ASA Practice Advisory for Perioperative Management of Patients with Cardiac Implantable Electronic Devices: Pacemakers and Implantable Cardioverter-Defibrillators 2019 Update
Supplement 4: Evidence Tables

Table 1. EMI Incidence Monopolar Electrosurgery

Study	Data Source	Country	Study Design*	Age** (y)	CIED Type***	Total N	EMI N	Incidence Rate (%)
Cheng 2008	Study data (Apr 2005-Jun 2006)	USA	OS	66 ± 12.8	PM, ICD	92	0	0.0
Mahlow 2013	Medical records (Jan 2008-Sept 2010)	USA	CC		PM, ICD	376	10	2.7
Gifford 2014	Study data (Dec 2011-Apr 2013)	USA	RCT		ICD	59	4	6.8
Baeg 2016	Medical records (Jan 2007-Nov 2013)	Korea	RS	69 ± 9.1	PM, ICD	49	0	0.0
Gifford 2017	Study data (Feb 2014-Aug 2015)	USA	OS	73 ±10	PM, ICD	331	34	10.3
Schulman 2018	Study data (May 2012-Sept 2016)	USA	OS		ICD	144	5	3.4

*OS- observational study, RCT- randomized controlled trial, CC- case control study, RS- retrospective study ** Values shown as Mean ± S.D. or Median (range)
***PM- pacemaker, ICD- implantable cardioverter defibrillator

Table 2. EMI Incidence Radiation

Study	Data Source	Country	Study Design*	Age** (y)	CIED Type***	Total N	EMI N	Incidence Rate (%)
Gelblum 2009	Physician questionnaire (Jun 2005-Dec 2007)	USA	OS		ICD	33	1	3.0
Makkar 2012	Study data (2005-2011)	USA	OS	74 ± 9.3	CIED	69	0	0.0
Elders 2013	Study data	Netherlands	OS	72 (60-78)	ICD	15	5	33.3
Gomez 2013	Study data (Mar 2009-Jul 2012)	USA	OS		CIED	42	5	11.9
Grant 2015	Medical records (Aug 2005-Jan 2014)	USA	RS	73 (25-93)	PM, ICD	215	18	8.4
Brambatti 2015	Study data (Feb 2008-Dec 2012)	Canada	OS	77.9 ± 9.4	PM, ICD	261	4	1.5
Zaremba 2015	Danish National Patient Registry (2003-2012)	Denmark	RS	75.6 (69.3-81.7)	PM, ICD	560	17	3.0

*OS- observational study, RS- retrospective study ** Values shown as Mean ± S.D. or Median (range)
***PM- pacemaker, ICD- implantable cardioverter defibrillator, CIED-Cardiovascular implantable electronic device

Table 3. EMI Incidence Radiofrequency Ablation

Study	Data Source	Country	Study Design*	Age** (y)	CIED Type***	Total N	EMI N	Incidence Rate (%)
Chang 1994	Study data	USA	OS	55 ± 17	PM	27	1	3.7
Ellenbogen 1996	Study data	USA	OS	63 ± 12	PM	35	13	37.1
Pfeiffer 1995	Study data	USA	OS	55.2 ± 11.2	PM	25	8	32.0
Sadoul 1997	Study data (Jan 1991-Jun 1996)	France	OS	65 ± 9	PM	38	3	7.9
Skonieczki 2011	Study data (2001-2008)	USA	OS	78 (65-91)	PM, ICD	22	2	9.0

*OS- observational study, RS- retrospective study ** Values shown as Mean ± S.D. or Median (range)
**PM- pacemaker, ICD- implantable cardioverter defibrillator

Table 4. EMI Incidence Magnetic Resonance Imaging (MRI)

