Troubleshooting pacemakers and implantable cardioverter-defibrillators

David L. Scher

Purpose of review

The purpose of this review is to provide an update on stored diagnostic information furnished by new model pacemakers and implantable cardioverter-defibrillators (ICDs). This information provides crucial information about both device function and arrhythmias discovered with device interrogation and is invaluable when troubleshooting problems with devices.

Recent findings

The most recent generation of pacemakers and ICDs provides extensive diagnostic data regarding both device and lead function. Regular measurements of lead impedance and pacing thresholds allow for early detection of lead insulation break, fracture, dislodgement, or other problems. Analysis of stored intracardiac electrograms (EGMs) alerts the physician to oversensing and undersensing problems, which may manifest as abnormal device function, inappropriate arrhythmia detection, or inappropriate therapy. Simultaneous dual-chamber EGMs help the clinician diagnose the electrophysiologic mechanism of atrial and ventricular tachyarrhythmias, whether they are sustained, nonsustained, symptomatic, or asymptomatic. Detection and specific diagnosis of arrhythmias with EGMs may determine the need for anticoagulation, institution or change of antiarrhythmic drug therapy, or reprogramming of device detection or therapy parameters. Some devices also have the ability to function as patient-activated monitors.

Summary

Better diagnostic data by current pacemakers and ICDs allow for earlier and more accurate identification of device and lead malfunctions as well as better arrhythmia management. In addition, detection of asymptomatic clinically relevant arrhythmias may prompt actions by the physician that can alter clinical outcome.

Keywords

pacemaker diagnostics, implantable cardioverter-defibrillator, oversensing, troubleshooting, electrograms

Curr Opin Cardiol 19:36–46. © 2003 Lippincott Williams & Wilkins.

Cardiac Electrophysiology, PinnacleHealth System, Harrisburg, Pennsylvania, USA

Correspondence to David L. Scher, MD, Director, Cardiac Electrophysiology, PinnacleHealth System, 2808 Old Post Road, Harrisburg, PA 17110, USA
E-mail: dlsmd@comcast.net

Current Opinion in Cardiology 2004, 19:36–46

Abbreviations

EGM	electrogram
EMI	electromagnetic interference
ICD	implantable cardioverter-defibrillator
VT	ventricular tachycardia

0268-4705

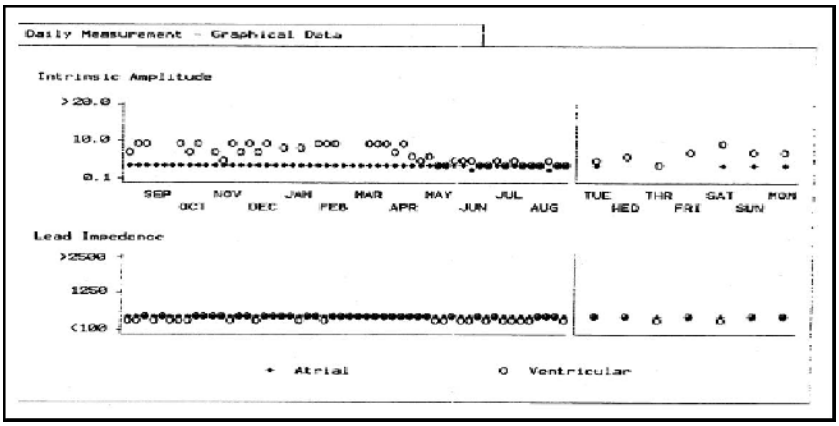
Introduction

New pacemakers and implantable cardioverter-defibrillators (ICDs) contain detailed comprehensive data storage capabilities that have revolutionized the clinician's ability to not only troubleshoot clinically obvious device malfunctions, but give insight into subclinical, intermittent, or impending device malfunction. Abnormalities in sensing and pacing can also be discovered via observations of stored data of a device's arrhythmia log. Implantable defibrillators have long had the capability of recording the frequency, date and time of occurrence, and dual-chamber electrograms (EGMs) of arrhythmias, essentially acting as lifelong rhythm monitors. However, pacemakers today also contain the same diagnostic tools. By examining arrhythmia logs of pacemakers and ICDs, the clinician can determine whether the arrhythmia was a true arrhythmia or a byproduct of a sensing abnormality; the appropriateness of device therapy for the detected arrhythmia; the electrophysiologic mechanism of the arrhythmia; and possibly the correlation of the event with the presence or absence of symptoms. Some of the most common problems encountered in today's pacemakers and ICDs are highlighted in this article, as well as how the clinician can use diagnostic data to troubleshoot them.

Data analysis of device function

New pacemakers have the ability to constantly monitor their own indicators of function. Atrial and ventricular sensing measurements as well as lead impedances are determined automatically at regular intervals by the pacemaker itself (Figs. 1 and 2). In addition, pacing capture thresholds are also determined automatically, with output then determined at a set preprogrammed multiple of the threshold. Significantly abnormal measurements of predetermined ranges or deviations from previous measurements are usually highlighted as an alert on the programming screen upon interrogation of the pacemaker. Some pacemakers and ICDs have patient alarms manifested as audible tones, which are prompted by abnormal measurements. They alert the patient, via previous instruction, to have the device interrogated by the clinician. This information may be used to identify subclinical lead performance or dislodgement that may significantly alter patient management (*ie*, device programming, or need for lead repositioning or replacement). Lead performance data are especially important just prior to elective pacemaker generator replacement,

Figure 1. Example of graphic image of daily atrial and ventricular sensing and lead impedance measurements



to formulate the most appropriate surgical plan regarding leads.

A complementary method of determining device function is to analyze stored arrhythmia data. Review of atrial and tachyarrhythmia episodes (via marker channels and all available EGMs) may reveal sensing abnormalities that resulted in the misclassification of tachyarrhythmias. For example, false detection of atrial tachyarrhythmias prompting mode switching may occur with electromagnetic interference (EMI) (see below), far-field oversensing, or even a loose set screw [1,2••]. The function of an ICD system can be monitored by the examination of stored arrhythmia detection and delivered therapy. One such analysis, prompted by an episode of inappropriate postshock oversensing in one case, led to an investigation of the ICD lead in question. This review uncovered a significant and unique indicator of lead failure [3•]. An example of oversensing from this lead is shown in Figure 3.

Oversensing

Oversensing by a cardiac rhythm device may be defined as the sensing of inappropriate signals. In pacemakers and ICDs it may result in pauses, inappropriate mode switching, or inappropriate ICD tachyarrhythmia detection or therapy delivery. The causes of oversensing can be determined by either real-time or stored marker channels, or if tachyarrhythmia detection criteria are met, by analysis of combined stored arrhythmia EGMs and marker channels [1,2••,3•,4••,5•].

Oversensing by a pacemaker or ICD may be classified as arising from oversensing of extrinsic (electrical signals other than myocardial) or intrinsic (myocardial) events. Oversensing in the ventricular channel may result in presyncope or syncope due to inhibition of ventricular pacing. It may also result in inappropriate ICD detection or therapy delivery.

Myopotential oversensing is not as much a clinical problem as in the past, due to the widespread use of bipolar pacing leads today. The most common events are those from sensing of skeletal muscle (Fig. 4). However, the existence of unipolar pacemakers and leads, as well as insulation complications, which may rarely necessitate temporary unipolar programming, makes this problem relevant. Myopotential sensing may result in failure to pace and in the appearance of pacemaker failure [4••].

