Ambulatory External Electrocardiographic Monitoring

Focus on Atrial Fibrillation

Suneet Mittal, MD,* Colin Movsowitz, MBC,HB,† Jonathan S. Steinberg, MD*
New York, New York; and Wynnewood, Pennsylvania

There has been progressive development in ambulatory external electrocardiogram (AECG) monitoring technology. AECG monitors initially consisted of 24- to 48-h Holter monitors and patient-activated event and loop recorders. More recently, several ambulatory cardiovascular telemetry monitors and a patch-type 7- to 14-day Holter monitor have been introduced. These monitoring systems are reviewed along with their utility and limitations, with particular emphasis on their role in the diagnosis and evaluation of patients with atrial fibrillation (AF). AECG monitoring is necessary when asymptomatic AF is suspected (as in patients presenting with cryptogenic stroke) or when an ECG diagnosis of unexplained arrhythmic symptoms is warranted. In addition, AECG plays an important role in patients with known AF to guide ventricular rate control and anticoagulation therapy, and assess the efficacy of antiarrhythmic drug therapy and/or ablation procedures. Finally, we outline areas of uncertainty and provide recommendations for use of available AECG monitors in clinical practice. (J Am Coll Cardiol 2011;58:1741–9) © 2011 by the American College of Cardiology Foundation

The 12-lead electrocardiogram (ECG) has served as the “gold standard” for arrhythmia diagnosis for over a hundred years. However, for nearly as long, the limitations inherent to an ECG have also been recognized. Arrhythmias can be paroxysmal and asymptomatic; thus, a baseline resting ECG may be insufficient for diagnosis. Atrial fibrillation (AF) is the prototypical example of an arrhythmia in which a 12-lead ECG is insufficient to guide clinical management. Since the development of the Holter monitor in the 1940s, there has been progressive development in ambulatory external electrocardiogram (AECG) monitoring technology (Fig. 1). This review focuses on these new technologies with an emphasis on their role in the diagnosis and management of patients with AF.

Types of Available AECG Monitors

Holter, event, and loop monitors. The 1999 practice guidelines released jointly by the American College of Cardiology and the American Heart Association categorized AECG monitors as either continuous short-term recorders (24 to 48 h) or intermittent longer-term recorders (patient-activated event and loop recorders) (1). During Holter monitoring, a patient is typically connected to 3 to 5 ECG electrodes, which yield 2 ECG vectors and a third derived electrogram. Some systems can also derive a 12-lead ECG recording, which can be useful to evaluate the QRS morphology. The ECG signals are acquired at up to 1,000 samples per second, which yield high-fidelity tracings. The patient maintains a diary to document the time when symptoms are experienced and their description. After the 1- to 2-day recording period is completed, the patient returns the monitor; the data stored within the flashcard memory are digitized and downloaded to a local workstation or transmitted over the Internet to a central workstation. Only then can it be determined whether the ECG tracings were of adequate quality and whether any diagnostic information was obtained. The computer-scanned Holter recording is read by a trained technician who then forwards the report to the physician for final review and official interpretation. Assuming that the recording quality is adequate, Holter monitors can determine the average heart rate and heart rate range, quantify atrial and ventricular ectopy counts, and determine whether AF is present. Information about shortest and longest duration of AF, burden of AF, the heart rate during AF, and pattern of initiation and termination of AF can also be determined.

Patient-activated event and loop recorders can be used for several weeks at a time. Event recorders are small, leadless devices that are carried by the patient. When a patient experiences a symptom, the device is applied to the chest wall. Since electrodes are present on the back of the device, a brief (typically up to 90 s) single-lead ECG recording can be stored. The event recorder can store only a few tracings since they have only about 10 min of storage capacity; thus,
Abbreviations and Acronyms

AECG = ambulatory external electrocardiogram
AF = atrial fibrillation
ECG = electrocardiogram

to minimize loss of data, once an event is recorded, it needs to be immediately transmitted transtelephonically (using an acoustic coupler modem) to a central monitoring site for validation and analysis. By design, event recorders do not provide information about asymptomatic episodes.

