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ACC/AHA PRACTICE GUIDELINES

ACC/AHA Guidelines for Ambulatory Electrocardiography

A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Revise the Guidelines for Ambulatory Electrocardiography)

Developed in Collaboration with the North American Society for Pacing and Electrophysiology

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PREAMBLE

It is important that the medical profession play a significant role in critically evaluating the use of diagnostic procedures and therapies in the management or prevention of disease states. Rigorous and expert analysis of the available data documenting relative benefits and risks of those procedures and therapies can produce helpful guidelines that improve the effectiveness of care, optimize patient outcomes, and affect the overall cost of care favorably by focusing resources on the most effective strategies.

The American College of Cardiology (ACC) and the American Heart Association (AHA) have jointly engaged in the production of such guidelines in the area of cardiovascular disease since 1980. This effort is directed by the ACC/AHA Task Force on Practice Guidelines. Its charge is to develop and revise practice guidelines for important cardiovascular diseases and procedures. Experts in the subject under consideration are selected from both organizations to examine subject-specific data and write guidelines. The process includes additional representatives from other medical practitioner and specialty groups where appropriate. Writing groups are specifically charged to perform a formal literature review, weigh the strength of evidence for or against a particular treatment or procedure, and include estimates of expected health outcomes where data exist. Patient-specific modifiers, comorbidities, and issues of patient preference that might influence the choice of particular tests or therapies are considered as well as frequency of follow-up and cost-effectiveness.

These practice guidelines are intended to assist physicians in clinical decision making by describing a range of generally acceptable approaches for the diagnosis, management, or prevention of specific diseases or conditions. These guidelines attempt to define practices that meet the needs of most patients in most circumstances. The ultimate judgment regarding care of a particular patient must be made by the physician and patient in light of all of the circumstances presented by that patient.

The executive summary and recommendations are published in the August 24, 1999, issue of *Circulation*. The full text is published in the *Journal of the American College of Cardiology*. Reprints of both the full text and the executive summary and recommendations are available from both organizations.

These guidelines have been officially endorsed by the North American Society for Pacing and Electrophysiology.

Raymond J. Gibbons, MD, FACC
Chair, ACC/AHA Task Force on Practice Guidelines

I. INTRODUCTION

The ACC/AHA Guidelines for Ambulatory Electrocardiography (AECG) were last published in 1989 (1). Since then, there have been improvements in solid-state digital technology that have expanded transtelephonic transmission of ECG data and enhanced the accuracy of software-based analysis systems. These advances, in addition to better signal quality and greater computer arrhythmia interpretation capabilities, have opened new potential uses for AECG. Despite these advances, a true automated analysis system has not been perfected and technician/physician participation is still essential.

Traditional uses of AECG for arrhythmia detection have expanded as the result of increased use of multichannel and telemetered signals. The clinical application of arrhythmia monitoring to assess drug and device efficacy has been further defined by new studies. The analysis of transient ST-segment deviation remains controversial, but considerably more data are now available, especially about the prognostic value of detecting asymptomatic ischemia. Heart rate variability (HRV) analysis has shown promise for predicting mortality rates in high-risk cardiac patients. Technological advances with long-term event recorders have permitted the self-activation of AECG monitors, but the reliability of fully automatic recording systems has not been established for routine clinical use. Rapid technological advances portend further improvements in equipment in the near future.

These guidelines focus on the use of AECG to aid clinical decision making. Thus, emphasis will be placed on the most common clinical uses of the technique. Evaluation of the clinical utility of a diagnostic test is more difficult than assessing the efficacy of a therapeutic intervention because diagnostic tests do not usually have the same direct impact on patient outcomes (2). In considering the use of AECG in individual patients, the following factors were important:

1. The technical capacity of the available equipment used for performing the study and the quality, expertise, and experience of the professional and technical staff necessary to perform and interpret the study
2. The diagnostic accuracy of the technique
3. The accuracy of the technique as compared with other diagnostic procedures
4. The effect of positive or negative results on subsequent clinical decision making
5. The influence of the technique on health-related outcomes.

The usefulness of AECG techniques in specific clinical situations is indicated by means of the following classification:

Class I: Conditions for which there is evidence and/or general agreement that a given procedure or treatment is useful and effective

Class II: Conditions for which there is conflicting evidence and/or a divergence of opinion about the usefulness/efficacy of a procedure or treatment

Class IIa: Weight of evidence/opinion is in favor of usefulness/efficacy

Class IIb: Usefulness/efficacy is less well established by evidence/opinion

Class III: Conditions for which there is evidence and/or general agreement that the procedure/treatment is not useful/effective, and in some cases may be harmful

This report includes brief descriptions of instrumentation and systems and reviews the use of AECG for 1) arrhythmia detection; 2) prognosis; 3) efficacy of antiarrhythmic therapy; 4) assessing pacemaker function and implantable cardioverter-defibrillator (ICD) function; 5) detecting myocardial ischemia; and 6) use in children. Tables appear in each section that summarize the recommendations for that particular application.

The Committee reviewed and compiled pertinent published reports by computerized and hand searches, excluding abstracts, and the recommendations made are based on these reports. Data tables are presented where multiple reports are available, but formal meta-analyses were not performed because of the nature of the available data and cost constraints. When few or no data existed, this is identified in the text, and recommendations are based on committee consensus. A complete list of the multiple publications on AECG is beyond the scope of this communication, and only selected references are included, emphasizing new data since 1989. Finally, although cost considerations are important, there were insufficient data to present formal cost-effectiveness analyses. However, cost was considered in general terms for the recommendations.

The Committee membership consisted of acknowledged experts in AECG, general cardiologists, cardiologists with expertise in arrhythmias and pacing, 1 family practitioner, and 1 general internist. Both the academic and private practice sectors are represented. No member reported a conflict of interest bearing on committee participation. The guidelines will be considered current unless the Task Force publishes revisions or a withdrawal.

II. AECG EQUIPMENT

Since the introduction of portable devices to record the ECG in 1957 by Dr Norman Holter, there have been major advances in recording and playback methodologies. The widespread and inexpensive availability of personal computers and workstations has allowed for the development of extremely sophisticated and automated signal processing algorithms. Current AECG equipment provides for the detection and analysis of arrhythmias and ST-segment deviation as well as more sophisticated analyses of R-R intervals, QRS-T morphology including late potentials, Q-T dispersion, and T-wave alternans.

There are 2 categories of AECG recorders. Continuous recorders, typically used for 24 to 48 hours, investigate symptoms or ECG events that are likely to occur within that time frame. Intermittent recorders may be used for long periods of time (weeks to months) to provide briefer, intermittent recordings to investigate events that occur infrequently. Two basic types of intermittent recorders have slightly different utility. A loop recorder, which is worn continuously, may be particularly useful if symptoms are quite brief or if symptoms include only very brief incapacitation such that the patient can still activate the recorder immediately afterward and record the stored ECG. It is sometimes possible for a family member to activate the recorder if the patient actually loses consciousness. However, even a loop recorder with a long memory may not be useful if loss of consciousness includes prolonged disorientation on awakening that would prohibit the patient from activating the device. Newer loop recorders can be implanted under the skin for long-term recordings, which may be particularly useful for patients with infrequent symptoms. Another type of intermittent recorder is the event recorder, which is attached by the patient and activated after the onset of symptoms. It is not useful for arrhythmias that cause serious symptoms such as loss of consciousness or near loss of consciousness because these devices take time to find, apply, and activate. They are more useful for infrequent, less serious but sustained symptoms that are not incapacitating. For this review, equipment will be described for the recorders first and then for the playback systems. Only selected technical details are presented in this review. A more complete description of the technical requirements for AECG equipment can be found in the 1994 American National Standard developed by the Association for the Advancement of Medical Instrumentation (3).

A. Continuous Recorders

Conventional AECG recorders typically are small, lightweight devices (8 to 16 oz) that record 2 or 3 bipolar leads. They contain a quartz digital clock and a separate recording track to keep time. They are generally powered by a 9-V disposable alkaline battery and a calibration signal automatically inserted when the device is energized. A patient-activated event marker is conveniently placed on the device for the patient to indicate the presence of symptoms or to note an event. The frequency response of the recording and playback system should be reasonably flat, from 0.67 to 40 Hz.

The conventional format for recording has been magnetic cassette-type tape. Tape speed typically is 1 mm/s, and speed is kept constant by an optical speed sensor on the flywheel and a crystal controlled phase locked loop. This technology has been the standard for many years and has the advantage of being inexpensive and providing a permanent record of all electrical activity throughout the recording period. This format allows for playback and interrogation of the entire recording period (so-called "full disclosure"). It is adequate to detect abnormalities of rhythm or conduction, but it may be limited for recording low-frequency signals such as the ST segment. An inadequate low-frequency response or marked phase shift from the higher-frequency QRS signal can lead to artifactual distortion of the ST segment that may be incorrectly interpreted as ischemic, particularly using some amplitude-modulated (AM) systems (4). More recent AM systems have been designed with improved low-frequency recording and playback characteristics and have been documented to record accurately ST-segment deviation (5) and even T-wave alternans (6). The frequency-modulated (FM) systems avoid this bias because they can be designed with an ideal low-frequency response without a low-frequency "boost" and are less prone to phase shift (4). However, FM systems are not as widely available, are more costly, and are subject to more baseline "noise" than AM systems (4). Regardless of whether AM or FM recording techniques are used, the tape itself may stretch and consequently distort the electrical signal.

Rapidly evolving technologies now allow for direct recording of the ECG signal in a digital format by use of solid-state recording devices. The direct digital recording avoids all of the biases introduced by the mechanical features of tape recording devices and the problems associated with recording data in an analog format, which requires analog-to-digital conversion before analysis. ECG signals can be recorded at up to 1000 samples per second, which allows for the extremely accurate reproduction of the ECG signal necessary to perform signal averaging and other sophisticated ECG analyses. These solid-state recordings can be analyzed immediately and rapidly, and some recorders are now equipped with microprocessors that can provide "on-line analysis" of the QRS-T complex as it is acquired. If specific abnormalities are detected, such as ST-segment deviation, immediate feedback can be provided to the patient. The solid-state format also provides for ready electronic data transfer to a central analysis facility. Limitations of this technology include its expense, the limited storage capacity of digital data, and, in the case of on-line analysis, reliance on a computer algorithm to identify abnormalities accurately. A 24-hour recording includes approximately 100,000 QRS-T complexes and requires almost 20 megabytes of storage per channel. Problems of storage capacity have been approached with 2 techniques of "compressing" the recorded data: 1) "lossy" compression of QRS-T complexes with very high compression ratios and 2) "loss-less" compression combined with enhanced storage capacity. Much of the reluctance of physicians to use solid-state methodologies in the past has been due to lack of faith in the "lossy" compression methods because their accuracy is dependent on the ability of the microprocessor to distinguish important physiological abnormalities from artifact or a wandering baseline. Confirmation of the "decisions" by the microprocessor cannot be made because the primary data are not recorded in their entirety and cannot be retrieved nor reproduced without error (ie, non-full disclosure). Because it is essential that representative ECG complexes from all ischemic episodes or arrhythmias be confirmed by an experienced technician or physician, the lack of full disclosure may limit the reliability of the compressed storage method (7,8). Accuracy of the on-line interpretations also may be different for ischemia versus arrhythmia analyses (9). The clinical usage of "lossy" compressed recordings and on-line interpretations is limited. There are insufficient data comparing analyses based on full-disclosure recordings versus "lossy" compressed recordings that are interpreted on-line to determine the suitability of the high-ratio compression methodologies for widespread use.

The newer technologies of enhanced storage capacity allow for all of the technical advantages of solid-state recording and now allow "full disclosure" by using loss-less compression methods, which reduce the amount of storage required by a factor of 3 to 5 but still permit reconstruction of the waveform with no loss of information. The storage methodologies available include a flash memory card or a portable hard drive. Flash cards are very small, compact storage devices, which are about the size of a credit card and have the capacity to store 20 to 40 megabytes of data. The flash cards are removed from the recording device once the recording is completed and are inserted into a separate device where the data can be played back and analyzed or the data can be transmitted electronically to another location for analysis. Miniature hard drives utilize the same technology used in laptop computers and can store more than 100 megabytes of data. Unlike flash cards, the hard drives are not removed from the recorder but the data are downloaded to another storage device or electronically transferred.

B. Methods of Electrode Preparation and Lead Systems Used

The skin over the electrode area should be shaved, if necessary, gently abraded with emery tape, and thoroughly cleansed with an alcohol swab. To optimize recordings of the low-frequency ST segment, skin resistance may be measured with an impedance meter once the electrodes are applied. The measured resistance between electrodes should be $\leq$5 kΩ and preferably $\leq$2 kΩ.

Most recorders utilize 5 or 7 electrodes attached to the chest, which record the signal from 2 or 3 bipolar leads onto 2 or 3 channels. The third channel may be dedicated to recording pacemaker activity. A variety of bipolar lead configurations are used, the most common being a chest modified V_5 (CM_5), a chest modified V_3 (CM_3), and a modified inferior lead. If a patient undergoing AECG monitoring for ischemia has had an exercise test with ischemic changes, the AECG lead configuration should mimic those leads with the greatest ST-segment change during exercise. A test cable can be connected from the recorder to a standard ECG machine when the device is attached to the patient to verify amplitude, rate, and morphology of waveforms that will be recorded. Once the leads have been applied, before the patient leaves the laboratory, supervised recordings should be made with the patient in the standing, sitting, right and left lateral decubitus, and supine positions to ensure that artifactual ST-segment deviation does not occur.