Figure 2. Numerical table of atrial and ventricular sensing, and lead impedance data featured in Figure 1

Guidant PULSAR MAX

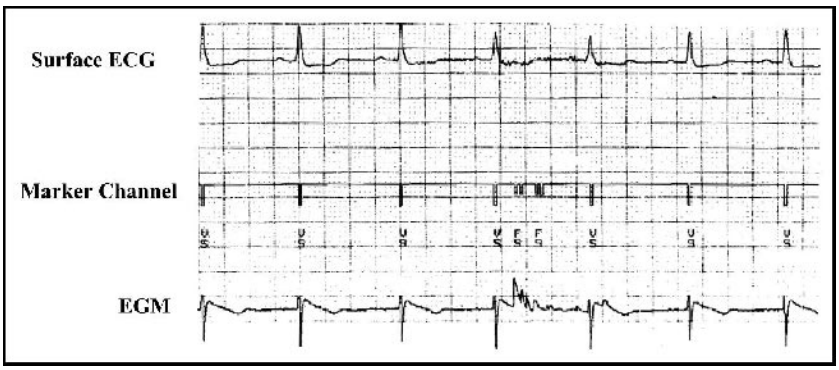
12-AUG-2003 10:10

Institution
Patient [redacted]
Model 1270 Serial 606071 Programmer 030023
2890 Software 4.0

Daily Measurement - Data Table

Date	Atrial Amplitude (mV)	Atrial Impedance (Ω)	Ventricular Amplitude (mV)	Ventricular Impedance (Ω)
11-AUG-2003	>3.5	470	7.1	460
10-AUG-2003	>3.5	480	7.1	460
09-AUG-2003	>3.5	470	9.1	440
08-AUG-2003	PACED	470	7.0	460
07-AUG-2003	PACED	470	4.5	440
06-AUG-2003	PACED	470	6.5	460
05-AUG-2003	>3.5	480	5.4	460
03-AUG-2003	>3.5	470	4.5	440
27-JUL-2003	>3.5	470	4.0	460
20-JUL-2003	2.8	470	4.7	460
13-JUL-2003	>3.5	480	3.7	460
06-JUL-2003	>3.5	480	3.7	440
29-JUN-2003	>3.5	470	4.1	440
22-JUN-2003	>3.5	470	5.0	440
15-JUN-2003	>3.5	470	4.5	440
08-JUN-2003	>3.5	470	5.0	460
01-JUN-2003	3.7	470	4.5	440
25-MAY-2003	3.8	470	4.4	460
18-MAY-2003	3.1	470	5.3	440
11-MAY-2003	>3.5	470	5.0	440
04-MAY-2003	>3.5	470	4.7	460
27-APR-2003	>3.5	470	4.1	440
20-APR-2003	>3.5	460	4.5	440
13-APR-2003	>3.5	470	6.0	460
06-APR-2003	>3.5	470	4.8	460
30-MAR-2003	>3.5	470	6.2	460
23-MAR-2003	>3.5	470	9.2	460
16-MAR-2003	>3.5	470	7.0	460
09-MAR-2003	>3.5	470	>9.0	460
02-MAR-2003	>3.5	470	>9.0	460
23-FEB-2003	>3.5	470	>9.0	460

Figure 3. Electrical noise with real-time oversensing of Medtronic 6936 ICD lead, brought out with Valsalva maneuver



Though rare in ICDs because of bipolar sensing, it may be seen with oversensing of myopotentials arising from the patient's diaphragm (Fig. 5). This occurs most commonly with devices programmed to extremely high sensitivity settings [5•], and may result in inappropriate ICD shocks. It can often be reproduced with the Valsalva maneuver while recording real-time EGMs. Diaphragmatic myopotential oversensing is rectified with reprogramming of the sensitivity (which should be accomplished with ICD testing performed on the final setting).

EMI, like myopotentials, does not cause pacing inhibition as frequently in newer pacemakers because of the predominant use of bipolar pacing leads, as well as the development of automatic reversion modes, which prevent EMI-dependent pauses. EMI continues to remain a concern with ICDs and can result in inappropriate tachyarrhythmia detection and therapy [6]. Interrogation of the ICD reveals characteristic high-frequency electrical signals superimposed on a predominant EGM having a rate substantially lower than the marker channel detection intervals. Examples of oversensing from EMI from an electrical source near a swimming pool and a retail store security screening device resulting in inappropriate ICD shocks are seen in Figures 6 and 7, respectively.

Another less common cause of extrinsic oversensing that may result in inappropriate ICD therapy comes from a loose set screw at the lead's attachment to the generator. The electrical noise generated from the collision of the lead's connector pin and the set screw causes oversensing in the ventricular channel, leading to inappropriate tachyarrhythmia detection. ICD device interrogation reveals the cause of the inappropriate therapy with characteristic EGMs of lead "chatter" (Fig. 8). Lead set "chatter" may also cause mode switching as well, when the loose set screw involves the atrial lead [1].

Oversensing of intrinsic events can cause clinical problems that can be identified via device interrogation. This may occur with oversensing of depolarizing events or repolarization events (T-wave oversensing).

Oversensing of depolarizing events can occur with oversensing of events from another channel (far-field oversensing) or signals from the same channel. Oversensing is discovered or confirmed with examination of EGMs

Figure 4. Myopotential oversensing resulting in ventricular pacemaker inhibition

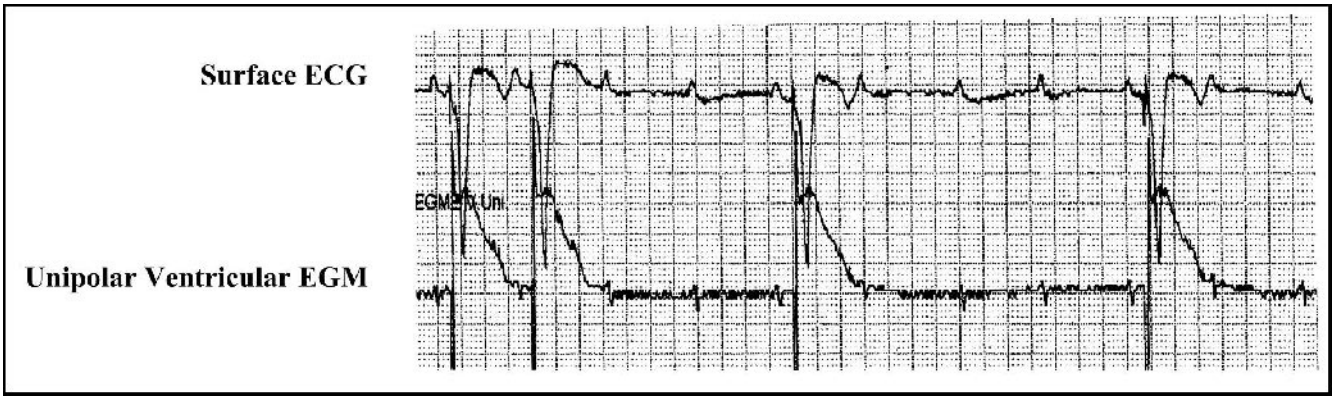
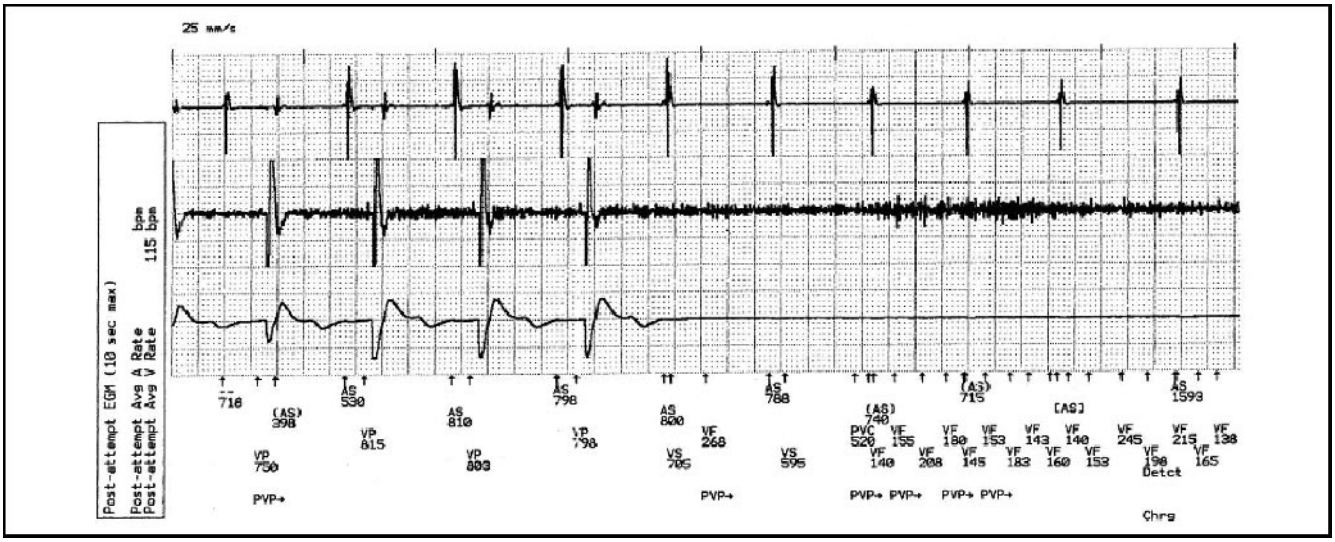


