Electromagnetic Interference From Welding and Motors on Implantable Cardioverter-Defibrillators As Tested in the Electrically Hostile Work Site

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Objectives. This study was designed to determine the susceptibility of an implanted cardioverter-defibrillator to electromagnetic interference in an electrically hostile work site environment, with the ultimate goal of allowing the patient to return to work.

Background. Normal operation of an implanted cardioverter-defibrillator depends on reliable sensing of the heart's electrical activity. Consequently, there is concern that external electromagnetic interference from external sources in the work place, especially welding equipment or motor-generator systems, may be sensed and produce inappropriate shocks or abnormal reed switch operation, temporarily suspending detection of ventricular tachycardia or ventricular fibrillation.

Methods. The effects of electromagnetic interference on the operation of one type of implantable cardioverter-defibrillator (Medtronic models 7217 and 7219) was measured by using internal event counter monitoring in 10 patients operating arc welders at up to 900 A or working near 200-hp motors and 1 patient close to a locomotive starter drawing up to 400 A.

Results. The electromagnetic interference produced two sources of potential interference on the sensing circuit or reed switch operation, respectively: 1) electrical fields with measured frequencies up to 50 MHz produced by the high currents during welding electrode activation, and 2) magnetic fields produced by the current in the welding electrode and cable. The defibrillator sensitivity was programmed to the highest (most sensitive) value: 0.15 mV (model 7219) or 0.3 mV (model 7217). The ventricular tachycardia and ventricular fibrillation therapies were temporarily turned off but the detection circuits left on.

Conclusions. None of the implanted defibrillators tested were affected by oversensing of the electric field as verified by telemetry from the detection circuits. The magnetic field from 225-A welding current produced a flux density of 1.2 G; this density was not adequate to close the reed switch, which requires ~10 G. Our testing at the work site revealed no electrical interference with this type of defibrillator. Patients were allowed to return to work. The following precautions should be observed by the patient: 1) maintain a minimal distance of 2 ft (61 cm) from the welding arc and cables or large motors, 2) do not exceed tested currents with the welding equipment, 3) wear insulated gloves while operating electrical equipment, 4) verify that electrical equipment is properly grounded, and 5) stop welding and leave the work area immediately if a therapy is delivered or a feeling of lightheadedness is experienced.

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Table 1. Power Ratings of Electrical Equipment Capable of Producing Electromagnetic Interference Interaction on the Implantable Cardioverter-Defibrillator

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Power Rating</th>
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<tbody>
<tr>
<td>Welders</td>
<td></td>
</tr>
<tr>
<td>Lincoln arc</td>
<td>AC or DC from 2 to 375 A</td>
</tr>
<tr>
<td>TIG-300/300</td>
<td></td>
</tr>
<tr>
<td>AC 2255</td>
<td>AC maximum 225 A</td>
</tr>
<tr>
<td>Weld-Pak</td>
<td>DC maximum 88 A</td>
</tr>
<tr>
<td>Portable</td>
<td>14 hp/130 A</td>
</tr>
<tr>
<td>Carbon arc</td>
<td>35 VDC/450 A</td>
</tr>
<tr>
<td>Submerged arc</td>
<td>30 VDC/900 A</td>
</tr>
<tr>
<td>Data Weld 650</td>
<td>30 VDC</td>
</tr>
<tr>
<td>2-simultaneous welding</td>
<td>375 A and 350 A</td>
</tr>
<tr>
<td>Forney</td>
<td>AC 180 A</td>
</tr>
<tr>
<td>Hobart Arc</td>
<td>28 VDC/250 A</td>
</tr>
<tr>
<td>RC-500</td>
<td>40 VDC/300 A</td>
</tr>
<tr>
<td>MB-304</td>
<td></td>
</tr>
<tr>
<td>Miller AC/DC Gas Tungsten</td>
<td>30 V/310 A</td>
</tr>
<tr>
<td>DiLare HF</td>
<td>(high frequency superimposed)</td>
</tr>
<tr>
<td>Millermatic</td>
<td>28 VDC/200 A</td>
</tr>
<tr>
<td>Apollo Arc</td>
<td>220 VAC/250 A</td>
</tr>
<tr>
<td>AC motors</td>
<td>200 hp, 460 VAC</td>
</tr>
<tr>
<td></td>
<td>130 hp, 460 VAC/189 A</td>
</tr>
<tr>
<td></td>
<td>20 hp, 220 VAC/40 A</td>
</tr>
<tr>
<td>Magnetek Transformers</td>
<td>75 KVA/506 VAC</td>
</tr>
<tr>
<td>Kohler model MV20 2 cylinder mower</td>
<td>20 hp, 25K Vignition†</td>
</tr>
<tr>
<td>EMD locomotive (GM)</td>
<td>Starter 200–400 A</td>
</tr>
<tr>
<td>Raymond Electric Forklift</td>
<td>6 hp, 24 VDC/43.8 A</td>
</tr>
</tbody>
</table>

*The study patients either used or were exposed to all equipment listed.
†Magneto ignition as noted on motor faceplate. KVA = kilovolt amperes; VAC = volts alternating current; VDC = volts direct current.