In a recent study of simultaneous recordings of a 3-lead AECG and a conventional 12-lead ECG recording during an exercise treadmill test (10), CM_5 was the single lead with the highest sensitivity (89%) in detecting myocardial ischemia. The addition of CM_3 to CM_5 increased sensitivity to 91%, and the addition of an inferior lead to CM_5 increased the sensitivity to 94%, particularly improving detection of isolated inferior ischemia. The combination of all 3 AECG leads had a sensitivity of 96%, only 2% more than the best combination of 2 leads (CM_5 plus an inferior lead). Thus, routine identification of ischemic ST-segment deviation may only require 2 leads. Use of an inverse Nehb J lead, in which the positive electrode is placed on the left posterior axillary line, may enhance sensitivity to detect ischemia (11). Some new AECG monitor systems can record a true 12-lead ECG, whereas others derive a 12-lead ECG from 3-lead data through the use of a mathematical transform.

C. Variability of Arrhythmias and Ischemia and Optimal Duration of Recording

The day-to-day variability of the frequency of arrhythmias or ST-segment deviation is substantial (12–22). Most arrhythmia studies use a 24-hour recording period, although yield may be increased slightly with longer recordings or repeated recordings (23). Major reductions in arrhythmia frequency are necessary to prove a treatment effect. To ensure that a change is due to the treatment effect and not to spontaneous variability, a 65% to 95% reduction in arrhythmia frequency after an intervention is necessary (12).

The variability of the frequency, duration, and depth of ischemic ST-segment depression is also marked (24–28). Because most ischemic episodes during routine daily activities are related to increases in heart rate (29), the variability of ischemia between recording sessions may be due to day-to-day variability of physical or emotional activities (30). It is therefore essential to encourage similar daily activities at the time of AECG recording. The optimal and most feasible duration of recording to detect and quantify ischemia episodes is probably 48 hours (25). Most patients are quite comfortable wearing the recorder for 48 hours.

The variability of AECG ischemia strongly influences clinical trial design to identify the efficacy of a therapeutic intervention (26,28). For example, a 75% reduction in the number of ischemic episodes would be necessary to achieve statistical significance within an individual patient monitored for 48 hours before and after an intervention (28). Families of relations have been calculated for sample size estimates and statistical power for intervention trials (26,28).

D. Intermittent Recorders

These devices, which are also termed "event recorders," include those that record and store only a brief period of ECG activity when activated by the patient in response to symptoms and those that record the ECG in a continuous manner but store only a brief period of ECG recording (eg, 5 to 300 seconds) in memory when the event marker is activated by the patient at the time of a symptom (loop recorder). These devices often use solid-state memory and can transfer data readily over conventional telephone lines. These recorders can be used for prolonged periods of time (many weeks) to identify infrequently occurring arrhythmias or symptoms that would not be detected with a conventional 24-hour AECG recording. Newer loop recorders can be implanted for longer-term monitoring. An event recorder relies on rapid placement of electrodes, such as paddles connected to the recorder or a wrist bracelet, to record the ECG at the time of the symptom. Loop recorders use continuously worn electrodes. The recorded signal can be transmitted to a receiving station or may be saved in memory and transferred at a later time to a central analysis facility.

Intermittent recorders have the advantage of being small and light, easy to use, and can be programmed to record many short episodes during an extended period of time (in most cases up to 30 days). Single-, 2-, 3-, and reconstructed 12-lead formats are available.

E. AECG Recording Capabilities Associated With Pacemakers and ICDs

Most current ICDs continually monitor the intracardiac electrogram and store in memory a summary of tachycardia and bradycardia episodes as well as a brief electrogram meeting prespecified criteria preceding and following each therapeutic discharge.

Intracardiac electrograms may be recorded from a variety of leads and electrode pairs, depending on the equipment used (31). These devices can store only a limited number or duration of recordings (32). Many pacemakers have the capability to calculate heart rate for a selected period of time. See Section VII for further description of recording capabilities of current pacemakers and ICD devices.

F. Playback Systems and Methods of Analysis

Most current playback systems use generic computer hardware platforms running proprietary software protocols for data analysis and report generation. Facsimile, modem, network, and Internet integration allow for rapid distribution of AECG data and analyses throughout a healthcare system. Signals recorded in analog format (ie, magnetic tape) are digitized at either a rate of 128 or 256 samples per second for subsequent analysis. The clock track on the tape can compensate for variations in tape speed by a phase lock loop circuit. The resolution is usually at least 8 bits and the sampling rate is nominally 128 samples per second. The signal amplitude can be adjusted by the technician on the basis of the calibration signal recorded automatically at the initiation of each recording. Tape playback and scanning options include rapid playback with either superimposition (up to 1000 times real time) or page-type displays.

It is critical that each classification of arrhythmia morphology and each ischemic episode be reviewed by an experienced technician or physician to ensure accurate diagnosis because AECG recordings during routine daily activities frequently have periods of motion artifact or baseline wander that may distort the ST-segment or QRS morphology. The presence of artifacts can be minimized by good skin preparation, use of high-quality ECG electrodes and monitoring leads, lead placement secured by loops of the electrode cable, and awareness of ST-segment deviation caused by changes in body position. Although the identification of ischemia made by the computer algorithm alone may be helpful, the interpretations are frequently found to be incorrect when assessed by an experienced observer. Overreading is essential. In an experienced laboratory, the interobserver and intraobserver agreement for the presence and characterizations of ischemic episodes should be high. Preliminary studies suggest that there may be differences in interpretation of ST-segment activity among different laboratories. Much more investigation concerning the uniformity of interpretations of ischemic ST-segment deviation is necessary before widespread application of ischemia monitoring is feasible and reliable. Interobserver and intraobserver agreement is excellent for categorization of arrhythmias, but discrepancies of 10% to 25% in total ventricular arrhythmia counts for the same recording may occur if frequent or complex arrhythmias are present (33).

1. Arrhythmia Analysis. Each beat is classified as normal, ventricular ectopic, supraventricular ectopic, paced, other, or unknown, and a template for each type of abnormality is created. The computer tabulates the number of ectopic beats in each template. Summary data describing the frequency of atrial and ventricular arrhythmias are displayed typically in both tabular and graphical formats. The system automatically stores strips of significant arrhythmia events detected as well as patient events and entered diary notation times.

2. Ischemia Analysis. The QRS-T morphology must be carefully scrutinized to ensure that it is suitable for interpretation to identify ischemic changes (34). The rhythm should be normal sinus rhythm. The baseline ST segment should have $\leq$0.1 mV deviation, and the morphology ideally should be gently upsloping with an upright T wave. Although an ST segment that is flat or associated with an inverted T wave may still be interpretable, downsloping or scooped ST-segment morphology should be avoided. The R-wave height of the monitored lead should be $\geq$10 mm. Patients whose 12-lead ECG demonstrates left ventricular (LV) hypertrophy, preexcitation, left bundle-branch block, or nonspecific intraventricular conduction delay $\geq$0.10 second are not suitable for detecting ischemia by AECG. The lead selected for AECG ischemia monitoring should not have a Q wave $\geq$0.04 second or marked baseline ST-segment distortion. ST-segment deviation in the presence of right bundle-branch block may be interpretable, especially in the left precordial leads. Medications such as digoxin and some antidepressants distort the ST segment and preclude accurate interpretation of ST-segment deviation. ST-segment deviation is usually tracked by the use of cursors at the P-R segment to define the isoelectric reference point and at the J-point and/or 60 to 80 ms beyond the J-point to identify the presence of ST-segment deviation. Ischemia is diagnosed by a sequence of ECG changes that include flat or downsloping ST-segment depression $\geq$0.1 mV, with a gradual onset and offset that lasts for a minimum period of 1 minute. Each episode of transient ischemia must be separated by a minimum duration of at least 1 minute, during which the ST segment returns back to baseline ($1 \times 1 \times 1$ rule) (35), although many investigators prefer a duration of at least 5 minutes between episodes. We recommend a 5-minute interval between episodes because the end of one episode and the onset of another episode will take longer than 1 minute to be physiologically distinct.

During superimposition scanning, the system displays the normal complexes used for ST-segment measurement. The magnitude of ST-segment deviation and the slope of the ST segment typically is identified and presented as part of a 24-hour trend. Episodes of ST-segment deviation are characterized by identification of an onset and offset time, magnitude of deviation, and heart rate before and during the episode. Representative ECG strips at the time of ST-segment deviation in real time may be provided in the report format. Ischemic episodes are displayed in a summary table. Miniaturized full-disclosure display can be printed for all or part of the 24-hour recording.

G. Emerging Technologies

There are a number of important new technologies that hold promise for the future. During the playback of the recorded ECG signal and the analysis process, there are electrophysiological variables that can be measured other than arrhythmias and ST-segment deviation. These include T-wave alternans (6), Q-T interval dispersion (36), and signal-averaged analysis (37). For these analyses, high-resolution data are necessary, which may require data acquisition at rates up to 1000 samples per second (38).

III. HEART RATE VARIABILITY

A. General Considerations

Analysis of R-R variability has been available for several years and is generally referred to as HRV. The balance between the cardiac sympathetic and vagal efferent activity is evidenced in the beat-to-beat changes of the cardiac cycle. Determination of this HRV is often performed to assess patients with cardiovascular disease. Several systems are commercially available to analyze spectral and temporal parameters of HRV.

Analysis of the beat-to-beat oscillation in the R-R interval is generally performed by 2 methods. Spectral analysis provides an assessment of the vagal modulation of the R-R interval. Spectral analysis is most commonly accomplished by fast Fourier transformation to separate R-R intervals into characteristic high (0.15 to 0.40 Hz), low (0.04 to 0.15 Hz), very low (0.0033 to 0.04 Hz), and ultra low (up to 0.0033 Hz) frequency bands. Spectral measures are collected over different time intervals (approximately 2.5 to 15 minutes), depending on the frequency being analyzed (39). Parasympathetic tone is primarily reflected in the high-frequency (HF) component of spectral analysis (40–42). The low-frequency (LF) component is influenced by both the sympathetic and parasympathetic nervous systems (43,44). The LF/HF ratio is considered a measure of sympathovagal balance and reflects sympathetic modulations (45).

Table 1. Components of HRV

Spectral Component	Time-Domain Correlates	Normal Measures for 24 Hours
HF	rMSSD	<15 h
	pNN50	<0.75%
LF	SDNN index	<30 ms
VLF	SDNN index	<30 ms
ULF	SDNN	<50 ms
	SDANN	<40 ms
	HRV index	. . .
TP	SDNN	<50 ms
	HRV index	. . .

VLF indicates very-low frequency; ULF, ultra-low frequency; TP, total power; SDNN index, mean of standard deviation of R-Rs; HRV index, integral of the total number of normal R-Rs divided by the maximum of the density distribution (an expression of overall 24-hour HRV).
From References 54, 56, and 57.

Nonspectral or time domain parameters involve computing indexes that are not directly related to specific cycle lengths. This method offers a simple means of defining patients with decreased variability in the mean and standard deviations of R-R intervals. Time domain parameters analyzed include mean R-R, the mean coupling interval between all normal beats; SDANN, standard deviation of the averaged normal sinus R-R intervals for all 5-minute segments of the entire recording; SDNN, standard deviation of all normal sinus R-R intervals; SDNN index, mean of the standard deviations of all normal R-R intervals for all 5-minute segments of the entire recording; pNN50, the percentage of adjacent R-R intervals that varied by more than 50 ms; and rMSSD, the root mean square of the difference between the coupling intervals of adjacent R-R intervals. Another time domain measure of HRV is the triangular index, a geometric measure obtained by dividing the total number of all R-R intervals by the height of the histogram of all R-R intervals measured on a discrete scale with bins of 7.8 ms. The height of the histogram equals the total number of intervals found in the modal bin. These 2 analytical techniques are complementary in that they are different mathematical analyses of the same phenomenon. Therefore certain time and frequency domain variables correlate strongly with each other (Table 1).

B. Technical Requirements for Recording and Analysis

1. Duration of Recording. Depending on the specific indication for analysis of HRV, either long-term (24-hour) or short-term (5-minute) recordings are made. HRV increases with increased periods of observation, and it is important to distinguish ranges on the basis of duration of recording. The Task Force of the European Society of Cardiology (ESC) and the North American Society of Pacing and Electrophysiology (NASPE) (45) provided frequency ranges for each parameter of HRV obtained during short- and long-term recordings (Table 2).