Figure 5. Diaphragmatic myopotential oversensing resulting in false VF detection, prompting ICD charging. Inhibition of pacing is a response to ICD charging by this specific device



and marker channels. An example of far-field sensing of ventricular signals in the atrial channel is seen in Figure 9A and sensing of atrial signals in the ventricle is seen in Figure 9B. Any cause of oversensing in the atrial channel may result in inappropriate mode switching [1,7•]. Far-field oversensing of atrial signals in an ICD may trigger false tachyarrhythmia detection (and therapy if the atrial rate is sufficient). Far-field oversensing of atrial depolarization has been seen in biventricular cardiac resynchronization therapy devices. This may manifest as failure to pace and is most commonly a result of either lead dislodgement or placement of the lead in a middle or anterior cardiac vein of the coronary sinus (Fig. 10). Examination of the EGMs and marker channels of the device will furnish the diagnosis [8].

Oversensing of depolarization events arising from the same lead has been seen with markedly prolonged conduction. Oversensing due to double counting of atrial depolarization (an extremely rare event) in the case of significant interatrial conduction delay is seen in Figure 11. Abnormal pacing by the pacemaker prompted investigation that included inhibition of ventricular pacing and examining marker channels, confirming the diagnosis. Pacemaker reprogramming eliminates the problem. Figure 12 illustrates ventricular oversensing only with a spontaneous left bundle branch block. Intrinsic oversensing due to extreme interventricular conduction delay has been seen in biventricular pacing systems as well. This oversensing is due to extreme intraventricular conduction delays falling outside of device blanking periods.

Figure 6. EMI causing both false atrial tachyarrhythmia detection *and* false ventricular tachyarrhythmia detection

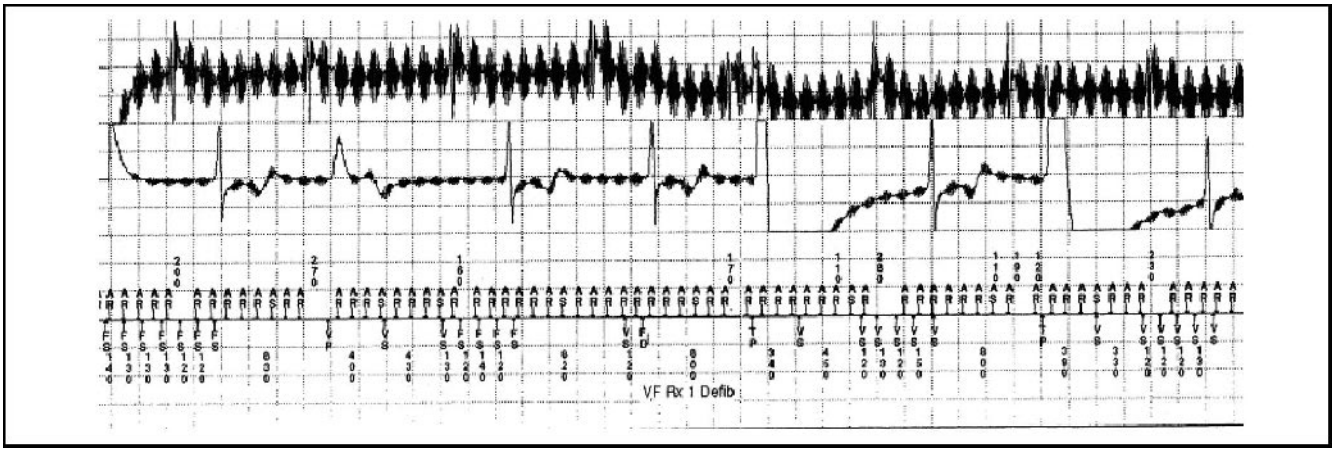
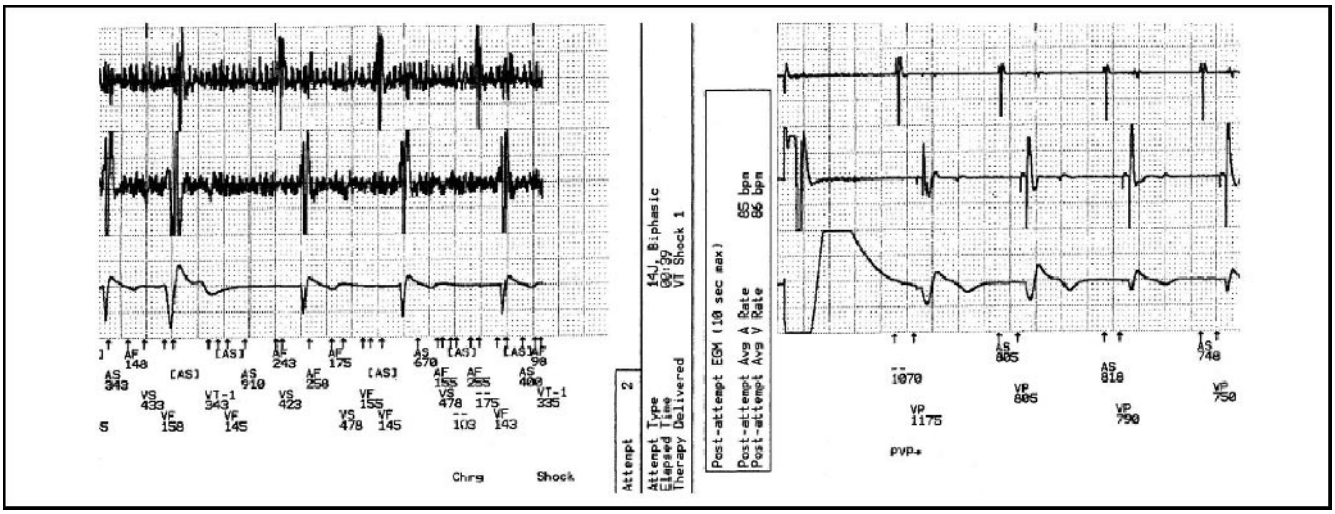


Figure 7. EMI from department store security surveillance device triggering oversensing by ICD



This has been observed in sinus rhythm as well as during ventricular tachycardia (VT) [9,10]. The ICD in these instances delivers either ventricular tachyarrhythmia therapies for a supraventricular rhythm, or inappropriately aggressive tachyarrhythmia therapies, respectively (Fig. 13).