Loop recorders on the other hand require that ECG leads be attached to the patient. As new ECG data are collected, older ECG data are deleted. When a patient activates the device, it stores a single-lead ECG before (typically about 45 to 60 s) and after (typically about 15 to 90 s) activation. As with event recorders, the devices have limited memory. Thus, to minimize loss of critical data, immediate transtelephonic data transmission following a symptomatic episode is necessary.

By design, loop recorders also do not provide information about asymptomatic episodes. To overcome this limitation, auto-triggered loop recorders were developed. These devices use a proprietary algorithm to trigger ECG storage of arrhythmic episodes such as bradycardia (including prolonged pauses), tachycardia, and atrial fibrillation. The available memory, typically 10 to 20 min in duration, is partitioned for patient-triggered and auto-triggered events. The device alerts (e.g., with a beeping noise) the patient when an auto-triggered event has been detected. The patient must transmit the data transtelephonically to a central monitoring station for review. It has been shown that these auto-triggered devices have higher diagnostic yield than standard 24-h Holter monitors and 30-day loop recorders. Auto-triggered loop recorders have evolved capability of transmitting stored ECG data wirelessly to a device that can then send data to a central monitoring station over a landline or cellular telephone network. Although these monitors can detect the onset of an arrhythmia such as AF, their algorithms are not designed to detect the onset of the arrhythmia. Thus, information about the burden of AF cannot be consistently ascertained. As a result, these types of monitors have fallen out of favor in our practice.

Ambulatory telemetry and patch-type monitors. Ambulatory telemetry monitoring was developed to overcome many of the limitations inherent to Holter, event, and loop monitoring, namely the need for long-term monitoring and the ability to capture information about symptomatic and asymptomatic arrhythmias. Currently, several systems are available in the United States (Table 1, Fig. 1B). Typically, patients are connected by 3 or 4 ECG electrodes to a battery-powered sensor for up to 30 days. The sensor can hold anywhere from 6 h to all 30 days of ECG data. In a “sensor-only” system, when the patient is in a location with available cellular coverage, the stored ECG data are transmitted directly to a central monitoring station. More commonly, systems incorporate a second handheld device. In this case, data from the sensor is sent to the handheld device when it is within 10 to 300 feet of the patient. Once the patient is in a location with available cellular coverage, the stored ECG data are transmitted from the handheld device to a central monitoring station. Patients can also use the handheld device to enter information about symptoms. The monitoring center can determine whether the patient is actually wearing the device and ascertain the quality of the contact with the ECG electrodes; by communicating directly with the patient, the compliance with the system and quality of the acquired data may be improved.

Currently available systems handle incoming ECG data differently. Some “push” ECG data to a central monitoring station only when the handheld device confirms that a bradycardic or tachycardic arrhythmia (including AF) event has occurred, based on proprietary algorithms that incorporate (depending on the vendor) information about rate, rhythm, and/or P and QRS morphology. Other systems push all ECG data forward. Since these devices capture information about symptomatic and asymptomatic events, information about AF burden during the recording period can also be ascertained. Not surprisingly, compared with loop monitoring, these systems significantly increase the likelihood of detecting AF. In addition to getting a summary report at the end of the recording period (either by fax or online), practices can develop their own emergent, urgent, and routine physician notification criteria.

Several issues with AECG monitoring systems merit comment. First, since the sensor captures beat-by-beat data, complete ECG analysis (like a Holter recording) should be available either intermittently or at the end of the recording period. However, currently only a few vendors offer this analysis, often only upon a specific request from a physician. Thus, physicians typically just assume ECG data has been appropriately recorded, scanned, and analyzed. Second, although touted as “real-time” telemetry, only 2 of these systems currently function in this manner (Table 1). One system sends ECG data from the sensor to a handheld device, which in turn forwards the accrued ECG information every 2 min to a central monitoring station. A physician can access the data over a secure web server. A second system transfers ECG data directly from the sensor to a central monitoring system. In this system, the physician has the ability to access real-time streaming ECG data from their patient on any computer with Internet access. Third, although critical data are made available to physicians on a 24 h/7 days a week basis and routine data on a daily basis, reimbursement to physicians does not take into account the need for daily monitoring for up to a month. Thus, although physicians must assume the responsibility for monitoring daily incoming data, the reimbursement to physicians for ambulatory cardiovascular telemetry is actually lower than that for Holter monitoring. The majority of the reimbursement is collected by the independent diagnostic
Figure 1 Types of AECG Monitors Currently Available in Clinical Practice