Frequency domain methods are preferable for short-term

Table 2. Selected Frequency Domain Measures of HRV

Variable	Units	Description	Frequency Range
Analysis of Short-Term Recordings (5 min)			
5-min total power	ms^2	The variance of NN intervals over the temporal segment	$\approx\leq$0.4 Hz
VLF	ms^2	Power in the VLF range	$\leq$0.04 Hz
LF	ms^2	Power in the LF range	0.04–0.15 Hz
LF norm	nu	LF power in normalized units LF/(total power−VLF)×100	
HF	ms^2	Power in the HF range	0.15–0.4 Hz
HF norm	nu	HF power in normalized units HF/(total power−VLF)×100	
LF/HF		Ratio LF [ms^2]/HF [ms^2]	
Analysis of Entire 24 Hours			
Total power	ms^2	Variance of all NN intervals	$\approx\leq$0.4 Hz
ULF	ms^2	Power in the ULF range	$\leq$0.003 Hz
VLF	ms^2	Power in the VLF range	0.003–0.04 Hz
LF	ms^2	Power in the LF range	0.04–0.15 Hz
HF	ms^2	Power in the HF range	0.15–0.4 Hz
α		Slope of the linear interpolation of the spectrum in a log-log scale	$\approx\leq$0.04 Hz

VLF indicates very-low frequency; ULF, ultra-low frequency.

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recordings. Recording should last at least 10 times the duration of the wavelength of the lowest frequency under investigation. For example, recordings should be approximately 1 minute for short-term evaluation of the HF and 2 minutes for evaluation of LF. The authors of the ESC/NASPE Task Force recommend standardization at 5-minute recordings for short-term analysis of HRV (45), which is endorsed by this Task Force.

2. Artifact and Arrhythmias. No matter whether short- or long-term data are analyzed, the analysis of HRV depends on the integrity of the input data. Most systems obtain computer-digitized ECG signals. The R-R intervals are derived either on-line or off-line. The rate of digitization varies from system to system. Many commercial AECG systems have a digitization rate of 128 Hz, which is not optimal for some experimental short-term recordings but is useful for long-term recordings in adults (46).

To optimize the temporal accuracy of R-wave peak identification, especially when the digitization rate is below 250 Hz, a template matching or interpolation algorithm should be used (45,47,48). Similarly, artifact or noise in the ECG signal can create errors in R-wave timing. Several approaches to this problem have been taken and include smoothing or filtering the digitized data (47–49). Although these methods help to reduce inaccuracies created by recorded noise, careful patient preparation and maintenance of recording equipment is very important to eliminate noise before it occurs.

If analog recording devices are used, rates of digitization are not a factor, but noise and other errors in R-wave timing remain important. AECG systems that record on magnetic tape for off-line processing can introduce errors related to tape stretch. The ESC/NASPE Task Force (45) provided guidelines for the routine evaluation of recording systems through simulated calibration signals with known characteristics.

A problem with ambulatory recordings for the determination of HRV is motion-related artifact. Missing R waves or spuriously detected beats can lead to large deviations in the R-R interval. Manual overview can usually detect these errors but can be tedious. Distribution-based artifact detection algorithms are best used to assist the visual approach (50–52).

An additional factor that introduces difficulties in the analysis of HRV is the presence of cardiac arrhythmias. HRV analysis is not possible with persistent atrial fibrillation. Intermittent abnormal heartbeats can distort the normal R-R intervals. Although HRV may be useful in predicting or characterizing abnormal rhythms, the presence of abnormal heartbeats must be processed in some way to avoid errors in the assessment of HRV. Two methods for handling abnormal heartbeats include interpolation of occasional abnormal beats (53) and limiting analysis to segments that are free of abnormal beats. Both methods have limitations, and application of both may be appropriate. However, in publications in which assumptions have been made, they must be stated clearly.

C. Day-to-Day Variability

In normal subjects, Kleiger et al (54) found 24-hour ambulatory recordings to reveal large circadian differences in the R-R interval, LF power, HF power, and LF/HF ratio.

Kleiger et al also described 3- to 4-fold changes in R-R variability between 5-minute segments of the same hour. However, the mean values for the LF and HF power were almost identical from day to day. Power spectral measures of R-R variability averaged across a 24-hour period were also essentially constant. Large differences were seen among the 5-minute intervals during the day (55). HRV in the normal population is affected by age and sex. Recent data have shown that SDNN index, rMSSD, and pNN50 in healthy people over the age of 60 years may actually fall below levels that have been associated with increased mortality rates. Younger women have less HRV than their age-matched counterparts, but these differences disappear by age 50 years. In subjects with coronary artery disease (CAD), Bigger et al (56) found no significant differences between 2 consecutive 24-hour recordings. Recommendations for the use of HRV analysis follow in Section V. K.

IV. ASSESSMENT OF SYMPTOMS THAT MAY BE RELATED TO DISTURBANCES OF HEART RHYTHM

A. Symptomatic Arrhythmias

One of the primary and most widely accepted uses of AECG is the determination of the relation of a patient's transient symptoms to cardiac arrhythmias (12,58,59). Some symptoms are commonly caused by transient arrhythmias: syncope, near syncope, dizziness, and palpitation. However, other transient symptoms are less commonly related to rhythm abnormalities: shortness of breath, chest discomfort, weakness, diaphoresis, or neurological symptoms such as a transient ischemic attack. Vertigo, which is usually not caused by an arrhythmia, must be distinguished from dizziness. More permanent symptoms such as those seen with a cerebrovascular accident can be associated less commonly with an arrhythmia, such as embolic events that occur with atrial fibrillation. A careful history is essential to determine if AECG is indicated.

If arrhythmias are thought to be causative in patients with transient symptoms, the crucial information needed is the recording of an ECG during the precise time that the symptom is occurring. With such a recording, one can determine if the symptom is related to an arrhythmia. Four outcomes are possible with AECG recordings. First, typical symptoms may occur with the simultaneous documentation of a cardiac arrhythmia capable of producing such symptoms. Such a finding is most useful and may help to direct therapy. Second, symptoms may occur while an AECG recording shows no arrhythmias. This finding is also useful because it demonstrates that the symptoms are not related to rhythm disturbances. Third, a patient may remain asymptomatic during cardiac arrhythmias documented on the recording. This finding has equivocal value. The arrhythmia may be useful as a clue to a more severe arrhythmia that actually causes symptoms. For example, nonsustained ventricular tachycardia recorded while the patient is asymptomatic may be a clue that the patient has a more serious ventricular tachycardia at other times, causing near syncope or syncope. Likewise, asymptomatic bradycardia may be a clue that symptoms may occur when the heart rate is even slower. However, asymptomatic arrhythmias are common, even in the general population without heart disease (60–63). Therefore the recorded arrhythmia may or may not be relevant to the symptoms. Fourth, the patient may remain asymptomatic during the AECG recording, and no arrhythmias are documented. This finding is not useful.

It is imperative that the physician and patient be persistent in attempting to record the cardiac rhythm simultaneous with transient symptoms. This may require multiple 24- or 48-hour AECG recordings or event recorders (23,64–69), especially for infrequent symptoms. The rhythm must be recorded during and not after the symptoms have occurred. The utility of AECG will be determined by the frequency, severity, duration, and conditions under which the symptoms occur. Less frequent arrhythmias will require more attempts to record. Significant cardiac arrhythmias are more likely to occur in patients with serious heart disease, so it is more likely that transient symptoms can be correlated to arrhythmias in the severely ill cardiac patient. It is essential that a complete and detailed history and physical examination be taken, and it is often necessary to perform blood work, a chest radiograph, a 12-lead ECG, and/or an echocardiogram as a part of the initial evaluation. Careful clinical judgment must be exercised. Causes of symptoms other than arrhythmias must be considered and appropriate additional studies obtained. Under some circumstances, particularly in patients with exertional symptoms, an exercise test might give a higher yield for correlation between symptoms and cardiac rhythm. Electrophysiological studies and tilt-table testing also may be considered in certain circumstances. If symptoms are severe, monitoring may need to be performed in-hospital continuously on telemetry. However, the sensitivity and specificity of automatic rhythm monitoring alarms may be inferior to analysis of AECGs.

B. Selection of Recording Technique

The characteristics of the patient's symptoms will often determine the choice of recording techniques. Selection of technique must be individualized. Specific indications for the different types of recorders should not be defined here because such detail would place undue limits on clinical judgment. Continuous AECG recording may be particularly useful in patients who have complete loss of consciousness and would not be able to attach or activate an event recorder. Continuous AECG recording is particularly useful if symptoms occur daily or almost daily, although most patients do not have episodic symptoms this frequently. Such a recording should include a patient diary of symptoms and activities and the use of an event marker. The event marker is activated whenever the patient has typical symptoms, simplifying the identification of the point in time during the recording when symptoms occurred. Usually

Table 3. Yield of AECG Monitoring for Syncope*

Author (Reference)	No. of Patients	Symptoms at Presentation	Symptoms During Monitoring, n (%)		No Symptoms During Monitoring, n (%)	
			Arrhythmia	No Arrhythmia	Arrhythmia	No Arrhythmia
Bass et al (23)	95	Syncope	1 (1)	19 (20)	2 (26)	50 (53)
Kapoor et al (59)	249	Syncope	15 (6)	55 (22)	42 (17)	137 (55)
Gibson and Heitzman (66)	1512	Syncope, near syncope, dizziness	30 (2)	225 (15)	15 (10)	1101 (73)
Kala et al (67)	107	Syncope, dizziness	8 (7)	8 (7)	17 (16)	74 (69)
Zeldis et al (68)	74	Syncope, dizziness	10 (14)	18 (24)	. . .	. . .
Clark et al (69)	98	Syncope, dizziness	3 (3)	39 (39)	41 (41)	17 (17)
Boudoulas et al (78)	119	Syncope, dizziness	31 (26)	15 (13)	32 (27)	41 (34)
Jonas et al (79)	358	Syncope, dizziness	14 (4)	. . .	57 (16)	286 (80)
All studies†	2612		112 (4)	379 (15)	369 (14)	1706 (65)

*From Linzer et al (65), with permission.
†Totals do not add up to 100% because information was missing from 2 studies.

24-hour recordings are performed, although yield may be increased slightly with longer recordings or repeated recordings (23).

Many patients have symptoms occurring weekly or monthly, in which case a single continuous AECG recording probably will not be useful. An intermittent or event recorder (which is often capable of transtelephonic downloading) is more useful for infrequent symptoms (70–75).

Some rhythm recording devices are implanted surgically and include pacemakers, cardioverter-defibrillators, and newly developed ECG recorders (76,77). Their utility is limited by the need for an invasive procedure.

C. Specific Symptoms

Few studies have evaluated the sensitivity, specificity, positive and negative predictive values, and cost-effectiveness of the various recording techniques in patients with symptoms potentially related to cardiac arrhythmias. Only in the subset of patients with syncope are detailed data available.

1. Syncope. The diagnostic evaluation of syncope is determined by many clinical factors (59,64–67,69,76,78,79). Many studies combine evaluation of syncope with near syncope and/or dizziness (Table 3) and use different arrhythmia end points to define a "positive" study (66–69,78,79). Unfortunately, the yield of AECG monitoring is relatively low. The majority of such patients have no symptoms during ambulatory recording, and further evaluation is necessary. However, because of the severity of the symptoms, such testing is usually warranted. Nevertheless, the rhythm during asymptomatic periods may be useful. For example, a patient may have syncope only during severe bradycardia. An ambulatory ECG that shows intermittent episodes of asymptomatic bradycardia may suggest the diagnosis and prompt further evaluation. One study (23) evaluated the utility of repeated 24-hour ambulatory recording on 3 separate occasions. The first 24-hour recording exhibited a major abnormality in 15% of the patients. The additive yield was 11% on the second and 4.2% on the third sequential recordings. Factors that identified a useful recording were advanced age, male sex, history of heart disease, and initial rhythm other than normal sinus. When continuous AECG monitoring is not useful, intermittent recorders (both patient-applied and loop) add incremental value to continuous recording. Furthermore, the memory capability of previously implanted pacemakers and ICDs can add diagnostic value.

Insufficient data exist regarding near syncope or dizziness alone to estimate the sensitivity and specificity of AECG recording for these conditions (12).

2. Palpitation. The yield of ambulatory monitoring that captures an episode of palpitation (Table 4) is higher than the yield for patients with syncope, probably because the frequency of occurrence of palpitation is higher than the occurrence of syncopal episodes, though findings are likely to be more variable in patients with palpitation (58,71). Palpitation accounts for 31% to 43% of indications for outpatient AECG monitoring (68,69). Furthermore, in patients with preexisting palpitation, asymptomatic episodes of supraventricular arrhythmias are more common than symptomatic episodes (80,81).

3. Other Symptoms. Other cardiac symptoms such as intermittent shortness of breath, unexplained chest pain, episodic fatigue, or diaphoresis might be related to cardiac arrhythmias. AECG monitoring may be indicated for these symptoms. Other conditions such as stroke or transient ischemic attack may be associated with cardiac arrhythmias, which could be detected by AECG (79,82).

Indications for AECG to Assess Symptoms Possibly Related to Rhythm Disturbances

Class I

1. **Patients with unexplained syncope, near syncope, or episodic dizziness in whom the cause is not obvious**

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Table 4. Yield of AECG Monitoring for Palpitation

Author (Reference)	No. of Patients	Symptoms at Presentation	Type of Monitoring	Symptoms During Monitoring, n (%)		No Symptoms During Monitoring, n (%)		
				Arrhythmia	No Arrhythmia	Arrhythmia	No Arrhythmia	Unknown§
Diamond et al (58)	85	Palpitation	24-h	37 (44)	17 (20)	3 (4)	28 (33)	
Shimada et al (74)	184	Palpitation, chest pain, other	Event recorder	42 (23)	†	*	*	142 (77)
Assayag et al (83)	1091	Palpitation (85%)	Event recorder	464 (43)	†	*	*	627 (57)
Kinlay et al (71)	43	Palpitation	48-h	0 (0)‡	15 (35)	§	§	28 (65)
			Event recorder‖	8 (19)‡	21 (49)	*	*	14 (33)

*Recording only performed during symptoms.
†Not specified how many patients transmitted an ECG.
‡"Clinically significant" arrhythmia.
§Not specified for asymptomatic patients.
‖n = 29 transmissions.