Oversensing of repolarizing events (T-wave oversensing) is the most common oversensing problem seen in ICDs. Oversensing of T waves can be intermittent because the absolute size of the T wave, as well as the size of the depolarization (R wave) relative to the T wave, is dynamic and can change with metabolic conditions (electrolytes, ischemia), as well as after ICD shock delivery. In one large series of cases [11•], T-wave oversensing was much more frequently seen in integrated bipolar leads than in dedicated bipolar leads. T-wave oversensing may be seen on routine interrogation of a stored ICD arrhythmia episode of nonsustained VT. Figure 14A demonstrates how T-wave oversensing can lead to a shock in sinus rhythm. The patient had real nonsustained polymorphic VT, detected by the ICD. After the VT terminates, however, the device, during charging, reconfirms the arrhythmia to avoid delivering therapy after spontaneous conversion. However, at the end of reconfirmation, a perfectly timed oversensed T-wave triggers an ICD shock during sinus rhythm because the interval between the T wave and next sensed depolarization met detection criteria. Figure 14B shows how T-wave size may be dynamic and lead to intermittent

Figure 8. ICD ventricular oversensing of lead chatter' leading to inappropriate VF detection

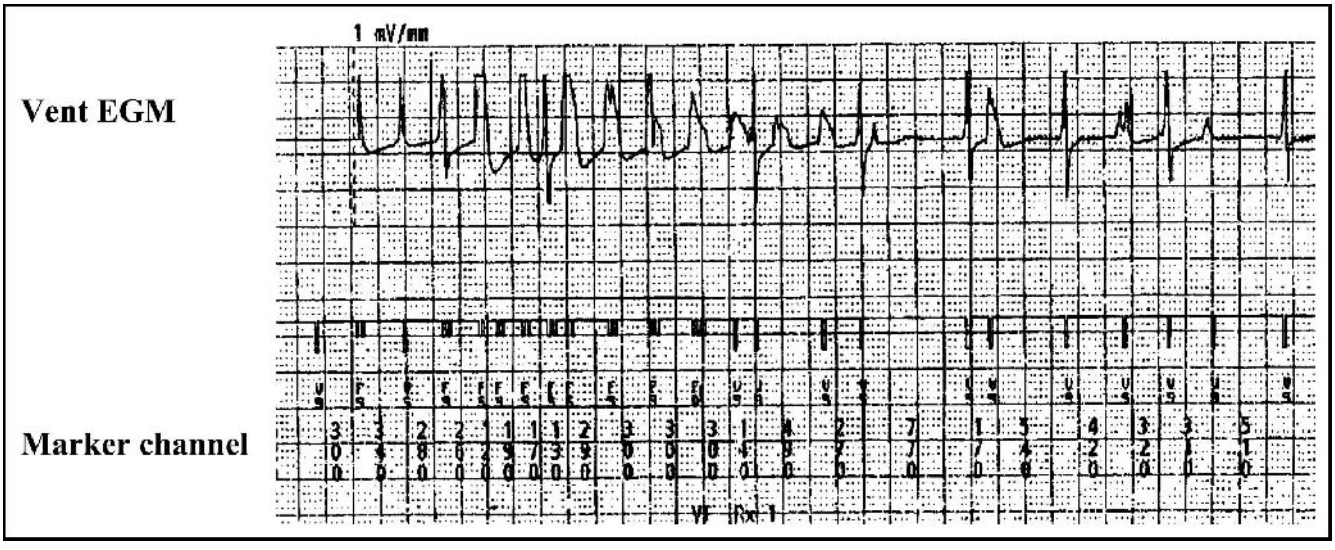
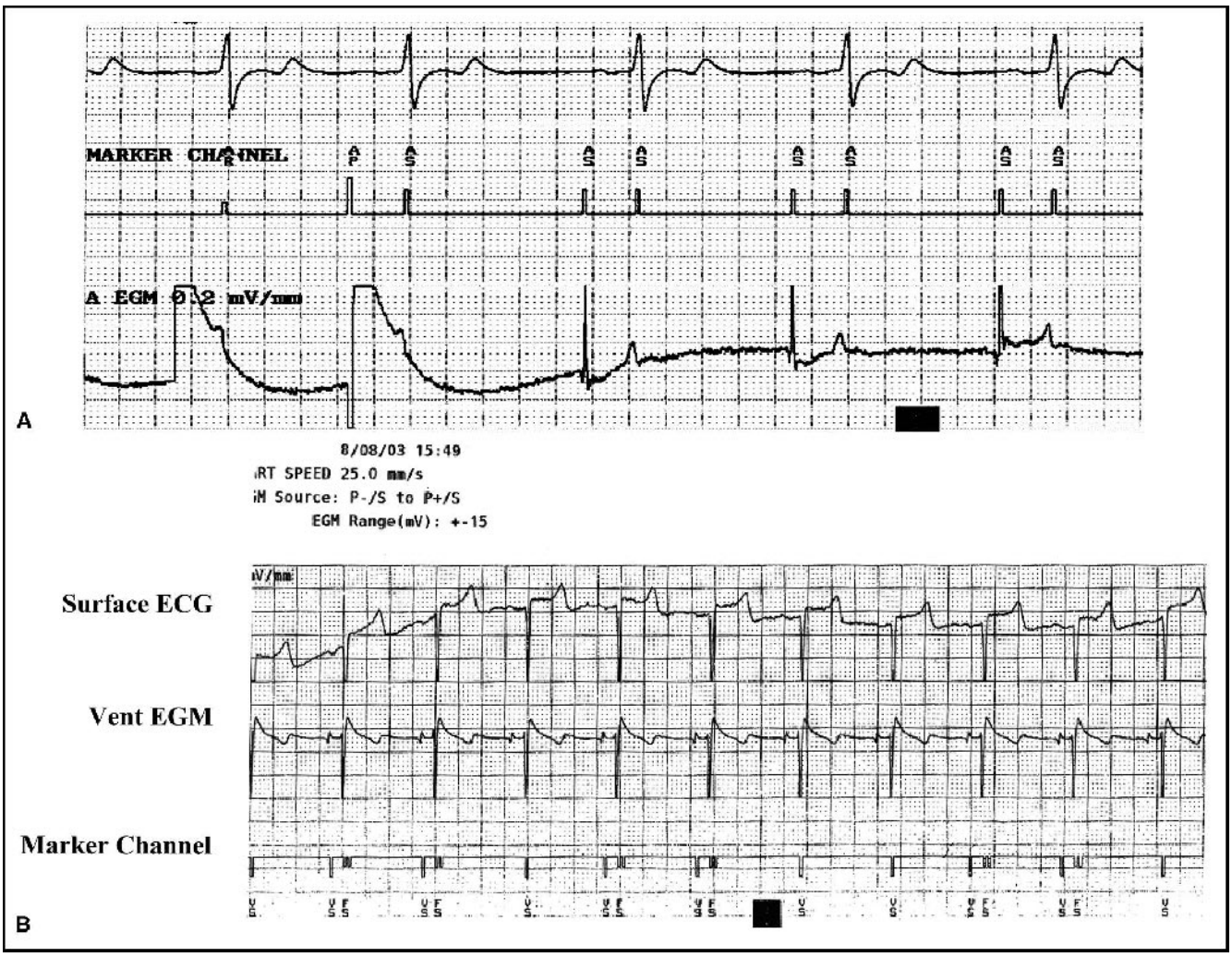


