgery below the hip is undertaken.

Compliance with ethical standards

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