(A) Holter, event, and loop monitoring; (B) patch-type extended Holter and ambulatory telemetry monitoring. AECG = ambulatory external electrocardiographic; ECG = electrocardiographic. Figure illustration by Craig Skaggs.
testing facility that owns and operates the ECG monitors. On the other hand, there is no mechanism for physicians to be reimbursed daily for their review of incoming ECG data. Since appropriate use guidelines for this type of ECG monitor have not yet been developed, some commercial carriers do not provide coverage or reimbursement at all on the grounds that mobile cardiovascular telemetry monitoring is “investigational.” In addition, the absence on the grounds that mobile cardiovascular telemetry monitoring is “investigational.” In addition, the absence of guidelines has to led to uncertainty regarding the potential liability for “missed” critical arrhythmic events. Fortunately, although these monitoring systems detect many arrhythmic events, only ~1% can ultimately be classified as emergent (4).

A recently developed alternative (Zio Patch, iRhythm Technologies, San Francisco, California) utilizes a small, lightweight, water-resistant patch that is placed in the left pectoral region and can store up to 14 days of continuous single-lead ECG data. A button on the patch can be pressed by the patient to mark a symptomatic episode. At the end of the recording period, the patient mails back the recorder in a pre-paid envelope to a central station (much like a Netflix DVD). A proprietary algorithm can process 14 days of acquired data within 10 min. A full report is provided to the ordering physician within a few days. Because the system has not yet been made widely available, clinical experience is currently lacking. It remains to be determined whether patients can actually tolerate the patch for 7 to 14 days and whether a set of near-field recording electrodes can yield a high-quality, artifact-free ECG recording through the entire recording period. Furthermore, the clinical implications of not having access to ECG information within the recording period need to be determined.

**Indications for AECG Monitoring**

Broadly speaking, the fundamental premise of AECG monitoring is the potential to capture real-time rhythm recordings that can be used to: 1) provide an explanation for an unexplained prior or recurrent symptomatic event; or 2) capture arrhythmic events that aid in assessing prognosis or treatment effect. Table 3 lists the currently accepted indications, based on published evidence demonstrating value in the assorted subcategories. A discussion of the non-AF indications is beyond the scope of this paper and has been the focus of other recent reviews (5); the use of AECG in patients with AF will be reviewed in detail, as this is an area of intense clinical and research interest.

**Diagnosis of AF.** When a patient presents with unexplained symptoms that suggest an arrhythmic mechanism, AF is virtually always among the diagnostic considerations. Symptoms of AF are very varied and include rapid or abnormal heart action, weakness and fatigue, dyspnea, physical limitations, polyuria, and others. Syncope is less common as a direct result of AF, but may be due to post-termination pauses, associated vagal phenomena, slow-conducted ventricular rates, hemodynamic compromise in the presence of severe structural heart disease, or proarrhythmia due to drug therapy. Hence, prolonged AECG recording becomes very valuable to sort out these possibilities, to clarify the need for additional treatment, to help reassure the patient and to project long-term prognosis.