Figure 9. (A) Oversensing of intrinsic ventricular depolarization in the atrial channel. (B) Far-field sensing of atrial depolarization by ICD



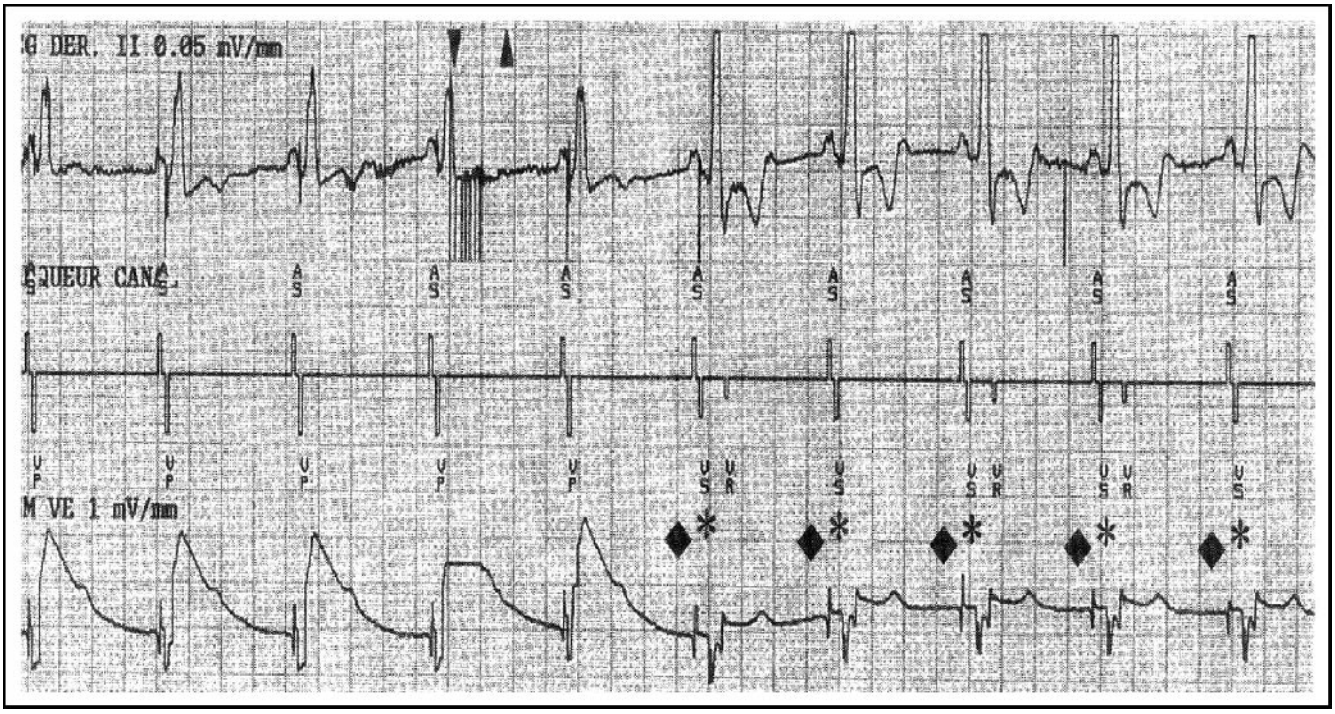
oversensing and inappropriate therapy. T-wave oversensing generally requires ICD lead repositioning or replacement.

Arrhythmia detection and analysis

New pacemakers have the ability to function as lifetime cardiac rhythm monitors as well as event recorders [4••,12••]. Atrial as well as ventricular tachyarrhythmia episodes may be stored (Figs. 15 and 16). Storage capability varies greatly among device companies and models and ranges from just a time log of sensed arrhythmias, to full storage of the arrhythmia itself, with marker channels and EGMs. These data are useful in assessing patient symptoms, as well as arrhythmia management. The ability to identify asymptomatic, potentially clinically significant arrhythmias via routine pacemaker interrogation is revolutionary and may have a profound impact on patient care. A retrospective analysis [13•] of 397 patients with dual-chamber pacemakers with EGM diagnostics revealed 84 patients (21%) with asymptomatic, previously undiagnosed atrial fibrillation, atrial flutter, or VT. Most (80 of 84 patients) had atrial tachyarrhythmias, and four had VT. All but two patients with atrial tachyarrhythmias were deemed to be at high risk for thromboemboli and were placed on long-term warfarin therapy. Two of the four patients with VT had a history of myocardial infarction. Echocardiograms were performed revealing significantly depressed ejection fractions and underwent electrophysiologic (EP) studies with inducible VT, resulting in the upgrade of their pacemakers to ICDs.

Patients with nonsustained VT may prompt an investigation into the presence of structural heart disease, which may lead to an electrophysiology study and upgrade to an ICD. Atrial fibrillation documented with atrial EGMs may prompt the recommendation for institution of thromboemboli prophylactic therapy.

Figure 10. The cause of sudden inhibition of ventricular pacing is demonstrated in the marker channels showing sensing of the atrial signal in the ventricle. Marker channels confirm that pacing inhibition is due to atrial signals sensed in the ventricule



Limitations of stored diagnostic data

Arrhythmia logs or marker channels alone (without EGMs) should not be used to diagnose arrhythmias. False-positive classification of tachyarrhythmias may occur because of far-field oversensing or noise generated by lead fracture, or other causes of oversensing as described here. Signals may vary with development of bundle branch block as well, possible leading to a false