2. Patients with unexplained recurrent palpitation

Class IIb

1. **Patients with episodic shortness of breath, chest pain, or fatigue that is not otherwise explained**
2. **Patients with neurological events when transient atrial fibrillation or flutter is suspected**
3. **Patients with symptoms such as syncope, near syncope, episodic dizziness, or palpitation in whom a probable cause other than an arrhythmia has been identified but in whom symptoms persist despite treatment of this other cause**

Class III

1. **Patients with symptoms such as syncope, near syncope, episodic dizziness, or palpitation in whom other causes have been identified by history, physical examination, or laboratory tests**
2. **Patients with cerebrovascular accidents, without other evidence of arrhythmia**

V. ASSESSMENT OF RISK IN PATIENTS WITHOUT SYMPTOMS OF ARRHYTHMIAS

AECG monitoring has been increasingly used to identify patients, both with and without symptoms, at risk for arrhythmias. The selection of patients for different types of devices and duration of recording is similar to that previously discussed in Sections II and III.

A. After Myocardial Infarction

Myocardial infarction (MI) survivors are at an increased risk of sudden death, with the incidence highest in the first year after infarction (84,85). The major causes of sudden death are ventricular tachycardia and ventricular fibrillation. The risk of developing an arrhythmic event has declined with the increasing use of thrombolytic agents and coronary revascularization (86–88). Currently, the 1-year risk of developing a malignant arrhythmia in an MI survivor after hospital discharge is 5% or less (86,87,89–91). The goal in risk-stratifying patients is to identify a population of patients at high risk of developing an arrhythmic event and reduce such events with an intervention. Ideally, these patients would be identified by a test or combination of tests with a high sensitivity and a very high positive predictive accuracy, so that as few patients as possible are unnecessarily exposed to treatment.

AECG monitoring usually is performed over a 24-hour period before hospital discharge. Some studies suggest that 4 hours of AECG monitoring provides as much information as 24 hours (92,93). In many studies, AECG monitoring was performed at least 6 and often approximately 10 days after the acute MI (Table 5). Frequent premature ventricular contractions (PVCs) (eg, 10 per hour) and high-grade ventricular ectopy (eg, repetitive PVCs, multiform PVCs, ventricular tachycardia) after MI have been

Table 5. Sensitivity and Specificity of AECG for Predicting Arrhythmic Events After MI

Author (Reference)	No. of Patients	Criteria	Sensitivity, %	Specificity, %	PPV, %	NPV, %	End Points
Olson et al (174)	115	≥10 PVCs/h or multiform or pair or VT	25	79	12	90	Cardiac death
Kostis et al (96)	1640	≥10 PVCs	25	88	6	96	Sudden death
		≥10 PVCs/h or PVC pair or VT	43	75	8	96	
		≥10 PVCs/h or (PVC pair or VT) or multiform	67	61	8	97	
		≥10 PVCs/h and (PVC pair or VT) and multiform	16	94	11	96	
Mukharji et al (94)	533	≥10 PVCs/h	10	93	8	95	Sudden death
de Cock et al (98)	99	≥10 PVCs/h	44	83	52	78	Death or MI
		VT	26	100	100	75	
		SVT	41	97	86	80	
Farrell et al (89)	416	PVCs >10/h	54	82	16	82	Arrhythmic event
		Repetitive PVCs	54	81	15	97	
Richards et al (175)	358	Lown 3–5	82	40	6	98	Arrhythmic event
		Lown 3–5	75	76	16	98	Cardiac death
McClements and Adgey (86)	301	≥10 PVCs/h or repetitive	38	74	6	96	Arrhythmic event
Pedretti et al (100)	305	≥2 runs NSVT	42	91	25	96	Arrhythmic event
Hohnloser et al (87)	173	Lown 4	22	78	5	95	Arrhythmic event
El-Sherif et al (90)	1158	≥10 PVCs/h or VT	61	69	8	98	Arrhythmic event

NPV indicates negative predictive value; VT, ventricular tachycardia; SVT, supraventricular tachycardia; and NSVT, nonsustained ventricular tachycardia.

associated with a higher mortality rate among MI survivors (86,89–91,94–100). However, once patients have at least 6 PVCs per hour, the risk of an arrhythmic event does not increase with more frequent PVCs (101). The association between ventricular arrhythmias and adverse cardiac events has been demonstrated primarily in men (102,103).

The positive predictive value (PPV) of ventricular ectopy in most of these studies for an arrhythmic event has been low, ranging from 5% to 15%. The sensitivity of ventricular ectopy can be increased by combining it with decreased LV function. The PPV increases to 15% to 34% for an arrhythmic event if one combines AECG monitoring with an assessment of LV function (90,94,104,105).

Low values for high frequency measures of HRV (eg, rMSSD or pNN50) and baroreflex sensitivity (BRS) indicate decreased vagal modulation of R-R intervals (45,106). The specific mechanism by which HRV and BRS are reduced after MI remains unknown, but they decrease in patients early after MI (reaching a nadir after 2 to 3 weeks) and then increase back to normal levels by 6 to 12 months. Decreased HRV and BRS are independent predictors of increased mortality rates, including sudden death, in patients after MI (89,95,100,104,106–108) (Table 6). However, the predictive value of both HRV and BRS after MI, although statistically significant, is poor when used alone.

HRV may be determined from traditional 24-hour AECG monitoring or from shorter-duration monitoring. Although HRV measured from short-term recordings is depressed in patients at high risk, the predictive value increases with length of recording (109,110). Shorter-term recordings have lower specificity compared with 24-hour recordings in predicting patients at high risk, and there may be diurnal variation in HRV in some patients (110–112). The optimal time-domain parameters for analysis of risk are SDNN and HRV triangular index. High-risk patients have either an SDNN <70 ms, HRV triangular index <15, or BRS <3 ms/mm Hg. These patients may also be identified by examining power in the ultra-low-frequency range.

Although each of these tests has a predictive value independent of other well-established risk factors after MI, such as depressed LV function, their overall value is low. Combining these tests with each other and other clinical factors markedly improves their PPVs. As seen in Table 7, a variety of combinations has been used; however, it is not clear which is the best combination to use at the present time. The prognostic capability of these tests is reviewed in Table 8.

The combined use of AECG monitoring, LV function, and signal-averaged ECG has improved the positive predictive accuracy of risk stratification (sensitivity 80% and specificity 89%) (97). Also, Farrell et al (89) showed that reduced HRV and the presence of late potentials on signal-averaged ECG were a strong predictor of arrhythmic events after MI. These findings were present in only 10% of their patients, and even in this group the PPV was limited to 33%. The ATRAMI (Autonomic Tone and Reflexes

Table 6. Sensitivity and Specificity of HRV for Predicting Arrhythmic Events After MI

Author (Reference)	No. of Patients	Criteria	Sensitivity, %	Specificity, %	PPV, %	NPV, %	End Points
Kleiger et al (95)	808	HRV <50 ms*	34	88	34	88	All-cause death
Farrell et al (89)	416	HRV triangular index <20†	92	77	17	77	Arrhythmic event
		Mean R-R interval <750 ms	67	72	13	97	
Odemuyiwa et al (107)	385	HRV triangular index ≤30†	75	76			Arrhythmic event
Bigger et al (104)	715	ULF	28	93	41		All-cause death
		VLF	30	92	39		
		ULF+VLF	20	96	48		
Pedretti et al (100)	294	HRV triangular index ≤29†	89	68	15	99	Arrhythmic event
La Rovere et al (106)	1170	HRV <70 ms*	39	85	10	97	Arrhythmic event† and cardiac death
	1182	BRS <3.0 ms/mm Hg	35	86	10	97	Arrhythmic event‡ and cardiac death

NPV indicates negative predictive value; ULF, ultra-low-frequency power; and VLF, very-low-frequency power.
*HRV calculated using SDNN (standard deviation of all NN intervals).
†Total number of all NN intervals divided by the height of the histogram of all NN intervals measured on a discrete scale with bins of 7.8125 ms (1/128 seconds).
‡Arrhythmic event defined as nonfatal cardiac arrest caused by documented ventricular fibrillation.

after Myocardial Infarction) study also examined the practice of combining multiple markers of HRV. It showed that the presence of both a reduced HRV and reduced BRS increased a patient's relative risk of cardiac events 7-fold, but these 2 findings were present in only 5% of the patients (106). Adding more clinical findings (eg, ejection fraction) and demographic features (eg, age) further improves the ability to identify high-risk subgroups, but these patients represent very small proportions of the population (106). AECG is not needed in asymptomatic post-MI patients who have an ejection fraction of ≥40% (100) because malignant arrhythmias occur infrequently in such patients.

Long-term survivors of MI with reduced LV function remain at increased risk of dying from a cardiovascular event. However, the primary reason for patients to undergo AECG monitoring is to identify those with a poorer prognosis and ultimately to improve outcomes through active treatment. Recently, the Multicenter Automatic Defibrillator Implantation Trial (MADIT) showed that ICD therapy reduces mortality rates by approximately 50% in MI survivors who had a reduced LV ejection fraction (≤35%), who had at least 1 asymptomatic nonsustained ventricular arrhythmia, and in whom ventricular fibrillation or sustained ventricular tachycardia was reproducibly induced during electrophysiological testing and not suppressed by use of intravenous procainamide (113). Unfortunately, the study does not provide data on how many patients after MI had this combination of findings nor how many were identified as having asymptomatic ventricular arrhythmias detected only by AECG.

Similarly, a recent meta-analysis examined whether amiodarone prevented sudden death in a series of randomized controlled trials (114). Amiodarone reduced the incidence of sudden death, cardiac death, and total mortality rates in these trials. However, the patient populations were heterogeneous, and only two thirds of the trials required ventricular ectopy for study entry. In addition, survival for patients who received amiodarone was only different from the usual and active care groups; there was no significant difference when compared with placebo (ie, the alternative treatment may have been harmful, and this could have artificially increased the effect of amiodarone). Thus the role of AECG in identifying this population remains unanswered.

B. Congestive Heart Failure

Patients with congestive heart failure (CHF), whether caused by an ischemic cardiomyopathy or an idiopathic dilated cardiomyopathy, often have complex ventricular ectopy and a high mortality rate (115,116). There were conflicting findings in a series of small studies, with some suggesting a relation between ventricular arrhythmias and death (117–119) and others finding no such relation (115,116,120). Several more recent studies with larger populations have found that ventricular arrhythmias (eg, ventricular tachycardia, nonsustained ventricular tachycardia) are sensitive but not specific markers of death (121,122) and sudden death (122) (Table 9). Despite identifying a population with an increased relative risk of an adverse event, these tests are either not sensitive or have low PPVs.

HRV is decreased in patients with CHF (123,124). This decrease is improved with the use of angiotensin-converting enzyme inhibitor treatment (125,126). However, there are divergent results with respect to the association between HRV and arrhythmic events (127–132). In addition, there is no evidence that reducing the frequency of these arrhythmias or increasing the HRV with medications can significantly reduce the incidence of total death or sudden death in patients with severe CHF (114). Thus there is not sufficient evidence to support the routine use of AECG or HRV in patients with CHF or dilated cardiomyopathies.