**Diagnosis of AF as the cause of cryptogenic stroke.** Twenty-five percent of ischemic strokes remain unexplained after an initial thorough evaluation including 12-lead ECG and in-hospital telemetry monitoring and are designated cryptogenic stroke. AF is the most common cardioembolic source of ischemic stroke. Because the presence of AF will lead to a specific and effective medical intervention in this setting, that is, chronic oral anticoagulation to prevent recurrent stroke, it is critical to identify the 10% of patients whose index stroke was caused by AF (6). In about 5% of patients, this effort is made simple when AF is present on ECG or telemetry during the index hospitalization (7). However, prolonged outpatient monitoring will extend the diagnosis of AF to an additional 6% to 8% of patients, with

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**Table 1 Commercially Available Ambulatory Telemetry Monitoring Systems**

<table>
<thead>
<tr>
<th>Feature</th>
<th>BioMedical</th>
<th>Cardionet</th>
<th>LifeWatch</th>
<th>Medicomp</th>
<th>MedNet</th>
<th>ScottCare</th>
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<tr>
<td>Name</td>
<td>TruVue</td>
<td>MCOT</td>
<td>ACT III</td>
<td>ACT I</td>
<td>SAVI</td>
<td>ECAT</td>
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<td>Single unit</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Leads</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3, 5, 12</td>
</tr>
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<td>Channels</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
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<tr>
<td>Sampling rate</td>
<td>256 Hz</td>
<td>250 Hz</td>
<td>250 Hz</td>
<td>250 Hz</td>
<td>250 Hz</td>
<td>205 Hz</td>
</tr>
<tr>
<td>Sensor memory</td>
<td>30 days</td>
<td>30 days</td>
<td>6 h</td>
<td>6 h</td>
<td>4 days</td>
<td>30 days</td>
</tr>
<tr>
<td>Handheld/sensor interaction</td>
<td>100 ft</td>
<td>300 ft</td>
<td>10 ft</td>
<td>10 ft</td>
<td>15 ft</td>
<td>30 ft</td>
</tr>
<tr>
<td>2-way patient communication</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes*</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>24-h Holter analysis</td>
<td>Yes</td>
<td>No</td>
<td>Yes*</td>
<td>No</td>
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<td>Symptom correlation on screen</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
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<td>Auto/manual transmissions</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>QT/ST-segment analysis</td>
<td>Yes</td>
<td>No</td>
<td>Yes*</td>
<td>Yes</td>
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<td>No</td>
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<tr>
<td>Handheld device data storage capacity</td>
<td>NA†</td>
<td>NA†</td>
<td>28 days</td>
<td>28 days</td>
<td>30 days</td>
<td>NA†</td>
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<tr>
<td>Ability to visualize real-time ECG data</td>
<td>Yes‡</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes§</td>
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<td>Technology</td>
<td>CPT</td>
<td>Description</td>
<td>Reimbursement</td>
<td>Indications</td>
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<td>Holter monitors (up to 48 h; up to twice every 6 months)</td>
<td>93224</td>
<td>External electrocardiographic recording up to 48 h by continuous rhythm recording and storage; includes recording, scanning analysis with report, physician review and interpretation (global)</td>
<td>$118.64</td>
<td>Detection of transient episodes of cardiac dysrhythmias, permitting correlation of these episodes with current cardiovascular symptomology</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>93225</td>
<td>Recording (includes connection, recording, and disconnection)</td>
<td>$35.57</td>
<td>Detection of abnormalities of cardiac rhythm or electrocardiographic morphology associated with symptoms of syncope, near-syncope, palpitations, chest pain suggestive of cardiac ischemia, shortness of breath on exertion, and recurrent congestive heart failure where arrhythmia is the suspected cause</td>
<td></td>
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<tr>
<td></td>
<td>93226</td>
<td>Scanning analysis with report</td>
<td>$52.31</td>
<td>Evaluation of arrhythmias in the patient with documented coronary artery disease, including the assessment of the immediate post-myocardial infarction patient</td>
<td></td>
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<tr>
<td></td>
<td>93227</td>
<td>Physician review and interpretation</td>
<td>$30.57</td>
<td>Detection of arrhythmias (such as atrial fibrillation) in patients with acute stroke or TIAs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Event monitors (up to 30 days; no defined frequency limit)</td>
<td>93268</td>
<td>External patient and, when performed, autoactivated electrocardiographic rhythm-derived event recording with symptom-related memory loop with remote download capability up to 30 days, 24-h attended monitoring; transmission of data and physician review and interpretation of the data (global)</td>
<td>$313.03</td>
<td>No defined guidelines</td>
<td></td>
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<td></td>
<td>93270</td>
<td>Recording (includes connection, recording, and disconnection)</td>
<td>$19.27</td>
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<td></td>
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<tr>
<td></td>
<td>93271</td>
<td>Transmission download and analysis</td>
<td>$264.73</td>
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<tr>
<td></td>
<td>93272</td>
<td>Physician review and interpretation</td>
<td>$29.04</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mobile cardiovascular telemetry (up to 30 days; once every 6 months)</td>
<td>92229</td>
<td>Wearable mobile cardiovascular telemetry with electrocardiographic recording, concurrent computerized real-time data analysis and &gt;24 h of accessible ECG data storage (retrievable with query) with ECG-triggered and patient-selected events transmitted to a remote attended surveillance center for up to 30 days; technical support for connection and patient instructions for use, attended surveillance, analysis and physician-prescribed transmission of daily and emergent data reports</td>
<td>$860.35*</td>
<td>Detection, characterization, and documentation of symptomatic transient arrhythmias, when the frequency of the symptoms is limited and use of a 24-h ambulatory ECG is unlikely to capture and document the arrhythmia</td>
<td></td>
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<td></td>
<td>93228</td>
<td>Wearable mobile cardiovascular telemetry with electrocardiographic recording, concurrent computerized real-time data analysis and &gt;24 h of accessible ECG data storage (retrievable with query) with ECG-triggered and patient-selected events transmitted to a remote attended surveillance center for up to 30 days; physician review and interpretation with report</td>
<td>$28.95</td>
<td>Regulation of antiarrhythmic drug dosage, when needed to assess efficacy of treatment</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>To ensure the absence of atrial fibrillation prior to the discontinuation of anticoagulation therapy</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>To monitor patients who have had surgical or ablative procedures for arrhythmias</td>
<td></td>
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</tbody>
</table>