Study	Data Source	Country	Study Design*	Age** (y)	CIED Type***	Total N	EMI N	Incidence Rate (%)
Vahlhaus 2001	Study data	Germany	OS		PM	32	0	0.0
Martin 2004	Study data (Dec 1999-Dec 2002)	USA	OS		PM	47	0	0.0
Gimbel, Bailey 2005	Study data (1994-2004)	USA	OS		PM	46	0	0.0
Gimbel, Kanal 2005	Study data	USA	OS		ICD	7	1	14.3
Naehle 2009	Study data	USA	OS	62.4 ± 12.6	ICD	18	0	0.0
Buendía 2010	Study data (Oct 2007-Dec 2008)	Spain	OS		PM, ICD	33	0	0.0
Halshtok 2010	Study data (2004-2009)	Israel	OS	59 (11-94)	PM, ICD	18	3	16.7
Cohen 2012	Medical records (Feb 2006-Mar 2009)	USA	CC		PM, ICD	159	0	0.0
Friedman 2013	Study data	USA	OS		ICD	171	0	0.0
Awad 2015	ProMRI Phase C study	USA	NR	60 ± 12.8	MRI-conditional ICD	154	0	0.0
Bailey 2015	ProMRI AFFIRM study	USA, Europe	NR	71.2 ± 10.7	MRI-conditional PM	229	0	0.0
Keller 2015	Study data (Jun 2012-Dec 2013)	Czech Rep	OS	53.3 ± 19.5	Subcutaneous ICD	15	0	0.0
Bailey 2016	ProMRI AFFIRM study	USA, Europe	NR	68.4 ± 11.9	MRI-conditional PM	221	0	0.0
Camacho 2016	Study data	USA	OS	66 (20-89)	PM, ICD	104	8	7.7
Horwood 2016	Study data	USA	OS	62.9 ± 11.9	CIED	142	3	2.1
Nazarian 2017	Study data	USA	OS	69.3 (57.7-78.1)	PM, ICD	1509	9	0.6

*OS- observational study, CC- case control study, NR- non-randomized controlled study ** Values shown as Mean ± S.D. or Median (range)
***PM- pacemaker, ICD- implantable cardioverter defibrillator, CIED- Cardiovascular implantable electronic device

Table 5. EMI Occurrence ECG Monitors (Case Report/Series)

Study	Country	EMI Source	CIED Type*	Cases	Age (y)	Outcome
Chew 1997	Australia	ECG Monitor	PM	5		Pace rate increase
Southorn 2000	USA	ECG Monitor	PM	2	73, 77	Pacing dysfunction
Hu 2006	Australia	ECG Monitor	PM	1	74	Paced tachycardia
Lau 2006	Australia	ECG Monitor	PM	1	71	Tachycardia

*CIED- Cardiovascular implantable electronic device, PM- pacemaker

Table 6. EMI Occurrence by Body Region

Study	EMI Source	Study Design*	CIED Type**	Total N	Intervention 1	Intervention 2	Incidence Rate (%)
Gifford 2017	Electrosurgery (monopolar)	OS	ICD	331	Above iliac crest	Below iliac crest	21.0 vs 0
Schulman 2018	Electrosurgery (monopolar)	OS	ICD	144	Above umbilicus	Below umbilicus	13.0 vs 0

*OS- observational study
** CIED- Cardiovascular implantable electronic device, ICD- implantable cardioverter defibrillator

Table 7. EMI Occurrence by Body Region (Case Report/Series)

Study	EMI Source	CIED Type*	Age (y)	Surgery Region	Outcome
Mangar 1991	Electrosurgery (monopolar)	PM	15	Above umbilicus	EMI, Asystole
Kleinman 1997	Electrosurgery (monopolar)	PM	70	Above umbilicus	EMI, Asystole

*CIED- Cardiovascular implantable electronic device, **PM- pacemaker**

Table 8. EMI Occurrence After Programming to Asynchronous Mode or Suspending Antitachycardia Function of an ICD During Monopolar Electrosurgery

Study	Study Design*	CIED Type**	Total N	Group 1 N	Group 2 N	Intervention Group 1	Intervention Group 2	Incidence Rate (%)
Mahlow 2013	CC	PM, ICD	376	197	179	Alter pacing in all subjects	Alter pacing only in high-risk patients	3.2 vs 2.2
Gifford 2014	RCT	ICD	59	26	33	ICD programmed “OFF”	Donut magnet taped over generator	6.7 vs 8.3

