Journal of the American College of Cardiology
© 2011 by the American College of Cardiology Foundation
Published by Elsevier Inc.

Vol. 58, No. 17, 2011
ISSN 0735-1097/$36.00
doi:10.1016/j.jacc.2011.07.026

VIEWPOINT

Ambulatory External Electrocardiographic Monitoring

Focus on Atrial Fibrillation

Suneet Mittal, MD,* Colin Movsowitz, MBChB,† 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 reviews 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,

From the *Valley Heart and Vascular Institute, Columbia University College of Physicians & Surgeons, New York, New York; and the †Cardiology Consultants of Philadelphia, Lankenau Hospital, Wynnewood, Pennsylvania. Dr. Mittal is a consultant for Medtronic. Dr. Movsowitz is a consultant for Ambucor and Medtronic. Dr. Steinberg has received research support from Biosense-Webster, LifeWatch, and Medtronic; and is a consultant for St. Jude, Ambucor, and Biosense-Webster.

Manuscript received June 6, 2011; revised manuscript received July 11, 2011, accepted July 20, 2011.

JACC Vol. 58, No. 17, 2011
October 18, 2011:1741–9

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 (2). 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 offset 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 (3). 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 actually 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 (Table 2). The majority of the reimbursement is collected by the independent diagnostic