*Coverage for mobile cardiovascular telemetry monitoring from commercial insurance carriers varies from state to state; several carriers consider the service “investigational” and, thus, provide no reimbursement.

AECG = ambulatory electrocardiographic; CPT = Current Procedural Terminology; ECG = electrocardiographic; TIA = transient ischemic attack.
longer recordings producing greater yield (8,9), especially when AF is asymptomatic. Because paroxysmal AF is as likely as continuous AF to increase the risk of stroke (10), there is inherent logic in searching for the presence of transient AF over longer periods of surveillance. The appropriate duration of monitoring has not been determined with certainty, but present-day monitors that autocapture AF events accurately over a 21- to 30-day period seem justified. Tayal et al. (11) initiated 21-day mobile cardiac outpatient telemetry after hospitalization in 56 patients with cryptogenic stroke and identified new AF in 23%, although many patients had only AF of uncertain significance, lasting <30 s. The ongoing study CRYSTAL-AF (Study of Continuous Cardiac Monitoring to Assess Atrial Fibrillation After Cryptogenic Stroke) (12) is investigating the value of even longer-term monitoring using an implantable loop recorder, emphasizing the importance of identifying which patients with cryptogenic stroke should be candidates for anticoagulation.

**Monitoring AF.** AF is a chronic condition, and once the diagnosis has been established, periodic monitoring is necessary for a variety of reasons. The management of paroxysmal versus persistent AF may differ. When presented with a patient in AF in the office setting, it may be difficult to confidently determine whether the AF pattern is likely to be continuous or episodic, and thus recording an AECG over the course of 1 or more weeks may be useful. The evolution to persistent AF may be insidious but may suggest the need for more aggressive intervention including cardioversion, antiarrhythmic drug therapy, more intensive rate control regimens, specific ablation techniques (13), or reassessment of prognosis and long-term treatment goals.