Table 7. Sensitivity and Specificity of Combining Noninvasive Tests for Predicting Arrhythmic Events After MI

Author (Reference)	No. of Patients	Criteria	Sensitivity, %	Specificity, %	PPV, %	NPV, %	End Point
Olson et al (174)	115	EF <40%+(>10 PVCs/h or multiform or pairs of VT)	50	91	40	94	Cardiac death
Kuchar et al (97)	206	Lown grade 3 to 5+(RMS <20 μV or QRS >120 ms)	65	89	34	97	Arrhythmic event
		EF <40%+(RMS <20 μV or QRS >120 ms)	80	89	60	98	
Mukharji et al (94)	533	EF <40%+>10 PVCs/h	24	93	18	96	Sudden death
Farrell et al (89)	416	HRV <20 ms+late potential (A)	58	93	33	93	Arrhythmic event
		HRV <20 ms+>10 PVCs/h	50	94	34	96	
		HRV <20 ms+repetitive PVC	50	96	43	77	
		HRV <20 ms+repetitive PVC+late potential (A)	29	99	58	95	
		EF <40%+late potential (A)	25	94	19	94	
		EF ≤40%+>10 PVCs/h	33	93	19	94	
		EF ≤40%+repetitive PVC	25	91	15	95	
		EF <40%+>10 PVCs/h+late potential (A)	20	97	28	97	
Bigger et al (104)	715	EF ≥40%+≥3 PVCs/h	32	89	34		Total death
		≥3 PVCs/h+ULF+VLF	8	98	53		
		EF <40%+ULF+VLF	14	98	56		
		EF <40%+≥3 PVCs/h+ULF+VLF	6	99	50		
Zhang et al (105)	60	[QRS ≥120 ms or (RMS <25 μV+LAS >40 ms @ 40 Hz)] +(≥10 PVCs/h or couplets or NSVT or VT)	100	97	33	100	Arrhythmic event
		[QRS ≥120 ms or (RMS <25 μV+LAS >40 ms @ 40 Hz)] +EF <45%	80	72	29	96	
		EF <45%+(≥10 PVCs/h or couplets or NSVT or VT)	57	73	26	91	
		[QRS ≥120 ms or (RMS <25 μV+LAS >40 ms @ 40 Hz)] +EF <45%+(≥10 PVCs/h or couplets or NSVT or VT)	100	93	60	100	
McClements and Adgey (86)	301	EF <40% or (RMS <25 μV+LAS >40 ms @ 25 Hz)	85	67			Arrhythmic event
Pedretti et al (100)	292	≥2 of the following: EF ≤40%+late potential (B)+Lown 4	89	82	24	99	Arrhythmic event
		≥2 of the following: EF ≤40%+HRV <29+QRSD >106 ms	83	83	25	99	
		≥2 of the following: EF ≤40%+≥2 runs NSVT+QRSD >106 ms	89	93	44	99	
Hohnloser et al (128)	173	Occluded IRA	89	82	22	99	Arrhythmic event
		Occluded IRA+EF ≤40%	83	91	31	99	
		Occluded IRA+late potential (B)	83	90	31	99	
		Occluded IRA+EF ≤40%+late potential (B)	75	97	50	99	
El-Sherif et al (90)	1158	EF <40%+(≥10 PVCs/h or VT)	58	86	15	98	Arrhythmic event
		EF <40%+QRS ≥120 ms+(≥10 PVCs/h or VT)	33	97	32	97	
		QRS ≥120 ms+(≥10 PVCs/h or VT)	36	95	24	97	
		EF <40%+QRS ≥120 ms	39	95	25	97	

NPV indicates negative predictive value; OR, odds ratio; VT, ventricular tachycardia; EF, ejection fraction; LAS, low-amplitude signal; IRA, infarct-related artery; ULF, ultra-low-frequency power; VLF, very-low-frequency power.

Late potential (A), present if any 2 of the following criteria were present: QRS >120 ms, RMS voltage of last 40 ms of QRS complex <25 μV, LAS >40 ms after voltage decreased to <40 μV. Late potential (B), present if any 2 of the following criteria were present: QRS >114 ms, RMS voltage of last 40 ms of QRS complex <20 μV, LAS >38 ms after voltage decreased to <40 μV. RMS, root mean square voltage of the last 40 ms of the QRS complex; LAS duration of the low-amplitude signal (<40 μV) in the terminal portion of the QRS complex.

Table 8. Determining Prognosis of Acute MI Survivors Who Underwent 24-Hour AECG Monitoring

Author (Reference)	No. of Patients	Time Between AMI and AECG	Mean Follow-Up Duration	Tested Variables	Significant Variables	RR, Total Death	RR, Cardiac Death	RR, Arrhythmic Event
Mukharji et al (94)	533	10 d	18 mo	12 Clinical	≥10 PVCs/h		S	
				1 Nuc Med	EF ≤40%		S	
				3 Holter				
Kleiger et al (95)	808	11 d	31 mo	2 Clinical	Rales	2.4		
				2 AEM	EF <30%	2.0		
				1 Nuc Med	PVCs ≥10/h	1.9		
					HRV <50	1.7		
					NYHA class III/IV	1.5		
Kostis et al (96)	1640	2–21 d	25 mo	11–15 Clinical	≥10 PVCs/h	2.2*		
				11 Holter	Multiform PVC	1.7	2.4	
					≥10 PVCs/h or PVC pair or VT	2.1	1.7	
					≥10 PVCs/h or (PVC pair or VT) or multiform	2.0	2.2	
Kuchar et al (97)	206	11 d	14 mo	1 Holter	RMS <20 μV or QRS ≥120 ms			23.6*
				1 SAECG	EF <40%			17.9
				1 Nuc Med	Lown 3–5			7.6
Gomes et al (91)	94	10 d	14 mo	9 Clinical	QRS >114 ms @ 40 Hz	S		
				7 Holter	PVC pairs	S		
				9 SAECG	EF (continuous variable)	S		
				2 Nuc Med				
de Cock et al (98)	99	14 d	56 mo	11 Clinical	SVT		S	
				13 AEM	VT		S	
					10 PVCs/h		S	
					Killip class ≥II		S	
Farrell et al (89)	416	6–7 d	≈20 mo†	6 Clinical	HRV triangular index <20 ms	S		S
				5 AEM	Late potential (A)			S
					Repetitive PVCs	S		S
					Killip class ≥II	S		
Richards et al (175)	358	7–10 d	≈24 mo†	5 Clinical	EF ≤40%		3.1	
				1 Nuc Med	QRS ≥120 ms		4.5	
				1 EST				
				1 EPS				
				2 AEM				
Bigger et al (104)	715	11 d	30 mo	6 HRV	ULF	2.3	2.3	2.3
				3 Clinical	VLF	2.1	2.2	2.5
				1 Nuc Med	LF	. . .	. . .	. . .
				1 Holter	HF	1.7	. . .	. . .
					TP	2.1	1.9	1.9
					LF/HF	1.7	1.8	1.8

Table 8. (continued).

Author (Reference)	No. of Patients	Time Between AMI and AECG	Mean Follow-Up Duration	Tested Variables	Significant Variables	RR, Total Death	RR, Cardiac Death	RR, Arrhythmic Event
Wilson and Kostis (99)	3290	2–21 d	25 mo	15 Clinical 1 AEM	≥1 PVC/h	S		
Bigger et al (112)	331	1 y	26 mo	3 Clinical 1 Nuc Med 3 Holter 6 HRV	VLF LF	4.4 3.8		
McClements and Adgey (86)	301	2–6 d	12 mo	20 Clinical 12 AEM	≥10 PVCs/h or PVC pair (QRS >120 ms or RMS <25 μV+LAS >40 ms @ 25 Hz)			S S
Pedretti et al (100)	305	24–48 d	15 mo	6 Clinical 7 AEM	EF <40% HRV triangular index ≤29 QRSD ≥106 ≥2 runs NSVT			16 15 9 6
Hohnloser et al (128)	173	Before discharge	12 mo	11 Clinical 2 Nuc Med 2 Cath 1 SAECG	Patent infarct-related artery			S
El-Sherif et al (90)	1158	5–30 d	10 mo	10 Clinical 2 Holter 6 SAECG	EF <40%+(≥10 PVCs/h or VT) EF <40%+(≥10 PVCs/h or VT)+QRS ≥120 ms (≥10 PVCs/h or VT)+QR ≥120 ms EF <40%+QRS ≥120 ms			8.4 16.7 11.0 12.2
Olona et al (176)	115	7–15 d	≥5 y	5 EST 5 Thallium 3 Echo 6 Nuc Med 2 Holter 4 Cath	None			

AMI indicates acute MI; RR, relative risk; Nuc Med, nuclear medicine; EF, ejection fraction; AEM, ambulatory electrocardiographic monitoring; NYHA, New York Heart Association; VT, ventricular tachycardia; RMS, root mean square; SAECG, signal-averaged ECG; SVT, supraventricular tachycardia; EST, ECG stress test; EPS, electrophysiologic study; ULF, ultra-low frequency power; VLF, very-low-frequency power between 0.003 and 0.04 Hz; TP, total power; LAS, low-amplitude signal; NSVT, nonsustained ventricular tachycardia; Cath, catheterization; and Echo, echocardiogram.

*Odds ratio instead of relative risk ratio; S, significant finding, no relative risk calculated.

†Median follow-up duration.

Table 9. Sensitivity and Specificity of AECG and HRV for Predicting Arrhythmic Events in Patients With CHF

Author (Reference)	No. of Patients	Criteria	Sensitivity, %	Specificity, %	PPV, %	NPV, %	Adjusted RR (95% CI)	End Points
Doval et al (122)	516	NSVT	58	70	24	91	2.6 (1.6–4.1)	Sudden death
	295	NSVT or couplets	89	42	21	96	2.9 (1.1–7.6)	Sudden death
	516	NSVT	45	73	50	69	1.6 (1.2–2.2)	Total death
	295	NSVT or couplet	76	32	51	74	10.1 (1.9–52.7)	Total death
Szabo et al (121)*	204	VT	60	72	38	86		Cardiac death
Pelliccia et al (119)	104	Lown class ≥4	31	88	58	72		Cardiac death
Ponikowski et al (130)	102	SDNN <100	79	67	37	93		Total death
Huang et al (115)	35	NSVT	50	65	5	93		Sudden death
Igekawa (120)*	33	NSVT	71	81	50	91		Sudden death
		≥100 PVCs/h	71	81	45	91		
		NSVT+≥100 PVCs/h	57	96	80	89		
Holmes et al (117)	31	Lown class ≥4	7	53	11	41		Cardiac death

NPV indicates negative predictive value; NSVT, nonsustained ventricular tachycardia; VT, ventricular tachycardia.
*Calculations are derived from figures in published articles.

C. Hypertrophic Cardiomyopathy

Sudden death and syncope are common among patients with hypertrophic cardiomyopathy. The exact relation between ventricular arrhythmias or HRV and outcomes for patients with hypertrophic cardiomyopathy remains open to question. Three studies show that there is some association between ventricular arrhythmias and adverse events, but they differ on the nature of the association (133–135). Another study found no association between HRV indexes and adverse events (136). Although AECG monitoring may add to the prognostic information provided by known risk factors for patients with hypertrophic cardiomyopathy, treatment of these ventricular arrhythmias has not consistently been shown to increase life expectancy. Hence the specific role of AECG in the day-to-day treatment of these patients remains unclear.

D. Valvular Heart Disease

A few studies have examined the relation between valvular heart disease and HRV or ventricular ectopy. At the present time, the presence of mitral valve prolapse (137), chronic mitral regurgitation (138), or aortic valve prosthesis (139) without other symptoms does not establish the need for AECG monitoring nor for assessing HRV.

E. Diabetic Neuropathy

Diabetes is associated with diffuse degeneration of sympathetic and parasympathetic small nerve fibers. More than half the patients with symptomatic diabetic neuropathy will die within 5 years (140). Because heart rate and rhythm are under the control of the autonomic nervous system, several groups have studied the relation between HRV and diabetic neuropathy. High-frequency measures of HRV can detect small changes in cardiac autonomic function in diabetic subjects (141–143) and can distinguish diabetic subjects with neuropathy from those without neuropathy (144). Although these tests are reliable and sensitive for cardiac parasympathetic function, their clinical utility is limited for 2 reasons. First, large numbers of diabetic subjects have reduced HRV (142). Second, there is no evidence that early identification of subclinical diabetic neuropathy will lead to improved patient outcomes. In a report on the natural history of diabetic neuropathy, more than half the deaths were due to kidney failure and not cardiac arrhythmias (140). Thus, routine HRV testing is not indicated at this time.

F. Hemodialysis Patients

Patients with kidney failure who are receiving hemodialysis are at increased risk of dying from a cardiovascular event and have an increase in ventricular ectopy during dialysis (145). In a minority of these patients, significant ventricular arrhythmias develop (146). Those most at risk of having an abnormal AECG recording are patients with known coronary artery or peripheral vascular disease (147). Patients with Lown grade 3 or higher arrhythmia (148) have decreased survival compared with patients without ventricular ectopy (147). Whether this prognostic information justifies performing AECG monitoring on these patients is unknown.

G. Systemic Hypertension

Systemic hypertension is the most common cause of LV hypertrophy (149). Hypertensive patients with either ECG (150) or echocardiographic (151–153) criteria of LV hypertrophy have an increased incidence of complex ventricular arrhythmias. There is an increased risk of ventricular arrhythmias, MI, and sudden death in patients with LV hypertrophy (154,155). AECG monitoring of asymptomatic patients with LV hypertrophy is of uncertain value because those patients with complex or frequent arrhythmias have only a marginally significant risk of dying after adjusting for age, sex, and other clinical factors (OR 1.62; 95% CI 0.98–2.68) (156).

H. Preoperative and Postoperative Patients

AECG monitoring has been used in the preoperative evaluation of patients and after a variety of cardiac operations. No association has been found between preoperative ventricular arrhythmias and postoperative events when used before surgery in high-risk patients undergoing noncardiac surgery who have no myocardial ischemia and are without severe LV dysfunction (157). Similarly, no association has been found between the occurrence of complex ventricular ectopy after coronary artery bypass surgery and death after controlling for other clinical factors (158). Finally, although AECG is occasionally recommended for preoperative testing in patients with bundle-branch block, there are no data supporting this use.

I. Screening in Other Patients

There are conflicting results concerning the relation between asymptomatic ventricular arrhythmias and outcomes in the elderly, patients with obstructive lung disease, and others. Some studies demonstrate an increased risk and other studies show no difference in risk (159–164). AECG monitoring was not of value in patients who had sustained a myocardial contusion (165) nor in those with sleep apnea (166,167). Therefore there is insufficient evidence to support routine use of AECG monitoring in these patient populations.