Electromagnetic interference in an electrically hostile work site environment, and 2) to measure the radiofrequency current spectrum radiated during exposure to typical direct current and alternating current welding and large industrial electric motors at the work site. The ultimate goal was to determine whether a patient with an implanted cardioverter-defibrillator can safely return to work in such an environment.

Methods

Patient testing. The study group comprised 11 patients, all male, with a mean age ± SD of 53 ± 11.7 years. Three patients had a model 7217 pacemaker cardioverter-defibrillator (Medtronic, Inc.) implanted in an abdominal location, and 8 had a model 7219 Jewel pacemaker cardioverter-defibrillator positioned in the prepectoral region. All patients had an implanted transvenous ventricular lead consisting of coaxial-wound conductors, a high voltage coil, plus a ring and active fixation helix for bipolar sensing implanted in the right ventricular apex.

Patients were tested in their work environment. Each was instructed to weld at a distance of ≤1-ft (30.5 cm) between the implanted defibrillator and weld arc or ≤1 foot from two-cylinder motors, large 200-hp 460-V alternating current industrial motors or an electric starter motor in a locomotive as described in Table 1. The ≤1-ft separation between the implanted defibrillator and the weld arc or two-cylinder, industrial or starter motors was maintained because of mechanical restrictions of machinery or electrical hazards and was believed to be an adequate distance that was both unlikely to jeopardize the patient's safety and considerably less than an arm's length or normal working distance from these sources. During the welding process the patient was exposed both to direct current and to alternating current, which can create severe electromagnetic interference. Each test was of >30-s duration to allow sustained exposure to the electromagnetic interference. The cables of the welding machines were either straight or coiled and not changed from their usual configuration. The magnetic flux, which indicates the magnitude of the magnetic fields produced by the welding equipment or motors, was measured with an F.W. Bell model 4048 gauss meter (frequency response direct current to 10 kHz) in the vicinity of the interference source.

Each patient's test was coordinated with his primary care physician and permission from the physician, patient and work site management was obtained before proceeding with the tests.

Implantable cardioverter-defibrillator test protocol. The cardioverter-defibrillators implanted in this study provide non-invasive telemetered internal event counter information on episodes detected of ventricular tachycardia or ventricular fibrillation. Specific parameters in the defibrillator were temporarily reprogrammed (Table 2) to worst-case values to enhance the probability that detection of electromagnetic interference would produce inappropriate device operation. The sensitivity was reprogrammed to the most sensitive value available for each device model. Fibrillation and tachycardia detection intervals were set to nominal values with a minimal number of intervals to detect the interference. All ventricular tachycardia pacing or shock therapies and ventricular fibrillation shock therapies were temporarily disabled as a precaution in the event that the electromagnetic interference was sensed, thereby initiating a therapy. When feasible, the programmer head was retained over the implanted defibrillator to obtain continuous electrogram and marker channel telemetry. The
Figure 1. Counter data report telemetered by the model 7219D Jewel cardioverter-defibrillator to the programmer depicting the absence of detecting of any mimicked ventricular tachycardia (VT) or ventricular fibrillation (VF) due to exposure to electromagnetic interference. (The parameter I appears at the VF tachycardia counter only to illustrate detection of ventricular fibrillation; it is not indicative of this study because no episodes of ventricular tachycardia or ventricular fibrillation were detected during patient testing.) Brady = bradycardiac; FVT = fast ventricular tachycardia; R = registered events for each therapy.

model 7219 Jewel pacemaker cardioverter-defibrillator was reprogrammed to the “resume” parameter and the model 7217 pacemaker cardioverter-defibrillator to “cancel magnet,” which reactivated the ventricular tachycardia and ventricular fibrillation detections that are temporarily suspended by the magnet in the programmer head.

The defibrillator was interrogated after the patient completed each specific work function to determine whether the ventricular tachycardia or ventricular fibrillation detection algorithms were satisfied by detection of electromagnetic interference. The stored comprehensive data were telemetered to the programmer and printed in a counter data report (Fig. 1). This report would identify any detected episode of ventricular tachycardia or ventricular fibrillation under the “Tachycardia Counters” column by the number 1 (or higher for multiple detections). All parameters were reprogrammed to their original value after completion of the test.