The AECG can also be utilized to more accurately ascertain whether excessive ventricular rates are present, for what portions of the day, and to what heights. It is generally believed that exposure to excessive ventricular rates may risk tachycardia-induced cardiomyopathy (14), and the 5-s resting ECG is inadequate to assess this risk and indeed may be misleading. We advocate AECG recording of at least 24 h for rate assessment, prior to and during titration of medical therapy, usually targeting a resting ventricular rate of <80 beats/min and peak activity rates of <110 to 120 beats/min. The RACE II (RAte Control Efficacy in Permanent Atrial Fibrillation) study recently raised doubts about the need to aggressively pursue this objective (15), but particularly in heart failure patients, this treatment goal may still be critical. The AECG will also facilitate simultaneous monitoring of the main risk of aggressive rate control, excessive bradycardia during AF, at termination, or in sinus rhythm. At present, it is unknown whether 24 h is sufficient sampling of ventricular rate or whether longer recording durations would expose much greater day-to-day variability than suspected.

**Assessment of treatment efficacy.** ANTIARRHYTHMIC DRUG THERAPY. Antiarrhythmic drugs are primarily used to reduce AF prevalence in highly symptomatic individuals, but are assumed to be incapable of complete AF eradication in most patients. Patients with stroke risk factors are believed to be at continued risk, and chronic anticoagulation therapy is recommended (16). Thus, it is less important to perform AECG monitoring to confirm AF suppression in antiarrhythmic drug–treated patients.

**CATHETER ABLATION.** Percutaneous catheter procedures designed to eliminate the likely triggers of AF (usually the pulmonary veins) and sometimes directed to atrial substrate are increasingly used to control AF and its symptoms when medical therapy has been ineffective (13,17,18). AECG recording is often employed after the procedure has been completed and can play several roles: follow AF patterns during the early “blanking period”; clarify the cause of residual symptoms if present; detect asymptomatic AF; and, potentially, confirm the eradication of AF and thus the long-term prognosis and the need for continued medical therapy including anticoagulation.

In the weeks and first few months following ablation of AF, it has been noted that many patients may continue to experience arrhythmias that ultimately or gradually dissipate and do not portend failure to definitively respond to the procedure. In a study designed to comprehensively define the blanking period, Joshi et al. (19) performed continuous...
outpatient AECG with a device that utilized autodetection algorithms to capture all AF events greater than 30 s in duration over the first 3 months following ablation in 72 patients. Overall, 65% of patients had at least 1 AF event. The presence of AF during any of the 2-week epochs throughout this early follow-up period did not predict the ultimate response to the procedure (AF suppression in 72% of the cohort, as adjudicated at 6 months), but the absence of AF in the first 2 weeks had a 90% sensitivity for predicting absence of AF in the long-term. This observation would suggest that in the select patients with heavy symptomatic AF burden who undergo ablation, the absence of AF during early AECG monitoring may allow early discontinuation of intense outpatient ECG monitoring. After the blanking period has expired, the focus on post-ablation care is the determination of whether the patient has responded and to what degree. Symptom status will certainly be of value, but studies suggest that as many as one-half of the episodes of AF may be asymptomatic after ablation (20–22) and that ablation itself may increase the proportion of asymptomatic events (23) versus the pre-ablation pattern, perhaps by ablation of cardiac neuronal connections, placebo effect, or concomitant medical therapy. Thus, monitoring is an important tool to assess arrhythmia status post-ablation for capture of asymptomatic and symptomatic AF.