Figure 11. Interatrial conduction delay causing oversensing in atrial channel

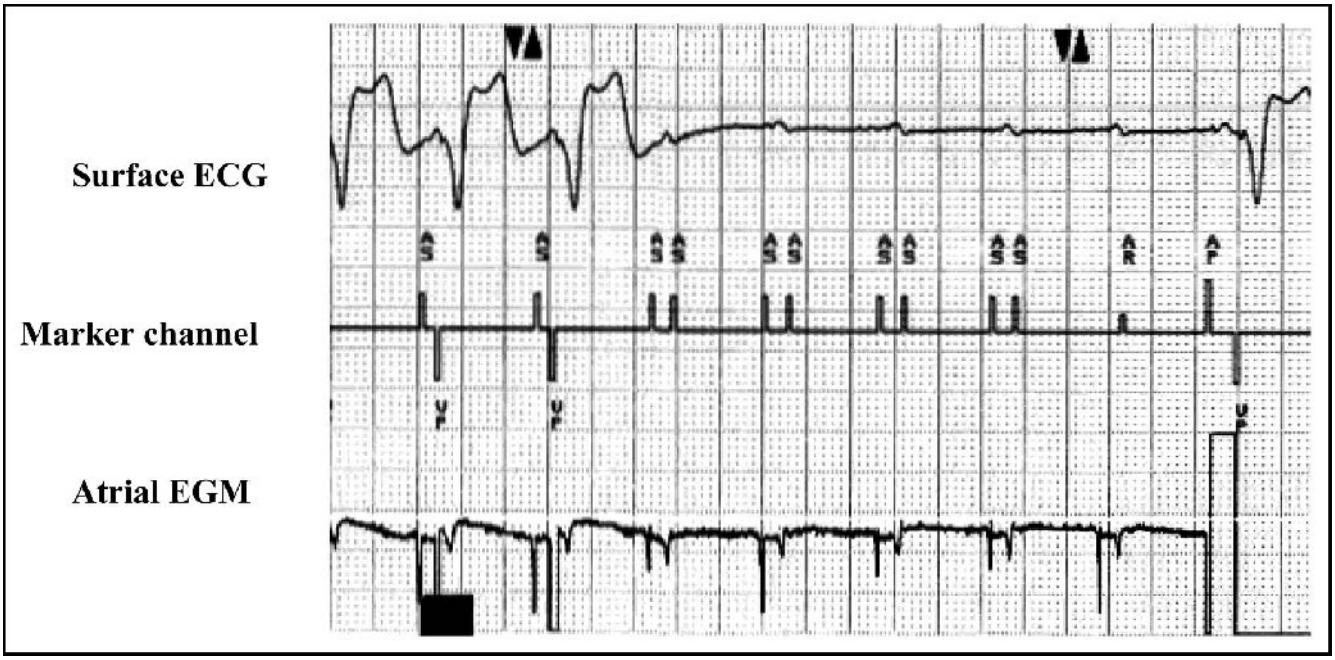
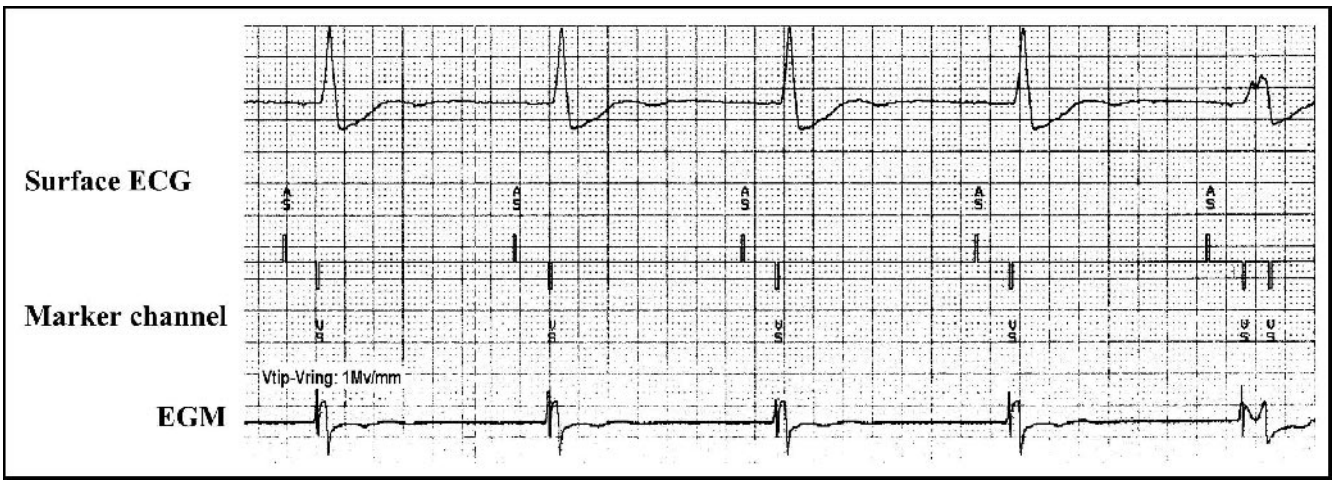


Figure 12. Ventricular oversensing due to conduction delay of last beat with LBBB. Notice much wider EGM on last beat



misclassification due to EGM morphology change [4••]. True EGMs (in both chambers for pacemakers) are the most accurate way for the diagnosis of arrhythmia mechanism. Other ways should be regarded as possibly suggestive, but not diagnostic, and should not be the basis of institution of antiarrhythmic therapy, invasive testing, or anticoagulation.

Pacemaker event recorder function

Pacemakers may also serve as cardiac event recorders, with patients activating the pacemaker to store EGM diagnostic data with the application of a magnet or company-specific device. Upon pacemaker interrogation, the EGMs correlating to the onset of the symptoms may be reviewed. Studies show that arrhythmias were present in 41% of patient-triggered events, and sinus rhythm was seen in 59% [4••]. Obviously, both negative and positive EGM arrhythmia findings are clinically useful.

Conclusion

The diagnostic data available in new pacemakers and ICDs offer invaluable information regarding the functional status of the device and leads. This is accomplished via direct measurements, as well as analysis of

Figure 13. Double counting of ventricular depolarization during sinus rhythm in a biventricular ICD. Notice that oversensing is intermittent and dependent on the conduction delay as seen in the ventricular EGM

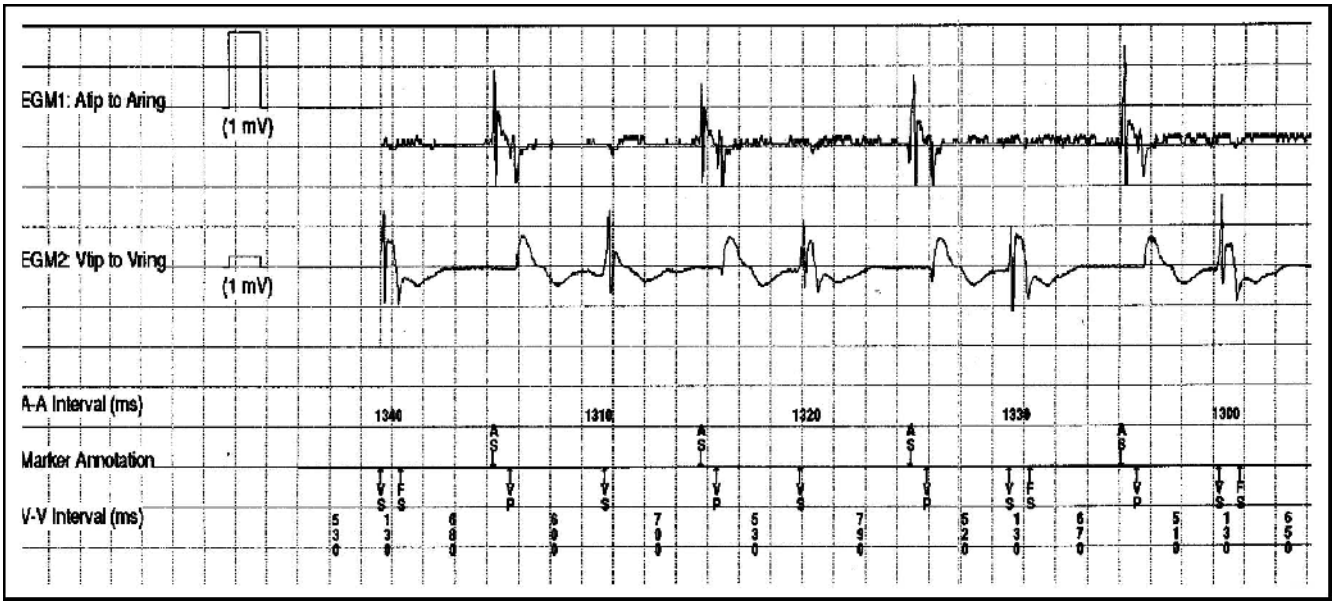


Figure 14. (A) EGM and marker channel showing nonsustained polymorphic VT followed by perfectly timed oversensed T wave (arrow) followed by a sinus beat. The 310 msec coupling interval between the T wave and sinus beat met criteria for arrhythmia reconfirmation, prompting the ICD shock. (B) EGM strip showing dynamic relationship of size between ventricular depolarization and repolarization, with T wave oversensing seen on left and not right. This patient received ICD shock for T wave oversensing