Results

Radiofrequency spectrum produced by welding. Electric welding produces a broad spectrum of energy (8). The radiofrequency current spectra, measured within a 1-MHz bandwidth on the cable connected to the operator-held welding electrode, are shown in Figure 2. The radiofrequency current amplitude decreases at high frequencies during direct current and alternating current arc welding. Near 2 MHz, spectral peaking is evident. The measured spectral levels are produced only during arc initiation when the machine is operated with spark “start only” in the direct current mode. When operating in the alternating current mode with spark “continuous,” the measured spectral levels are produced continually.

Implantable defibrillator nondetection of electromagnetic interference. The electrogram and marker channel telemetered from the implanted defibrillator during patient testing...
patients were able to return to work in what would seem to be
tinction detection and pacemaker function were normal. All
occurred and, ventricular tachycardia and ventricular fibrilla-
implantable defibrillators tested. No inappropriate sensing
welding cables of sufficient strength to close the defibrillator
an electrically hostile work site. There have been no subse-
were recorded on the programmer only periodically because
the electrical noise often prevented telemetry or ECG moni-
toring. The electromagnetic interference during welding or
from the electric motors did not produce any extraneous
or the normal sinus electrogram or extra detections
on the marker channel due to inappropriate sensing. This
condition of nondetection of electromagnetic interference
prevailed even during exposure to welding with a high fre-
quency voltage added to the welding current at an output of
310 A. At no time was any ventricular tachycardia or ventricu-
lar fibrillation counter activated by the radiated electromag-
netic interference for any test conducted on any patient. There
was no damage or reprogramming of any implanted defibril-
during the tests.

The amplitude of the magnetic fields produced for various
types of welders and motors as measured with a gauss meter is
shown in Table 3. The current in the return cable from the
welding site to the welder causes a reduction of the magnetic
field. The amount of cancellation depends on the spacing
between cables. The defibrillators tested contained a magnetic
reed switch that is closed by an ~10-G magnetic field. A strong
magnetic field placed over the defibrillator temporarily sus-
pends detection of ventricular tachycardia and ventricular fibrillation and the delivery of shock therapies. The field
strength of the measured magnetic flux density decreased
rapidly at 2 ft (61 cm) away from the source. The magnetic field
from a 225-A welder was only 1.2 G at 2 ft from the cable,
much less than that required to activate the reed switch. At no
time during these tests was the magnetic field ≥2 ft from the
welding cables of sufficient strength to close the defibrillator
reed switch.

**Discussion**

Findings in this study indicate that electromagnetic inter-
ference generated by large welding machines and motors did
not interfere with normal functional operation of the specific
implantable defibrillators tested. No inappropriate sensing
occurred and, ventricular tachycardia and ventricular fibrilla-
tion detection and pacemaker function were normal. All
patients were able to return to work in what would seem to be
an electrically hostile work site. There have been no subse-
quent reports of electromagnetic interference interaction with
their implantable cardioverter-defibrillators.

The warning and precautions section of the technical
manual for the defibrillators implanted in these patients states
that exposure to electromagnetic interference may prevent
detection of ventricular tachycardia or ventricular fibrillation,
causing the device to sense inappropriately and as a result
deliver an unneeded ventricular tachycardia or ventricular fibrillation shock therapy. There is a legitimate concern that
patients are at risk if they do not keep away from sources of
electromagnetic interference when the ventricular tachycardia
and ventricular fibrillation detection function of their defibril-
later is enabled. The concern that these devices will inappro-
priately sense the broad spectrum of radiofrequency energy
measured up to 100 MHz during welding was addressed
aggressively during this study. These data will be helpful in
developing increased understanding of the characteristics of
welding electromagnetic interference for future testing of
implantable defibrillator compatibility.

**Bipolar sensing characteristics.** The defibrillators tested
utilized standard bipolar sensing from a distal helix tip elec-
trode to a small surface sensing ring spaced 1 cm apart. Closely
spaced electrodes will reduce the sensing field for coupling
magnetic interference to the sense amplifier. Previous
studies (1,9,10) have demonstrated the noise discrimination
superiority of bipolar sensing. Also, the electromagnetic inter-
ference effects from specified electric equipment are mini-
mized with paired sensing electrodes spaced ≤1 cm apart (11).
Standard bipolar sensing was a most effective mechanism for
preventing transmission of inappropriate sensing of electro-
magnetic interference to the sense amplifier. This was clearly
demonstrated by the absence of artifact interference, as de-
noted from the continuous monitoring of the patients’ telemo-
tered electrogram and marker channel during exposure to the
source of electromagnetic interference. Filter circuits on the
feedthroughs of the header connector and the sense amplifier
bandwidth filter that rejects frequencies of <10 Hz and
>60 Hz could also contribute to rejection of electromagnetic
interference.