*RCT- randomized controlled trial, CC- case control study
**CIED- Cardiovascular implantable electronic device, PM- pacemaker, ICD- implantable cardioverter defibrillator

Table 8a. Device Outcomes After Programming to Asynchronous Mode or Suspending Antitachycardia Function of an ICD (Case Report/Series)

Study	EMI Source	Age (y)	CIED Type*	Intervention	Outcome
Mangar 1991	Electrosurgery (monopolar)	70	PM	Pacemaker programmed to VOO mode	Asystole
Kleinman 1997	Electrosurgery (monopolar)	15	PM	Pacemaker programmed to VOO mode	Asystole
Donohoo 2007	Radiofrequency Ablation	67	PM	Reprogrammed device to a pacing mode	Battery replacement indicator activated
Gimbel 2009	MRI (3 T)	79	PM	Pacemaker programmed to VOO mode	Asystole, reversion to “back up mode”

*CIED- Cardiovascular implantable electronic device, PM- pacemaker

Table 9. Device Outcomes After Suspending Antitachycardia Function for an ICD During MRI (1.5 Tesla)

Study	Study Design*	Age** (y)	Total N	ICD*** N	Intervention 1	Outcome (%)
Naehle 2009	OS	62.4 ± 12.6	18	18	Therapies programmed "off"	Oversensing of RF noise (12), incomplete recovery of battery voltage (75)
Buendia 2010	OS		33	5	Antitachycaridia deactivated in ICD patients	Change in pacing threshold (20)
Mollerus 2010	NR		133	22	Therapy features disables	Arrhythmia log erased (4.5)
Horwood 2016	OS	63 ± 12	142	106	ICD tachycardia therapy turned “off”	Ventricular tachycardia (0.2)

* OS – Observational Study, NR- non- randomized study ** Values shown as Mean ± S.D. or Median (range)
*** ICD- implantable cardioverter defibrillator

Table 9. Continuous ECG Monitoring Detects EMI Related Abnormalities (Case Report/Series)

Study	EMI Source	Age (y)	CIED Type*	Intervention	Outcome
Kellow 1993	Diathermy	70	PM	ECG monitoring	Failure to capture detected
Smith 1993	Diathermy	80, 87	PM	ECG monitoring	Tachycardia detected
Rubin 1995	Electrosurgery (monopolar)	76	PM	ECG monitoring	Pacemaker failure detected
Gimbel 2009	MRI (3 T)	79	PM	ECG monitoring	Asystole detected
Rodriguez-Blanco 2013	Electrosurgery (monopolar)	66	ICD	ECG monitoring	Bradycardia detected

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Table 10. EMI Occurrence Radiation Field (Case Report/Series)

Study	EMI Source	Age (y)	CIED Type*	Radiation Field	Outcome
Raitt 1994	Neutron radiation (4.8 Gy cumulative dose)	83	PM	Device outside radiation field (at least 2 cm)	Switch to magnet OFF mode, corruption of programming code, tachycardia
John 2004	Radiation (50 Gy in 20 fractions)	55	ICD	Leads inside of radiation field	Shock coil failure
Nemec 2007	Radiation (< 5.4 Gy)	61	ICD	ICD inside of radiation field	Corruption of device random access memory, tachycardia, polymorphic VT

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Table 11. Postoperative Interrogation

Study	EMI Source	Study Design*	Age** (y)	Total N	CIED Type***	Intervention	Outcome
Zaremba 2015	Radiation	RS	75.6 (69.3-81.7)	560	PM, ICD	Device evaluation after radiation therapy	Device malfunction detected (3.1% of pts)
Donohoo 2007	Radiofrequency Ablation	CR	67	1	PM	Pacemaker interrogated by cardiologist post-procedure	Pacemaker settings alterations after ablations detected
Schulman 2013	Electrosurgery (monopolar)	CR	69	1	ICD	Postoperative ICD check	Premature battery depletion detected

* RS- retrospective study, CR- case report ** Values shown as Mean ± S.D. or Median (range)
*** CIED- Cardiovascular implantable electronic device, PM- pacemaker, ICD- implantable cardioverter defibrillator