J. Monitoring Pharmacological Management

Several medications used in the treatment of patients with cardiac conditions affect either directly or indirectly the autonomic nervous system. Analysis of R-R variability may provide a tool for understanding these various pharmacological manipulations (168–173). To date, the prognostic implications of the noted alterations are unknown. In drug development, analysis of R-R variability may provide insights into mechanisms of action. Future studies should include outcomes research.

K. Summary

Although arrhythmia detection and HRV analyses each provide some incremental information that may be useful in identifying patients without symptoms of arrhythmias at increased risk of future cardiac events, their overall value is limited at the present time because of their relatively low sensitivity and PPV. Combining AECG, HRV, signal-averaged ECG, and LV function improves the quality of the information provided, but the best way to combine data from these different tests remains elusive. Three groups may benefit from either AECG or HRV monitoring: patients with idiopathic hypertrophic cardiomyopathy, patients with CHF, and post-MI survivors with reduced ejection fraction. However, these tests cannot be recommended for routine use in any other population at the present time.

Indications for AECG Arrhythmia Detection to Assess Risk for Future Cardiac Events in Patients Without Symptoms From Arrhythmia

Class I
None

Class IIb
1. **Post-MI patients with LV dysfunction**
2. **Patients with CHF**
3. **Patients with idiopathic hypertrophic cardiomyopathy**

Class III
1. **Patients who have sustained myocardial contusion**
2. **Systemic hypertensive patients with LV hypertrophy**
3. **Post-MI patients with normal LV function**
4. **Preoperative arrhythmia evaluation of patients for noncardiac surgery**
5. **Patients with sleep apnea**
6. **Patients with valvular heart disease**

Indications for Measurement of HRV to Assess Risk for Future Cardiac Events in Patients Without Symptoms From Arrhythmia

Class I
None

Class IIb
1. **Post-MI patients with LV dysfunction**
2. **Patients with CHF**
3. **Patients with idiopathic hypertrophic cardiomyopathy**

Class III
1. **Post-MI patients with normal LV function**
2. **Diabetic subjects to evaluate for diabetic neuropathy**
3. **Patients with rhythm disturbances that preclude HRV analysis (ie, atrial fibrillation)**

VI. EFFICACY OF ANTIARRHYTHMIC THERAPY

AECG has been widely used to assess the effects of antiarrhythmic therapy. The technique is noninvasive, provides quantitative data, and permits correlation of symptoms with ECG phenomena. However, limitations of AECG as a therapeutic guide affect its usefulness. These limitations include significant day-to-day variability in the frequency and type of arrhythmias in many patients, a lack of correlation between arrhythmia suppression after an intervention and subsequent outcome, uncertain guidelines for the degree of suppression required to demonstrate an effect, either statistical or clinical, and an absence of quantifiable spontaneous asymptomatic arrhythmias between episodes in many patients with a documented history of life-threatening arrhythmias (12).

The basis for the use of AECG has been the hypothesis that a reduction from baseline levels in arrhythmia frequency or type during serial monitoring after institution of therapy will correlate with an improved long-term clinical response. The majority of placebo-controlled, randomized data concerning this hypothesis has been generated in patients with asymptomatic ventricular ectopy. Uncontrolled data and data comparing AECG with electrophysiological studies are available in patients with prior sustained ventricular tachycardia or ventricular fibrillation. Because of the limited day-to-day occurrence of supraventricular arrhythmias and the uncertain significance of asymptomatic nonsustained atrial ectopy, quantitative analysis of long-term AECG recordings has not been widely used to guide therapy of supraventricular arrhythmias. However, intermittent monitoring to confirm the presence of an arrhythmia during symptoms and to document arrhythmia-free intervals has become a standard approach for evaluating the effects of antiarrhythmic therapy in patients with supraventricular arrhythmias (177). The AECG also may be used to monitor the effects of atrioventricular (AV) nodal blocking drugs on heart rate in patients with atrial arrhythmias.

A number of authors have examined the day-to-day variability in the frequency and type of arrhythmia detected in various patient populations (13–20,178–180). As shown in Table 10, short-term reproducibility of data between recordings was poor, and large reductions (63% to 95%) in arrhythmia frequency would be required to ensure that the change was due to an antiarrhythmic effect of any intervention. Long-term reproducibility of ventricular arrhythmia frequency and types is limited as well (17,21,181–184).

The Cardiac Arrhythmia Suppression Trial (CAST) tested the hypothesis that suppression of spontaneous ectopy by an antiarrhythmic drug would reduce mortality rates in patients with asymptomatic ventricular arrhythmias after MI (185–189). The active drugs used in the study were encainide, flecainide, and moricizine. In the initial design, all patients were assigned to active drug treatment, and suppression of spontaneous ectopy during a titration phase was monitored. Patients who did not manifest suppression were not randomly assigned and had a more than 2-fold higher mortality rate than did the patients whose arrhythmias were suppressed and who were randomly assigned to placebo (180,185–188). A higher mortality rate during follow-up was observed in those patients who had suppression and then received chronic encainide or flecainide therapy as opposed to placebo. After this observation, the trial design was altered and the study continued with moricizine as the only active agent. A higher mortality rate during a placebo-controlled drug titration with moricizine was observed, and there was no indication of benefit with long-term therapy (187).

The data from CAST led to a revision of many concepts concerning methods for guiding antiarrhythmic drug therapy in asymptomatic patients. It was seen that suppression of spontaneous asymptomatic or mildly symptomatic ventricular ectopy with an antiarrhythmic drug might not only be ineffective but actually harmful. Thus therapy in such patients with Class I antiarrhythmic drugs is currently not recommended. The data also gave rise to the concept of the "healthy responder" (ie, patients who respond to an intervention, in this case AECG-guided drug therapy, may have a different prognosis than those who do not) (190). This observation influences the interpretation of data from other studies that do not include an untreated control group.

Controlled data from mortality trials with AECG as a guide to therapy with other antiarrhythmic agents are not available, but many trials have evaluated the unguided use of Class Ia, Class Ib, and selected Class III antiarrhythmic agents (191,192). These trials have demonstrated either no benefit or an adverse effect with antiarrhythmic drug therapy. Studies with empiric use of amiodarone have been inconsistent, with some studies showing a benefit (193–196) and others showing no significant change in mortality rates (88,197,198). In one trial (198), amiodarone produced a significant reduction in arrhythmia frequency but had no effect on mortality rate. It has not been demonstrated that amiodarone therapy guided by responses during serial AECG would improve these results.

Placebo-controlled trials of antiarrhythmic interventions in patients with sustained life-threatening ventricular arrhythmias are problematic. One favorable early report showed improvements in arrhythmia-free survival in patients who met certain criteria for a drug response during serial AECG (199,200). It is not possible to estimate the effects of the "healthy responder" phenomenon on these observations.

AECG has been compared with serial electrophysiological studies in 2 randomized trials in patients with prior sustained ventricular arrhythmias. A small study by Mitchell et al (201) suggested that an electrophysiological study–based approach was superior, whereas the much larger Electrophysiologic Study Versus Electrocardiographic Monitoring (ESVEM) study showed no difference in outcome with the use of the 2 approaches to select initial therapy (202). Both of these studies, however, had many important limitations, and firm conclusions about the relative value of the 2 approaches remain uncertain. Of note, the ESVEM trial did not include amiodarone, the agent most commonly selected in patients with serious arrhythmias in several recently completed antiarrhythmic trials (113,203).

It is also important to note that not all patients with a history of sustained ventricular tachycardia will manifest high-frequency or complex ventricular ectopy. Swerdlow and Peterson (204) found, in a cohort of patients with CAD and sustained ventricular arrhythmias, that 76% had spontaneous ventricular arrhythmias suitable for drug assessment on a 24-hour AECG. In the 2 randomized trials mentioned above that compared serial AECG versus electrophysiological testing for selecting drug therapy, Mitchell et al (201) and the ESVEM group (202) found that 32% and 17%, respectively, of patients approached had insufficient spontaneous ectopy to enter the trial. The former single-center trial study screened consecutive patients at that site who presented with a symptomatic ventricular arrhythmia and required ≥30 PVCs per hour for enrollment. ESVEM, a multicenter study performed at 14 sites, did not always obtain an AECG to quantify ventricular ectopy in patients with consecutive ventricular arrhythmia at the sites and required in the monitored patients only 10 PVCs per hour for enrollment.

It should be noted that the ICD offers an alternate strategy for treatment of patients with life-threatening ventricular arrhythmias. Many current-generation ICDs store event electrograms for retrieval, and ambulatory monitoring is now rarely required to assess ICD utility.

Very few patients with sustained supraventricular arrhythmias have episodes on a daily basis. Guidelines for assessing therapy for supraventricular arrhythmias based on a quantitative analysis of the frequency or pattern of asymptomatic atrial ectopic beats are not available. However, protocols for rigorous assessment of antiarrhythmic drug efficacy with intermittent monitoring have been developed and validated. In these protocols, patients are asked to record and transmit ECG data from intermittent recording monitors to document the presence of arrhythmias during symptoms (205). Once a baseline frequency has been established, therapy is begun and the "arrhythmia-free" interval is used as a measure of drug effect. This type of protocol is now accepted as the standard for an antiarrhythmic drug development program for supraventricular arrhythmias because it provides a statistically valid measure of drug effect on symptomatic arrhythmias in a given population (205,206). Asymptomatic arrhythmias, also commonly present, would not be detected unless long-term recordings or periodic surveillance transmissions were also obtained (80). Use of a similar protocol in routine practice is not common, but the use of intermittent recordings in a nonquantitative manner may be clinically useful in patients with recurrent symptoms. AECG recordings are also of value for documenting control of the ventricular rate in patients with continuous atrial arrhythmias because they provide data on the heart rate during the patient's typical daily activities.

The concept of proarrhythmia includes both provocation of new arrhythmia and exacerbation of preexisting arrhythmia as a result of antiarrhythmic drug therapy (207,208). Proarrhythmia may occur early or late during the course of therapy. In previously asymptomatic patients with ventricular ectopy, proarrhythmia is usually defined as an increase in frequency of ventricular premature depolarizations or of runs of ventricular tachycardia. The increase needed to differentiate proarrhythmia from day-to-day variability may be estimated statistically on the basis of baseline arrhythmia frequency (207,208). In CAST, patients who manifest an early increase in ventricular premature depolarization had a higher mortality rate when treated with placebo than did those without this finding (209). Increased QT intervals, sinus node dysfunction, and new or worsened AV conduction abnormalities are other types of asymptomatic but still clinically relevant proarrhythmia that may be detected by AECG in patients receiving antiarrhythmic drug therapy.

Indications for AECG to Assess Antiarrhythmic Therapy

Class I

1. **To assess antiarrhythmic drug response in individuals in whom baseline frequency of arrhythmia has been well characterized as reproducible and of sufficient frequency to permit analysis**

Class IIa

1. **To detect proarrhythmic responses to antiarrhythmic therapy in high-risk patients**

Class IIb

1. **To assess rate control during atrial fibrillation**
2. **To document recurrent symptomatic or asymptomatic nonsustained arrhythmias during therapy in the outpatient setting**

Class III

None

VII. ASSESSMENT OF PACEMAKER AND ICD FUNCTION

Over the last 10 years, the function and diagnostic capabilities of pacemakers and ICDs have become more complex (210–215). As a result, trouble-shooting device function and determining optimal device programming has become more challenging. AECG is useful in correlating frequent symptoms with cardiac rhythm abnormalities and thereby can aid in evaluating symptomatic patients for pacemaker implantation. Guidelines have been previously set forth describing appropriate indications for permanent pacemaker implantation (216), and AECG is useful in both documenting the presence of significant bradyarrhythmias and establishing whether or not an association exists between a patient's symptoms and the presence of cardiac arrhythmia.

Once a device is implanted, AECG is useful in assessing postoperative device function as well as in guiding appropriate programming of enhanced features such as rate responsivity and automatic mode switching. AECG can sometimes be a useful adjunct to continuous telemetric observation after pacemaker implantation in assessing device function and thereby aid in determining the need for either device reprogramming or operative intervention (217). Present-generation pacemakers are capable of limited AECG monitoring function, which at the present time is not capable of entirely supplanting conventional AECG. They accomplish this with various algorithms by which complexes are classified according to whether or not they are preceded by atrial sensed or paced events (218). Tabular data can then be obtained from pacemaker memory at the time of follow-up interrogation, which quantifies how many or what percentage of atrial and ventricular events were either sensed or paced, including a separate quantification of sensed ventricular events without preceding atrial activity. Although these algorithms were primarily designed to profile pacemaker activity to optimize device programming including AV delay, rate responsivity, and upper and lower rate limits, these data can be used to broadly determine the frequency of ventricular ectopy. The resolution of the data, however, usually does not allow for minute-to-minute counts or detailed characterization of repetitive ectopy (ie, rate, duration, or morphology of ventricular tachycardia). Because present devices do not provide electrogram confirmation of these counts, the accuracy of the tabulated data provided by these devices depends on accurate sensing and pacing function. Undersensing or oversensing of cardiac events or events occurring during blanking or refractory periods will result in inaccurate counts.