**Sense amplifier operation.** The self-adjusting sensitivity
threshold amplifier in the tested defibrillators will automati-
cally raise the sensing level to ~10 times the programmed
sensitivity setting and return to the programmed value with an
~500-ms exponential decay time constant. This feature is
designed to prevent the sensing of T waves at low sensing
threshold levels. However, continuous artifacts sensed from
electromagnetic interference could maintain the raised sensing
level and reduce the amplifier sensitivity to the noisy electric
environment but still maintain normal R wave sensing. This
sense amplifier operation will contribute to maintaining pac-
emaker function in the defibrillator, providing backup brady-
cardia support during exposure to electromagnetic interference.

**Magnetic field inhibition.** Electromagnetic interference
has been reported to deactivate a specific model of implantable
cardioverter-defibrillator by closing its magnetic reed switch
and rendering the patient without protection from ventricular

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**Table 3. Magnetic Field Measurements**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Test Current</th>
<th>Magnetic Flux Density (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincoln AC 2255</td>
<td>225 A</td>
<td>40, at cable surface; 1.2, at 2 ft from cable</td>
</tr>
<tr>
<td>Lincoln DC Weld Pak</td>
<td>88 A</td>
<td>44, at cable surface; 0.5, at 2 ft from cable</td>
</tr>
<tr>
<td>Mower, Kohler model MV20</td>
<td>Flywheel</td>
<td>2.530, at surface; 0.8, at 1 ft from surface</td>
</tr>
</tbody>
</table>

*The magnetic fields were measured directly at or 1 to 2 ft from the surface
of the welding cable or flywheel containing a magnet in its magneto ignition system.

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tachycardia or ventricular fibrillation (12). Patients with an implanted cardioverter-defibrillator have been counseled carefully to avoid close contact with devices such as arc welders, which emit a powerful magnetic field (13). The magnetic flux generated by a 225-A current flowing through the welding cable was measured to be 40 G at its surface; this level is capable of activating the reed switch should these cables be placed directly over the implanted defibrillator, as is possible when they are carried over a worker’s shoulder on the side of the implanted defibrillator. At 2 ft from the cable surface, this same magnetic field decreased to 1.2 G, which was only a fraction of the level necessary to activate the reed switch. The field density required to close the defibrillator reed switch could actually be higher because of nonideal field alignment with the switch. The implanted defibrillator in a patient who is standing would normally be >2 ft away from electric cables lying on the floor and thus be far enough away to prevent reed switch activation by the magnetic fields emitted by these cables.

**Study limitations.** Testing was performed with a limited number of welders and motors in only 11 patients with an implanted defibrillator that utilized standard bipolar sensing electrodes spaced 1 cm apart and was produced by a single manufacturer. As there were no observed problems in the 11 patients, the upper 95% confidence limit for the failure rate of 0 is 24%. The effects of electromagnetic interference on implantable defibrillators may differ for 1) integrated bipolar sensing from a distal tip electrode to a large right ventricular shocking coil, 2) separation of the sensing electrodes by >1 cm (e.g., epicardial leads), or 3) electrodes with a larger surface area. Greater electrode separation and surface area will increase the sensing field and may increase the likelihood of sensing electromagnetic interference. Electrical characteristics of equipment can change either by failure of an arc welder or by a high voltage line affecting the amount of electromagnetic interference in the same work site. The model of the implantable defibrillator may change as a result of routine replacement procedure. It is advisable to reschedule another test for electromagnetic interference interaction should any of these differences be observed.

**Conclusions.** We conclude that certain implantable cardioverter-defibrillators are safe in general. However, it would be prudent to provide an extra margin of safety before the patient returns to an electrically hostile work site by 1) having a technical consultant from the device manufacturer conduct a comprehensive electromagnetic interference test with patients at their work site; 2) increasing the defibrillator sensitivity to 0.6 mV, programing the number of intervals to detect ventricular tachycardia to a minimum of 16 and programming the number of intervals to detect ventricular fibrillation to a minimum of 18; 3) determining the type of electrical equipment that the patient will be operating and assuring that appropriate electrical grounding is maintained in good condition; 4) ensuring that the patient’s implantable defibrillator is >2 ft from the electrical source of the electromagnetic interference; 5) having patients wear gloves to avoid inadvertent contact with circuit electrical potentials; 6) advising patients to stop operating the electrical equipment if they experience a shock or lightheadedness and to immediately contact their primary physician.

We greatly appreciate the cooperation from the primary care physicians at the Minneapolis Heart Institute, Minneapolis, Minnesota. We thank United St. Paul Hospital, St. Paul, Minnesota and Mercy Hospital, Des Moines, Iowa for granting permission to test their patients with an implanted defibrillator at the work site, and we thank Mr. Gerry Becker, Medtronic, Inc., Minneapolis for technical assistance.

### References