The optimal monitoring strategy has not been defined, although expert consensus documents endorse the importance of periodic AECG (17). There is a continuum of monitoring that can be entertained, ranging from the minimal, 12-lead ECG recording at follow-up outpatient visits, to the ideal that does not yet exist, a permanently implanted and accurate wireless monitoring system (Fig. 2). The latter is only approachable given present-day technology with an implanted pacing device (pacemaker, defibrillator, resynchronization system) inserted for independent cardiovascular telemetry monitoring were commercially available. In 2007, the Heart Rhythm Society, in conjunction with the European Heart Rhythm Association and European Cardiac Arrhythmia Society, developed a consensus statement on electrocardiography and ambulatory electrocardiography was published in 1999 (1); at that time, neither auto-triggered loop recorders nor mobile cardiovascular telemetry monitoring were commercially available. Although ambulatory cardiovascular telemetry monitoring has emerged as a commonly used diagnostic tool in patients with suspected or known AF, some important concerns persist with respect to these systems. First, there are no clinical guidelines that guide practitioners on the use of AECG monitoring in patients with AF. The last American College of Cardiology/American Heart Association clinical competence statement on electrocardiography and ambulatory electrocardiography was published in 1999 (1); at that time, neither auto-triggered loop recorders nor mobile cardiovascular telemetry monitoring were commercially available. In 2007, the Heart Rhythm Society, in conjunction with the European Heart Rhythm Association and European Cardiac Arrhythmia Society, developed a consensus statement to provide recommendations in patients undergoing catheter or surgical ablation of AF (17). Although acknowledging that “the more intensively a patient is monitored and the longer the period of monitoring, the greater the likelihood of detecting both symptomatic and asymptomatic AF,” no specific guidelines were provided regarding the optimal AECG monitoring system. Most recently, the European Society of Cardiology published updated guidelines for AF management (27). They suggest that “the intensity and duration of monitoring should be determined by the clinical need to establish the diagnosis, and should be driven mainly by the clinical impact of AF detection. More intense AF recording is usually necessary in clinical trials than in clinical practice.” However, specific recommendations for which AECG monitoring system should be used are also not provided.

CONFIRMING ADEQUACY OF BIVENTRICULAR PACING. There is no possibility of response to cardiac resynchronization therapy (CRT) if effective ventricular capture does not occur during biventricular (BiV) pacing. The percentage of BiV pacing alone as recorded by the CRT device may be an inaccurate surrogate of complete and consistent BiV capture. Fusion and pseudo-fusion beats resulting from an interaction between intrinsically conducted and paced beats may be responsible for ineffective pacing, despite apparent delivery of CRT as assessed by a high percentage of BiV pacing (25). Using 12-lead Holter ECG and template matching, this hypothesis was tested in a recent study (26) that demonstrated that the absolute percentage of BiV pacing alone, as obtained from CRT device interrogation in patients with permanent AF, was an unreliable surrogate of effective pacing. Although CRT devices documented >90% pacing, in actuality, fusion and pseudo-fusion beats as determined on AECG constituted as much as 40% of the overall paced beats in many patients, and only consistently effectively paced patients showed a favorable clinical response and evidence of reverse remodeling following CRT.

Areas of Uncertainty

Although ambulatory cardiovascular telemetry monitoring

![Figure 2](image-url)
Second, there is a paucity of data regarding the accuracy of these systems for detecting AF. On October 28, 2003, the Food and Drug Administration (FDA) released a statement to guide industry interested in developing an Arrhythmia Detector and Alarm system (28). For AECG monitoring systems, testing needs to be performed according to guidelines stipulated in a 1998 statement from the American National Standard Institute and Association for the Advancement of Medical Instrumentation (29). Any system proposed to provide information on AF must be tested against the Massachusetts Institute of Technology–Beth Israel Hospital Arrhythmia Database (48 records of 30 min each) and the Noise Stress Test Database (12 ECG records of 30 min plus 3 records of noise only). These databases consist of digitized excerpts of 2-channel Holter-type reference recordings, with each beat labeled by expert cardiologist-annotators. Although industry needs to report the sensitivity and specificity of their AF detection algorithms to the FDA, comparative information across vendors is not readily available. Furthermore, with only a single exception (30), the details of the algorithm being used by any given vendor for AF detection are not publically available. Interestingly, although several vendors claim to capture information on every ECG beat acquired during the recording period, none have published the sensitivity and specificity of their autodetect AF algorithm against the “gold standard” of complete ECG data in the same patient.