When compared with pacemakers, present-generation ICDs are capable of more detailed electrogram recording of events precipitating device activation. These recordings, however, are made over a significantly more limited time duration (usually on the order of 5 to 30 seconds per event, up to approximately 5 to 10 minutes of total recording duration). Although these recordings provide more complete disclosure and allow for direct physician review, the limited recording duration and absence of a surface ECG with which to provide data regarding QRS morphology are substantial limitations. Currently under development are devices capable of AECG while acquiring on-line telemetric data from an implanted device (219). This data link can then be used to correlate device function with a recorded ECG signal, thus allowing for more detailed analysis of pacemaker or ICD function during a more prolonged time period.

During outpatient follow-up of patients undergoing device implantation, AECG is useful in correlating intermittent symptoms with device activity (76,220). Pacing thresholds in the atrium and ventricle evolve after lead implantation, and abnormalities of sensing and capture can be documented during chronic follow-up. Device longevity can be maximized with appropriate programming of output parameters, and AECG can be useful in assessing device function after such reprogramming.

Patients having undergone ICD implantation for the management of ventricular arrhythmias often have ICD shock therapy during follow-up. AECG can be a useful adjunct in establishing the appropriateness of such therapy (221,222). The efficacy of adjunctive pharmacological therapy in suppressing spontaneous arrhythmias in an attempt to minimize the frequency of device activation also can be assessed by this technique. Although present-generation ICDs are capable of storing electrograms of the spontaneous rhythm resulting in device activation, differentiating supraventricular from ventricular arrhythmias solely on the basis of these recordings can be difficult (222). At the present time, AECG remains a useful adjunct in fine tuning device function (222), including ensuring that there is no overlap in programmed tachycardia detection rate and the maximum heart rate achieved during daily activity.

Technology remains a moving target (223,224). Devices capable of more robust telemetry capabilities are already under development, and although it is conceivable that future devices implanted for the management of tachyarrhythmias and bradyarrhythmias may be totally self-sufficient in their diagnostic function, at the present time AECG remains a useful adjunct in the evaluation of pacemaker and ICD function.

Indications for AECG to Assess Pacemaker and ICD Function

Class I

1. **Evaluation of frequent symptoms of palpitation, syncope, or near syncope to assess device function so as to exclude myopotential inhibition and pacemaker-mediated tachycardia and to assist in the programming of enhanced features such as rate responsivity and automatic mode switching**
2. **Evaluation of suspected component failure or malfunction when device interrogation is not definitive in establishing a diagnosis**
3. **To assess the response to adjunctive pharmacological therapy in patients receiving ICD therapy**

Class IIb

1. **Evaluation of immediate postoperative pacemaker function after pacemaker or ICD implantation as an alternative or adjunct to continuous telemetric monitoring**
2. **Evaluation of the rate of supraventricular arrhythmias in patients with implanted defibrillators**

Class III

1. **Assessment of ICD/pacemaker malfunction when device interrogation, ECG, or other available data (chest radiography, etc) are sufficient to establish an underlying cause/diagnosis**
2. **Routine follow-up in asymptomatic patients**

VIII. MONITORING FOR MYOCARDIAL ISCHEMIA

A. General Considerations

During the past decade, AECG monitoring has been extensively used for detection of myocardial ischemia. Although in the past there were a number of technical limitations that led to inadequate and unreliable evaluation of ST-segment changes, with the recent advent of technological advancements it is now widely accepted that AECG monitoring provides accurate and clinically meaningful information about myocardial ischemia in patients with coronary disease (225–230). A number of well-designed clinical studies have evaluated the prevalence and prognostic significance of myocardial ischemia detected by AECG monitoring (227,228,230–242). Most of these studies have been conducted in patients with proven CAD, and there is a relative paucity of data regarding the role of AECG monitoring in asymptomatic subjects without known CAD or peripheral vascular disease. There is presently no evidence that AECG monitoring provides reliable information concerning ischemia in asymptomatic subjects without known CAD. Most of the studies that have evaluated the relation between the findings obtained during exercise testing and AECG monitoring demonstrated that ST-segment changes indicative of myocardial ischemia during AECG monitoring are relatively infrequent in patients with no evidence of ischemia during exercise testing (243,244). However, in those with an ischemic response during exercise testing, between 25% and 30% of patients demonstrate ischemia during AECG monitoring. There is a significant correlation between the magnitude of ischemia during the exercise tolerance test and the frequency and duration of ischemia during AECG monitoring (34). However, the strength of the correlation is limited, indicating that the 2 tests are not redundant to characterize coronary patients (34).

Unlike exercise testing, AECG monitoring has the distinct advantage of providing long-term monitoring for myocardial ischemia in the outpatient setting while the patient is performing usual daily activities (226,227), including mental stress (245,246). AECG monitoring is also useful for detection of myocardial ischemia in preoperative risk stratification for patients who cannot exercise because of physical disability, peripheral vascular disease, or advanced lung disease. Ischemia monitoring by AECG can also be helpful for evaluation of patients with anginal syndrome with a negative exercise tolerance test if variant angina is suspected. In addition, AECG monitoring for 24 to 48 hours can provide information regarding the circadian pattern of myocardial ischemia as well as underlying pathophysiological mechanisms responsible for the ischemic episodes during daily life. However, in symptomatic patients, diagnostic accuracy is greater with exercise testing (225).

AECG monitoring has the ability to provide comprehensive evaluation of ischemia for a given patient. A number of studies have documented that as much as 80% of ischemic episodes that occur during daily life are not associated with symptoms and would remain undiagnosed unless evaluated by AECG monitoring (226–230). The results of some studies have also demonstrated that episodes of asymptomatic ischemia during AECG monitoring can be frequently detected in patients with angina pectoris who are receiving antianginal drug therapy and are considered to have adequate control of symptoms (227–230). Such residual ischemia, which would remain undetected without AECG monitoring, has been documented in patients with acute ischemic syndromes (unstable angina and after MI) as well as in patients with stable CAD (227–236). However, the clinical significance of such residual ischemia is unclear.

B. Prevalence and Predictive Value

The prevalence of myocardial ischemia detected by AECG monitoring in patients with stable CAD and angina pectoris ranges between 20% and 45%, with the highest prevalence demonstrated in patients with more advanced multivessel CAD (227–229,247). The available data from a number of clinical studies have shown that between 30% and 40% of patients with unstable angina and those with a recent MI have evidence of myocardial ischemia during AECG monitoring (230,239–242). A number of these studies have emphasized that between 60% and 80% of ischemic episodes detected by AECG monitoring are not associated with symptoms (225–242). Because of lack of symptoms and/or any patient discomfort, the detection of myocardial ischemia by AECG monitoring would only be of clinical significance if its presence was associated with adverse prognosis. Indeed, a number of recent studies have demonstrated that myocardial ischemia detected by AECG monitoring identifies high-risk patients (230–242,248,249). In patients with stable CAD, the results of studies (Table 10) have shown that the presence of ischemic episodes detected by AECG monitoring is associated with a significantly greater risk of future coronary events and cardiac death (231–238). The results of these studies have also documented that ischemia detected during AECG monitoring is an independent predictor of clinical outcome (when compared with several clinical predictors and ECG variables) (231–238,249). In addition, some recent studies have compared the prognostic value of data obtained during exercise testing with the information available from AECG monitoring, and the results of these studies have demonstrated that ischemia detected by AECG monitoring can provide prognostic information additional to that available from established parameters obtained during exercise testing (233,237,242).

AECG monitoring has also been used for preoperative evaluation (Table 11) of patients with peripheral vascular disease with no clinical evidence of CAD (250–259). Between 10% and 40% of patients referred for major vascular surgery have evidence of ischemia detected by AECG monitoring (250–258). Although the independent prognostic value of ischemia detected by AECG monitoring for postoperative cardiac complications has been reported (Table 12), more recent and larger studies have emphasized that the presence of ischemia detected by AECG monitoring in these patients also predicts a poor long-term prognosis (250–259). However, on the basis of the available data, when feasible, exercise testing alone or with an imaging study remains the preferred test of choice for risk stratification of patients with CAD or for preoperative evaluation. For patients who cannot perform exercise, AECG can be used for further evaluation.

Table 10. Variability of AECG Arrhythmia Monitoring

Author (Reference)	No. of Patients	Inclusion Criteria	Methods	Conclusions
Coronary artery disease				
Winkle et al (178)	51	AMI within 8 to 11 days, no arrhythmia required	Three consecutive 24-h AECGs	Prevalence of "complex PVCs" increased with duration of recording. Low-frequency events (for example, VT) were poorly reproducible
Pratt et al (13)	88	AMI within 60 days, >10 PVCs/h at baseline	Two 24-h AECGs	95% reduction in PVCs was required to exclude spontaneous variability
CAPS Investigators (179)	100	AMI within 6 to 60 days, ≥10 PVCs/h	Repeat AECGs on placebo	37% of patients had >70% PVC suppression at some point
Hypertrophic cardiomyopathy				
Mulrow et al (14)	16	Nonsustained VT	Two 24-h AECGs	50% had no VT on repeat monitoring
Mixed diagnoses				
Pratt et al (15)	26	>40 PVCs/h at baseline	Repeat 24-h AECG 1 y after drug withdrawal	50% had a decreased number of PVCs; 65% had a decreased number of pairs; and 83% had decreased VT
Raeder et al (16)	45	History of VF, sustained VT, or nonsustained VT	Two 24-h AECGs	>64% reduction in PVCs and >63% reduction in VT were necessary to exclude random variation
Toivonen (17)	20	"Hospitalized for arrhythmia"	Two AECGs during first week, repeated after 6 to 12 mo	Long term was much worse than short-term reproducibility
Michelson and Morganroth (18)	20	≥30 PVCs/h at baseline	Four consecutive 24-h AECGs	>65% reduction in PVCs was needed to show a treatment effect
Pratt et al (19)	100	Nonsustained VT at baseline	Four consecutive 24-h AECGs	There was greater variability in patients with CAD; reductions necessary to exclude random variation were ≥78% in PVCs, ≥83% in pairs, and >77% in VT
Morganroth et al (20)	15	≥30 PVCs/h at baseline	Three consecutive 24-h AECGs	≥83% reduction in PVCs was necessary to show a treatment effect
Reiter et al (180)	119	10 PVCs/h at baseline, suppressed on drug	Repeat 24-h AECG on same therapy	83% met efficacy criteria on both recordings

CAPS indicates Cardiac Arrhythmia Pilot Study; AMI, acute MI; CAD, coronary artery disease; VF, ventricular fibrillation; and VT, ventricular tachycardia.
Adapted with permission from DiMarco and Philbrick (12).

Table 11. Studies Defining Incidence and Prognostic Significance of Daily Life Ischemia in Stable CAD

Author (Reference)	No. of Patients	% With AECG Ischemia	End Points	Mean Follow-Up	Event Rates: With AECG Ischemia	Event Rates: Without Ischemia	*P*	Comments
Rocco et al (231)	86	57%	Death, MI, UA, revascularization	12.5 mo	40%	3%	0.003	Patients monitored once off Rx
Tzivoni et al (233)	118	33%	Cardiac death, MI, UA, revascularization	28 mo	51%	20%	<0.001	All patients with previous MI
Deedwania and Carbajal (232)	107	43%	Cardiac death	23 mo	24%	8%	0.02	Monitored on Rx
Raby et al (234)	176	18%	Cardiac death, nonfatal MI	20 mo	38%	7%	<0.0001	Patients with peripheral vascular disease
Yeung et al (236)	138	59%	Death, MI, revascularization	37 mo	56%	42%	0.02	Monitored off Rx
Deedwania and Carbajal (237)	86	45%	Cardiac death	24 mo	23%	4%	<0.008	Monitored on Rx that controlled symptoms
deMarchena et al (235)	50	32%	Cardiac death, MI, UA, revascularization	10 mo	56%	21%	<0.02	All patients monitored on Rx that controlled symptoms
Madjilessi-Simon et al (238)	331	27%	Death, MI, revascularization, or worsening angina	21 mo	33%	17%	0.004	All patients initially treated with a β-blocker

Rx indicates drug therapy; and UA, unstable angina.

C. Role in Therapeutic Evaluation

During the past 5 to 7 years, AECG monitoring has been used for the evaluation of efficacy of anti-ischemic therapy in patients with CAD. The results of these studies have revealed that because of day-to-day variability in ischemic indexes, prolonged AECG monitoring for 48 hours is usually necessary for therapeutic evaluation (26,260). A number of studies have demonstrated that 48-hour AECG monitoring performed at baseline and after institution of therapy can provide reliable evaluation about the anti-ischemic efficacy of the drugs used in patients with CAD (261–270). The results of these studies have provided clinically meaningful information regarding differences in the efficacy of various antianginal drugs and shed further light on the pathophysiological mechanisms of actions of various drugs. Data emerging from randomized clinical trials (Table 13) suggest that suppression of myocardial ischemia as evaluated by AECG monitoring may be associated with improved outcome in patients with CAD (264,268,271). However, large-scale, prospective, randomized clinical trials are needed to confirm these results before definite recommendations can be made.