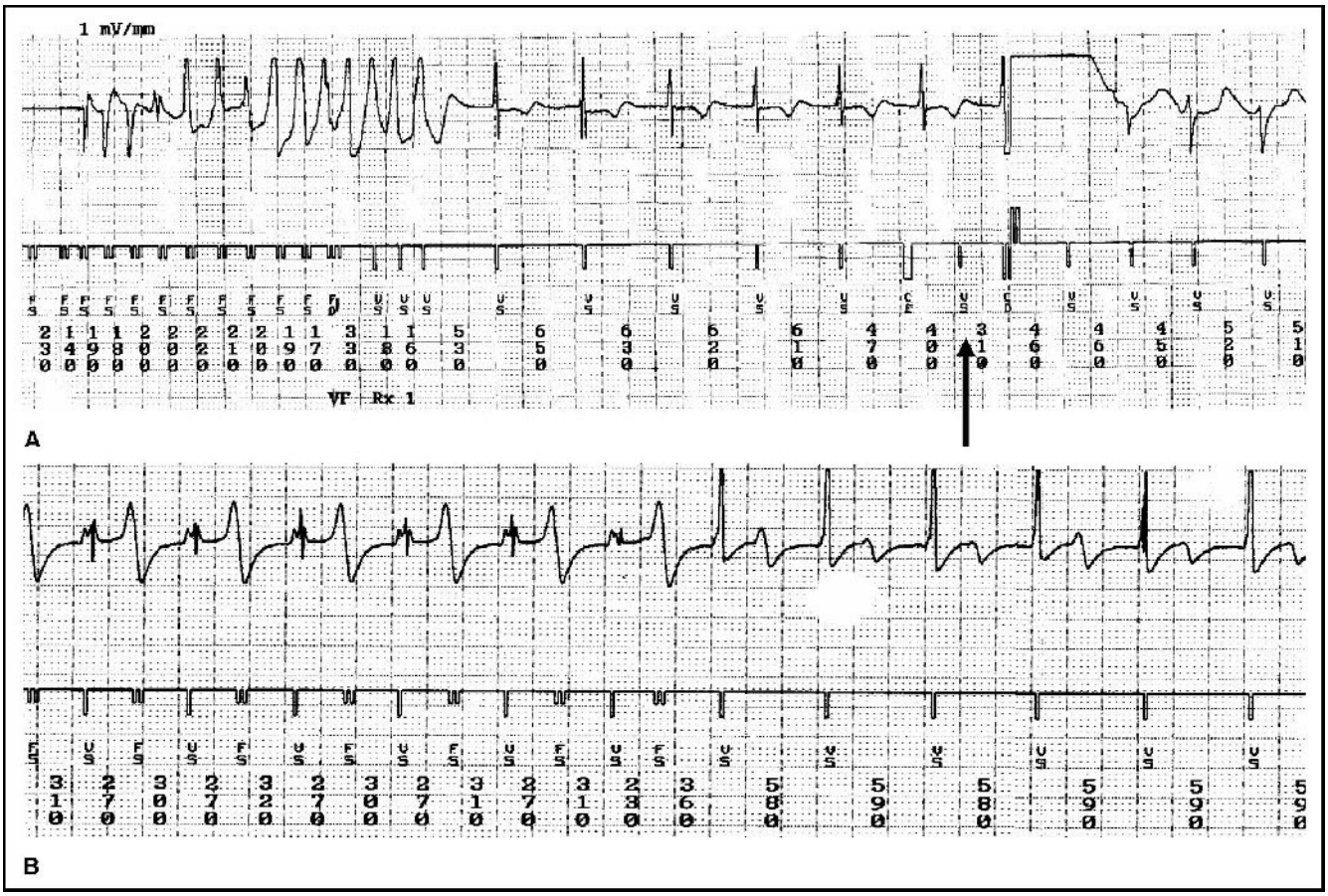


Figure 15. Asymptomatic atrial fibrillation found in arrhythmia log on routine pacemaker check

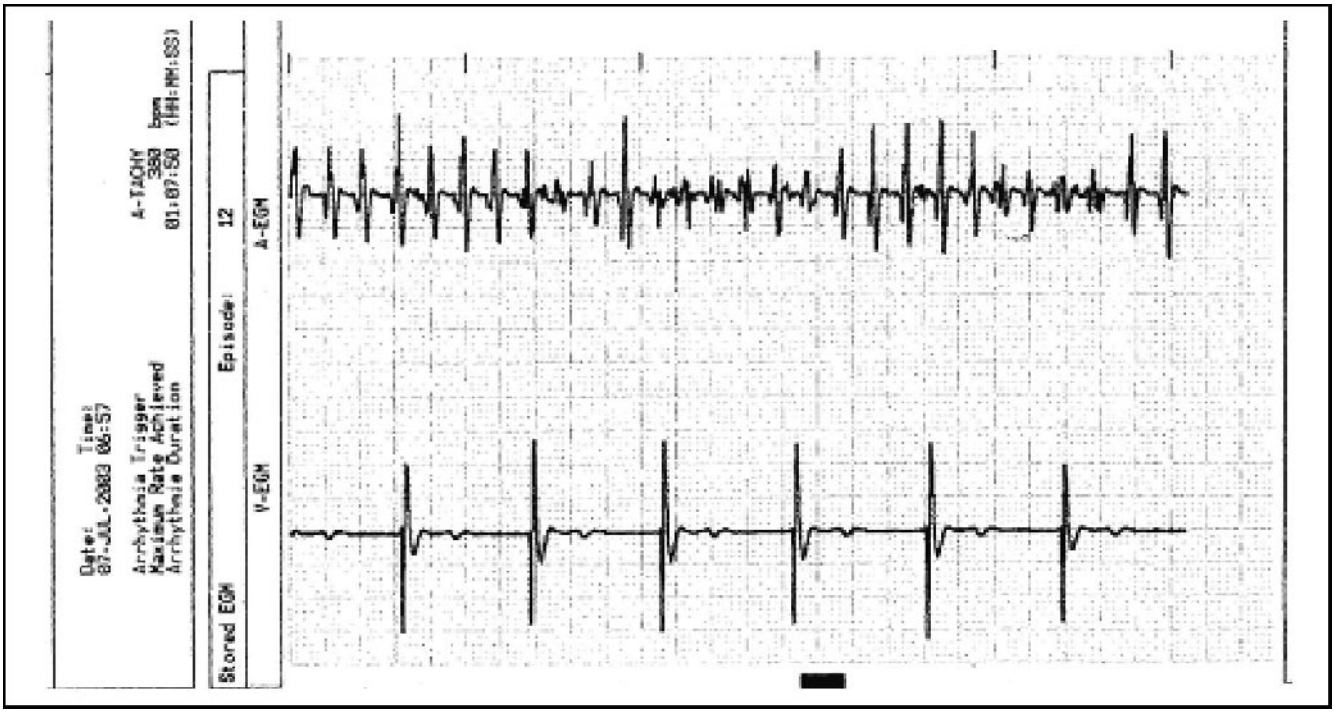
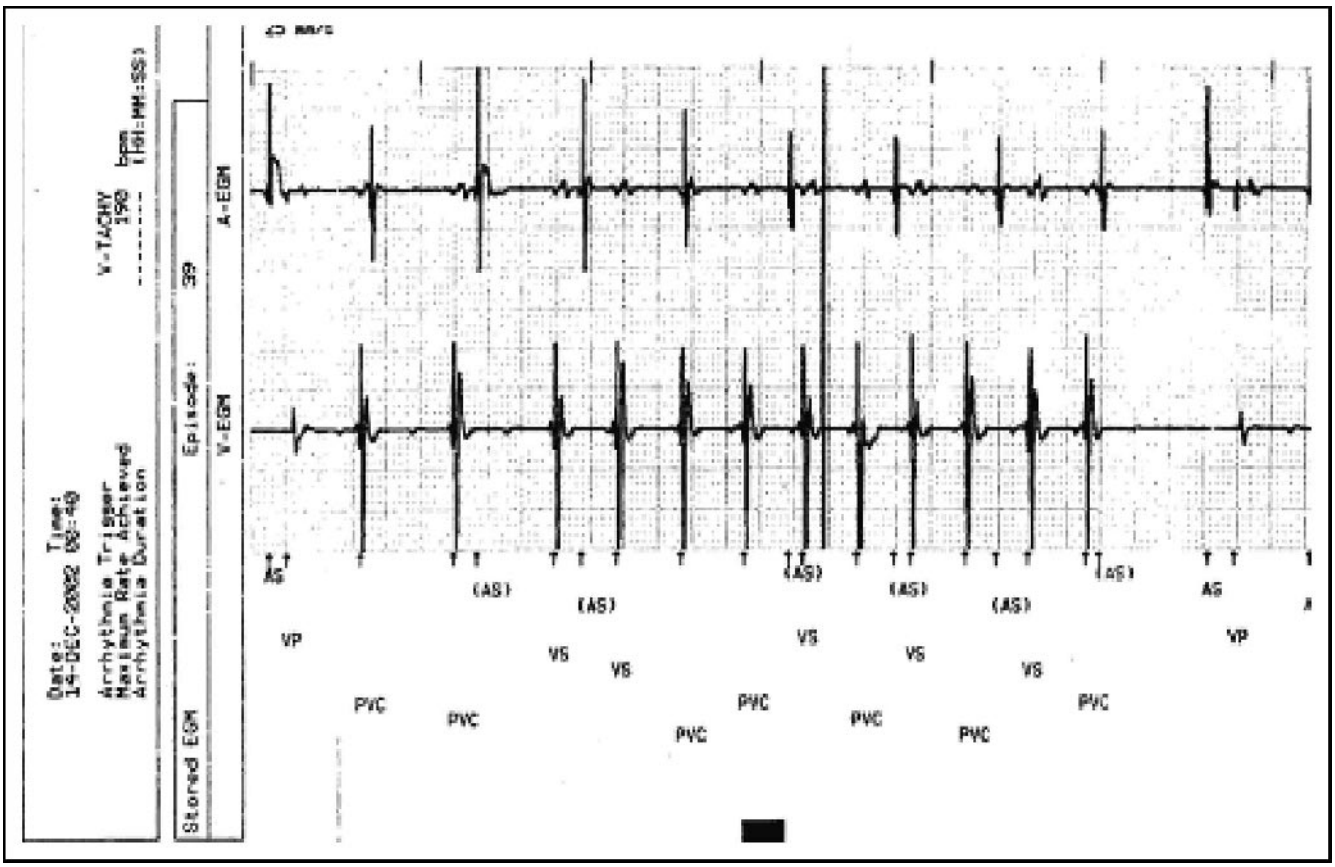