Third, when ongoing monitoring for AF is required, both ambulatory cardiovascular telemetry and extended Holter-type recordings from a patch are available options. In comparison to the patch, the 2 main advantages of ambulatory telemetry are access to data during the monitoring period and the ability to monitor for up to a month. Assuming that the patch technology could evolve to where it, too, could offer a month of monitoring, there are no compelling data to support the need for real-time access to ECG data as opposed to receiving a singular report at the conclusion of the recording period.

Finally, an emphasis of prolonged ECG monitoring strategies has been the detection of arrhythmias. Even if we assume that these monitors can detect arrhythmias with perfect accuracy, it has yet to be demonstrated in clinical trials that patient outcome is affected. In AF patients, an important goal of monitoring is to use the data to guide decisions regarding anticoagulation. However, before embarking down this road, we need to know what duration or burden of AF is clinically important enough to warrant initiation of anticoagulation and then develop an AECG monitoring device that is capable of reliably accurately detecting AF episodes of this duration or burden.

Conclusions

AECG monitoring often establishes a diagnosis of AF in a given patient. Once established, AF is a chronic disease, and AECG monitoring can be important to its long-term management. Table 4 summarizes our current recommendations for AECG monitoring in clinical practice. Technology developments are necessary to produce an ECG monitor that can be applied to any AF patient (preferable in the office setting), can capture ECG information accurately and continuously, and can relay critical data to the physician promptly without the need for patient participation. Finally, future studies need to address the impact of data acquired

### Table 4: Recommendations for Using AECG Monitoring in AF Patients

<table>
<thead>
<tr>
<th>AECG Monitor</th>
<th>Goal</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>24- to 48-h Holter</td>
<td>Assess adequacy of ventricular rate control in patients with persistent or permanent AF</td>
<td>Role of longer term monitoring undefined</td>
</tr>
<tr>
<td></td>
<td>Assess effective biventricular capture in patients with persistent or permanent AF in patients with a cardiac resynchronization therapy device</td>
<td>Requires 12-lead Holter monitor</td>
</tr>
<tr>
<td>Event recorder</td>
<td>Elucidate mechanism of symptomatic arrhythmic episodes not associated with hemodynamic compromise (in patients capable of employing this technology)</td>
<td>If initial 30-day evaluation is nondiagnostic, may need to consider ILR for longer-term ECG monitoring</td>
</tr>
<tr>
<td>30-day ambulatory cardiovascular telemetry monitors</td>
<td>Assess for asymptomatic AF in patients with cryptogenic stroke</td>
<td>Role of 7- to 14-day Holter patch remains unexplored</td>
</tr>
<tr>
<td></td>
<td>Compare average heart rate in sinus rhythm vs. AF; assess pattern of AF initiation and termination; determine whether AF is paroxysmal or persistent</td>
<td>If initial 30-day evaluation is nondiagnostic, may need to consider ILR for longer-term ECG monitoring</td>
</tr>
<tr>
<td></td>
<td>Routinely in the first month post pulmonary vein isolation</td>
<td>Role of 7- to 14-day Holter patch remains undefined</td>
</tr>
<tr>
<td></td>
<td>At 6 and 12 months post-ablation</td>
<td>Helps define relationship between symptoms and AF recurrences and assess burden of asymptomatic AF; role of 7- to 14-day Holter patch remains undefined</td>
</tr>
</tbody>
</table>

Patient-activated loop monitors (with and without automatic detection algorithms) do not offer any distinct advantages for the detection or monitoring of AF. Thus, we routinely use ambulatory cardiovascular telemetry instead in these patients.

AAD = antiarrhythmic drug; AF = atrial fibrillation; ILR = implantable loop recorder; other abbreviations as in Table 2.
through AECG monitoring on short- and long-term pa-

tient outcomes.

Reprint requests and correspondence: Dr. Suneet Mittal, Elec-
trophysiology Laboratory, St. Luke’s and Roosevelt Hospitals, 1111 Amsterdam Avenue, New York, New York 10025. E-mail: smittal@chpnet.org.

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