D. Limitations

It is important to note that ST-segment changes and other repolarization abnormalities can occur for reasons other than myocardial ischemia. These include hyperventilation, hypertension, LV hypertrophy, LV dysfunction, conduction abnormalities, postural changes, tachyarrhythmias, preexcitation, sympathetic nervous system influences, psychotropic drugs, antiarrhythmic drugs, digitalis, alterations in drug levels, and electrolyte abnormalities. Although the possibility of these false-positive changes should not preclude the use of AECG monitoring for detection of myocardial ischemia, it is critical to be aware of these conditions while evaluating the predictive value of ST-segment changes in a given patient. The other potential limitation to the clinical use of AECG monitoring (especially for the evaluation of therapeutic interventions) is the marked day-to-day variability in the frequency and duration of ST depression and ischemic episodes, which makes it difficult to assess the effects of therapy on ischemic indexes recorded during AECG monitoring. This can be partially rectified by performing prolonged (48- to 72-hour) AECG monitoring recordings and assessing similar physical and emotional activities performed by patients during serial monitoring sessions. Because of these complex technical requirements and diagnostic criteria, it is essential that the use of AECG monitoring for detection of myocardial ischemia be restricted to laboratories and personnel specifically trained in this area.

Although ST-segment depression is the most frequently encountered ECG sign of ischemia during AECG monitoring, it should be noted that occasionally one can encounter a period of ST-segment elevation (especially in patients

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Table 12. Predictive Value of Preoperative ST Monitoring by AECG for Perioperative Cardiac Events After Vascular Surgery

Author (Reference)	No. of Patients	Patients With Abnormal Test	Criteria for Abnormal Test	Perioperative Events: Positive* Test	Perioperative Events: Negative Test	Event	Comments
Raby et al (250)	176	18	A	10% (3/32)	1% (1/144)	D, MI	24–48 h during ambulation
Pasternack et al (256)	200	39	A	9% (7/78)	2% (2/122)	D, MI	
Mangano et al (252)	144	18	A, B	4% (1/26)	4% (5/118)	D, MI	Immediately before surgery
Fleisher et al (253)	67	24	A, B	13% (2/16)	4% (2/51)	D, MI	Immediately before surgery
McPhail et al (255)	100	34	A	15% (5/34)	6% (4/66)	D, MI	
Kirwin et al (254)	96	9	A	11% (1/9)	16% (14/87)	D, MI	Definition of MI based on enzymes only
Fleisher et al (257)	86	23	A, B	10% (2/20)	3% (2/66)	D, MI	Quantitative monitoring not predictive

A indicates ≥1 mm ST-segment depression; B, ≥2 mm ST-segment elevation; and D, death.
*Positive predictive value for postoperative cardiac events.

with variant angina or high-grade proximal stenoses) that is indicative of transmural ischemia. Occasionally, changes in T-wave polarity and morphology can be observed during AECG monitoring; however, there are presently no data to suggest that such changes are specific indicators of myocardial ischemia.

Indications for AECG for Ischemia Monitoring

Class I

None

Class IIa

1. **Patients with suspected variant angina**

Class IIb

1. **Evaluation of patients with chest pain who cannot exercise**
2. **Preoperative evaluation for vascular surgery of patients who cannot exercise**
3. **Patients with known CAD and atypical chest pain syndrome**

Class III

1. **Initial evaluation of chest pain patients who are able to exercise**
2. **Routine screening of asymptomatic subjects**

IX. PEDIATRIC PATIENTS

The purposes of AECG monitoring in pediatric patients include 1) the evaluation of symptoms that may be arrhythmia related; 2) risk assessment in patients with cardiovascular disease, with or without symptoms of an arrhythmia; and 3) the evaluation of cardiac rhythm after an intervention such as drug therapy or device implantation. As in adult patients, selection of the method of monitoring (ie, continuous recording versus patient activated) is predicated on the frequency and symptoms of the arrhythmia.

Table 13. Clinical Trials to Assess Effect of Anti-Ischemic Strategies on Prognostic Significance of Daily Life Ischemia

Author (Reference)	No. of Patients	End Points	Follow-Up, y	Event Rate by Treatment Group	*P*
Pepine et al (264)	306	Death, MI, unstable angina, worsening angina, or revascularization	1	25% placebo 11% atenolol	0.001
Rogers et al (268)	558	Death, MI, revascularization, hospital admission	1	32% angina-guided medical strategy 31% ischemia-guided medical strategy 18% revascularization strategy	0.003
Dargie et al (269)	682	Cardiac death, nonfatal MI, and unstable angina	2	13% atenolol 11% nifedipine 8% combination	NS
		Revascularization, worsening angina		8% atenolol 9% nifedipine SR 3% combination	NS
Von Arnim (270)	520	Death, MI, unstable angina, or revascularization	1	32% for non-100% responders 18% for 100% responders	0.008
				33% for nifedipine 22% for bisoprolol	0.03

SR indicates sustained release.

Table 14. Yield of AECG Monitoring for Evaluation of Palpitation in Pediatric Patients With No Structural Heart Disease

Author (Reference)	No. of Patients	Method	Symptoms During Monitoring, n (%)		No Symptoms During Monitoring,† No Arrhythmia, n (%)	Method	Mean No. of Days of Monitoring
			Arrhythmia	No Arrhythmia			
Dick et al (272)	6	E	2 (33)	4 (67)	0	E	
Fyfe et al (273)	41	E	9 (22) (8 SVT)	12 (29)	20 (49)	E	75
Porter et al (274)	25	H	3 (12)	9 (36)	13 (52)	H	1
Goldstein et al (275)	48	E	10 (21) (7 SVT)	15 (31)	23 (48)	E	14–90
Karpawich et al (276)	37	E	10 (27)	27 (73)	0	E	30
Karpawich et al (276)	45	H	0	9 (20)	36 (80)	H	1
Houyel et al (277)	201*	E	24 (12) (23 SVT)	112 (56)	65 (32)	E	85
Total	403		58 (14)	188 (47)	157 (39)		

E indicates patient-activated event recorder; SVT, supraventricular tachycardia; and H, Holter (continuous 24-h recorder).
*Includes 25 patients with heart disease.
†Recognition of asymptomatic arrhythmias limited because event recorder would not be activated by patient.

A. Evaluation of Symptoms

The use of AECG monitoring in pediatric patients for the evaluation of symptoms possibly related to an arrhythmia in the absence of heart disease has been the subject of several reports (272–277). These symptoms include palpitation, syncope or near syncope, and chest pain. Regarding palpitation, a patient-activated recorder is generally recommended because of the paroxysmal nature of the symptom. An arrhythmia, usually supraventricular tachycardia, has been reported to correlate with palpitation in 10% to 15% of young patients, whereas ventricular ectopy or bradycardia is demonstrated in another 2% to 5% (Table 14). By comparison, sinus tachycardia is identified in nearly 50% of young patients with symptoms of palpitation during ambulatory monitoring, whereas 30% to 40% of patients have no symptoms during monitoring. Therefore, one of the primary uses of AECG monitoring in pediatric patients is to exclude an arrhythmia as the cause of palpitation.

The role of AECG monitoring in young patients with transient neurological symptoms (syncope, near syncope, or dizziness) in the absence of structural or functional heart disease is limited (278). The intermittent nature of symptoms results in a low efficacy of 24 to 48 hours of continuous ECG monitoring; conversely, temporary patient incapacitation usually precludes patient-activated recording (279). Continuous ECG monitoring is primarily indicated in pediatric patients with exertional symptoms or those with known heart disease, in whom the presence and significance of an arrhythmia may be increased (278,280).

Chest pain may be evaluated by either continuous or patient-activated ECG monitoring. However, a cardiac cause of chest pain is identified in <5% of pediatric patients (281). Most AECG studies in pediatric patients have reported no yield in the evaluation of chest pain (273,275,281). Therefore the primary role of AECG monitoring in pediatric patients with chest pain may be to exclude rather than to diagnose a cardiac cause. However, although reassuring to the physician, exclusion of an arrhythmia as the cause of palpitation or chest pain may not alter the patient's perception of a possible cardiovascular problem (282).

B. Evaluation of the Patient With Known Cardiovascular Disease

AECG monitoring is commonly used in the periodic evaluation of pediatric patients with heart disease, with or without symptoms of an arrhythmia. The rationale for this testing is the evolution of disease processes (such as long QT syndromes or hypertrophic cardiomyopathies), growth of patients and the need to adjust medication dosages, and the progressive onset of late arrhythmias after surgery for congenital heart defects.

The use of AECG monitoring for periodic evaluation of patients with prior surgical treatment of congenital heart disease must be based on consideration of the type of defect, ventricular function, and risk of late postoperative arrhythmias. For example, uncomplicated repairs of atrial or ventricular septal defects are associated with a low incidence of late postoperative arrhythmias (283). Conversely, complex repairs or those with residual hemodynamic abnormalities have a well-recognized incidence of late-onset atrial and ventricular arrhythmias (284,285). Although the significance of arrhythmias in these patients remains controversial, high-grade ambulatory ventricular ectopy associated with ventricular dysfunction does appear to identify patients at an increased risk of late sudden death (286,287). Complex arrhythmias detected in these patients by AECG may indicate the need for further investigation, even in the absence of overt symptoms (288).

Periodic AECG monitoring for young patients with hypertrophic or dilated cardiomyopathies or the long QT syndromes is recommended because of the progression of these diseases and the need to adjust medication doses with growth. The risk of sudden death with these diseases is much greater in pediatric patients than adults, with sudden death a first symptom in 9% to 15% of patients (289,290). One primary role of AECG monitoring is to identify occult arrhythmias, which may indicate the need for reevaluation of therapy in an asymptomatic patient. However, the absence of an arrhythmia during monitoring does not necessarily indicate a low risk of sudden death.

AECG monitoring has a limited role for establishing a diagnosis of long QT syndrome in patients with borderline QT prolongation. This is due to differences in sampling, signal filtering, and recording methods compared with conventional ECG (291).

AECG monitoring may be used to identify asymptomatic patients with congenital complete AV block at increased risk for sudden arrhythmic events and who thus may benefit from prophylactic pacemaker implantation (292). Conversely, routine AECG evaluation of asymptomatic patients with preexcitation syndromes (Wolff-Parkinson-White) has not been demonstrated to define patients at risk for sudden arrhythmic death (293).

Unexplained syncope or cardiovascular collapse in patients with cardiovascular disease generally requires in-hospital continuous ECG monitoring, with an invasive evaluation when the cause of the event is uncertain (294). However, if a cause cannot be established by invasive methods, AECG monitoring may be used for subsequent evaluation to evaluate for both transient bradyarrhythmias and tachyarrhythmias (295).

C. Other Medical Conditions

Arrhythmias have become increasingly recognized in young patients with a number of diverse medical conditions. These include Duchenne or Becker muscular dystrophy, myotonic dystrophy, and patients who are survivors of childhood malignancies. Limited data would suggest that AECG monitoring may be indicated in these patients in the presence of symptoms compatible with an arrhythmia because of the potential for both ventricular arrhythmias and progressive conduction system disease (296–299).

D. Evaluation After Therapy or Intervention

AECG monitoring is useful to evaluate both beneficial and potentially adverse responses to pharmacological therapy in pediatric patients (300,301). The limitations of AECG monitoring as the result of day-to-day variance in ventricular ectopy have been discussed in Section 6. Additional indications for AECG monitoring include the evaluation of symptoms in patients with pacemakers or after radiofrequency catheter ablation or heart surgery, particularly when complicated by transient AV block (302,303). Specific considerations in the use of AECG monitoring for assessment of pacemaker function are addressed in Section 7. AECG monitoring is also indicated for the evaluation of cardiac rhythm after treatment of incessant tachyarrhythmias, which have been associated with progressive ventricular dysfunction (304).

Indications for AECG Monitoring in Pediatric Patients

Class I

1. **Syncope, near syncope, or dizziness in patients with recognized heart disease, previously documented arrhythmia, or pacemaker dependency**
2. **Syncope or near syncope associated with exertion when the cause is not established by other methods**
3. **Evaluation of patients with hypertrophic or dilated cardiomyopathies**
4. **Evaluation of possible or documented long QT syndromes**
5. **Palpitation in the patient with prior surgery for congenital heart disease and significant residual hemodynamic abnormalities**
6. **Evaluation of antiarrhythmic drug efficacy during rapid somatic growth**
7. **Asymptomatic congenital complete AV block, non-paced**

Class IIa

1. **Syncope, near syncope, or sustained palpitation in the absence of a reasonable explanation and where there is no overt clinical evidence of heart disease**
2. **Evaluation of cardiac rhythm after initiation of an antiarrhythmic therapy, particularly when associated with a significant proarrhythmic potential**
3. **Evaluation of cardiac rhythm after transient AV block associated with heart surgery or catheter ablation**
4. **Evaluation of rate-responsive or physiological pacing function in symptomatic patients**

Class IIb

1. **Evaluation of asymptomatic patients with prior surgery for congenital heart disease, particularly when there are either significant or residual hemodynamic abnormalities, or a significant incidence of late postoperative arrhythmias**
2. **Evaluation of the young patient (<3 years) with a prior tachyarrhythmia to determine if unrecognized episodes of the arrhythmia recur**
3. **Evaluation of the patient with a suspected incessant atrial tachycardia**
4. **Complex ventricular ectopy on ECG or exercise test**

Class III

1. **Syncope, near syncope, or dizziness when a noncardiac cause is present**
2. **Chest pain without clinical evidence of heart disease**
3. **Routine evaluation of asymptomatic individuals for athletic clearance**
4. **Brief palpitation in the absence of heart disease**
5. **Asymptomatic Wolff-Parkinson-White syndrome**

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