Figure 16. Asmptomatic nonsustained VT found in arrhythmia log during routine pacemaker follow-up. Patient had CAD, significant LV dysfunction, and ultimately went on to upgrade to ICD based on this finding



the stored arrhythmia data by the clinician, which can uncover inappropriate sensing and resultant therapy. In addition, detailed information regarding arrhythmias is furnished in the form of traditional marker channels, arrhythmia logs, and EGMs, all of which are used together to confirm the occurrence of the arrhythmia (or to diagnose false detection due to sensing or lead problems) and identify its mechanism in most cases. Knowledge about the unique diagnostic data available in individual devices (especially pacemakers) is important. Because detection criteria are programmable, they may be set up at the time of implant, or modified at follow-up visits, tapered to the individual patient's arrhythmia history or arrhythmias targeted (*eg*, setting up detection parameters of a pacemaker for detection of nonsustained VT in a patient with a history of myocardial infarction and decreased left ventricular function, or atrial tachyarrhythmia parameters in a patient with a history of atrial tachyarrhythmia ablation). Detection of asymptomatic arrhythmias by pacemakers may significantly alter patient management, specifically regarding atrial fibrillation/flutter and VT.

Pacemakers may also function as reliable patient-activated event recorders providing extremely valuable information about patient symptoms. Knowledge about specific pacemaker and ICD diagnostic features is important in prescribing the appropriate device for a given patient and for programming device monitoring, arrhythmia detection, and therapy features.

References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- • Of special interest
- •• Of outstanding interest

1 Kuruvilla C, Voigt L, Kachmar K, et al. Inappropriate mode switching in a dual chamber pacemaker due to oversensing of a high frequency signal from a conductor/ring discontinuity (loose set screw). PACE 2002; 25:115–117.

2 •• Israel C. Analysis of mode switching algorithms in dual chamber pacemakers. PACE 2002; 25:380–393.
An excellent review of performance and programming of mode switching algorithms in different pacemakers.

3 • Ellenbogen KA, Wood MA, Shephard RK, et al. Detection and management of an implantable cardioverter defibrillator lead failure. J Am Coll Cardiol 2003; 41:73–80.
An excellent illustration of how analysis of ICD-delivered therapy can lead to discovery of lead failure.

4 •• Nowak B. Pacemaker stored electrograms: teaching us what is really going on in our patients. PACE 2002; 25:838–849.
A comprehensive review of the utility of EGMs.

5 Niehaus M, Neuzner J, Vogt J, et al. Adjustment of maximum automatic sen-
• sitivity (automatic gain control) reduces inappropriate therapies in patients with implantable cardioverter defibrillators. PACE 2002; 25:151–155.
A description of diaphragm myopotential oversensing causing inappropriate ICD shocking.

6 Lee SW, Moak JP, Lewis B. Inadvertent detection of 60-Hz alternating current by an implantable cardioverter defibrillator. PACE 2002; 25(part I):518–551.

7 Collins R, Haugh C, Cassavant D, et al. Rate dependent far-field R wave
• sensing in an atrial tachyarrhythmia therapy device. PACE 2002; 25:112–114.

8 Lipchenca I, Garrigue S, Glikson M, et al. Inhibition of biventricular pacemakers by oversensing of far-field atrial depolarization. PACE 2002; 25:365–367.

9 Srivathsan K, Bazzell JL, Lee RW. Biventricular implantable cardioverter defibrillator and inappropriate shocks. J Cardiovasc Electrophysiol 2003; 14:88–89.

10 Garcia-Moran E, Mont L, Brugada J. Inappropriate tachycardia detection by a biventricular implantable defibrillator. PACE 2002; 25:123–124.

11 Weretka S, Michaelsin J, Becker R, et al. Ventricular oversensing: a study of
•• 101 patients implanted with dual chamber defibrillators and two different lead systems. PACE 2003; 26(part I):65–70.
A comprehensive review of causes of ICD oversensing.

12 Pollack W, Simmons J, Interian Jr. A, et al. Pacemaker diagnostics: a critical
•• appraisal of current technology. PACE 2002; 26(part I):76–98.
An excellent and complete overview of pacemaker diagnostic information.

13 Scher DL. Previously unknown AF and VT found during routine pacemaker
•• follow-up. Europace Supplements 2003; 4:A14.