

Ambulatory Holter Electrocardiography: Choice of Technologies and Clinical Uses

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Rapid growth in the use and complexity of Holter monitoring technologies has resulted in the diverse recorders and analysis devices that are compared in this review. Holter recording modes include continuous recording, which makes all electrocardiographic (ECG) data available for analysis; patient-activated recording, which is useful for capturing infrequent symptomatic arrhythmias; and event recording, which provides data on ECG events detected by the recorder, but whose reliability is limited. Various sophisticated, computer-based analysis systems exist, with varying prices and degrees of accuracy and reliability. Quantitative data are essential in the use of Holter monitoring to define the response of ventricular arrhythmias to therapeutic interventions, but the physician must be wary of quantitative data unless a quality-control program has been established and validated. Although Holter monitoring is safe, problems in recording and in differentiating artifacts from true cardiac rhythm disturbances may result in false clinical diagnoses unless these problems are recognized.

EVIDENCE IS MOUNTING that the diagnosis (1) and successful treatment (2) of ventricular arrhythmias reduce morbidity and mortality in patients at high risk of sudden cardiac death, and that the mechanism responsible for sudden death is, in more than 80% of patients, a ventricular tachyarrhythmia (3). Thus it is not surprising that in the last few years the use and complexity of Holter technologies for detecting and evaluating ventricular arrhythmias have grown rapidly. It has been estimated that revenues from Holter equipment will increase from about \$65 million in 1983 to over \$80 million in 1988. Revenues from scanning services are expected to increase from about \$138 million in 1983 to over \$300 million in 1988. Because most ventricular arrhythmias are often asymptomatic and do not correlate well with patient symptoms (4), their detection cannot rely on the clinical history, which is nonspecific and insensitive and whose main usefulness is to identify conditions that can trigger ventricular arrhythmias. Because of the high rate of spontaneous variability (5) of ventricular arrhythmias on electrocardiographic (ECG) recordings and exercise testing (6), ambulatory long-term ECG, or Holter monitoring is the most sensitive and specific means of detecting and evaluating arrhythmias (7).

Because of the rapid growth in the use of Holter monitoring and because its development has been undertaken primarily by commercial manufacturers, prospective studies to define quantitatively and qualitatively the rela-

tive cost : benefit of the various types of equipment have not been done.

This review describes the array of currently available Holter ambulatory ECG recorders and analysis systems, which is confusing to many clinicians. To date, no prospective comparative studies have evaluated the various Holter systems; thus, comments as to their relative usefulness and cost effectiveness are solely the opinion of the author.

Clinical Role of Holter Monitoring

The current clinical uses of Holter monitoring are listed in Table 1. The primary uses of Holter systems are to detect supraventricular and ventricular arrhythmias in patients with conditions that place them at high risk for these disorders, and to find arrhythmias that cause specific patient complaints. Holter monitoring has been used in epidemiologic and clinical studies to detect arrhythmias and assess risk of sudden cardiac death (1). Once an arrhythmia is detected, Holter monitoring is used also to detect a change in the frequency or severity of the arrhythmia after a therapeutic intervention. Evaluation is critical not only to ascertain the degree of success of the intervention but also to detect the opposite effect, a proarrhythmic response (8). Other uses of Holter monitoring include the evaluation of ST-segment structure in patients with documented or suspected ischemic heart disease, including those with coronary spasm, and the detection of pacemaker malfunction (9). Holter monitoring, with its diagnostic and therapeutic applicability, has emerged as one of the most frequently used and important tools of clinical medicine.

Origin of Holter Monitoring

The original Holter monitor was a 38.6-kg. backpack radio transmitter with limited range. After the invention of the transistor in the mid-1950s, a portable, magnetic-tape "electrocardiocorder" was developed that weighed only 1.8 kg and could record for up to 10 hours (10). The technique used to analyze this recorder's data was the superimposition of successive ECG complexes at 60 times faster than real time. An audio signal, the tone of which was altered by heart rate, was added, and the result was termed an audiovisual super-imposed electrocardiographic presentation (AVSEP), or a super-imposed ECG system (11)(Figure 1 Top). Further technologic developments in the 1960s produced a system that allowed for the direct recording of the ECG through elec-

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Table 1. Clinical Uses of Ambulatory Electrocardiography

Detect supraventricular and ventricular arrhythmias
In patients with conditions placing them at high risk for having asymptomatic arrhythmias
To correlate patient symptoms with arrhythmia occurrence
Detect paroxysmal heart block
Detect change in the frequency and severity of arrhythmias after therapeutic intervention
Detect change in ST-segment structure in patients with or without suspected ischemic heart disease
Detect pacemaker dysfunction

trodes attached to a patient's chest for several hours. After early clinical reports that Holter monitoring had found a relation between ventricular arrhythmias and heart-disease mortality (12), Holter monitoring was widely adopted. Studies using Holter monitoring have increased the physician's awareness of the importance of ventricular arrhythmias in various cardiac diseases, and as the technology has improved the potential of Holter monitoring for evaluating ST-segment changes and pacemaker functioning has emerged (9). The new technology, with its various applications, has demanded attention to the accuracy and reliability of the analytic and recording methods (13, 14).

The superimposed ECG system was released to private industry (Avionics Research Division of Del Mar Engineering Laboratories, now Del Mar Avionics; Irvine, California), which developed recorders capable of recording continuously for 8, 10, 12, and finally 24 hours. The development of printed circuit boards and smaller transistors made possible the manufacture of smaller recorders capable of longer recording (24 to 48 h) and playback systems that allow for various complex data analyses. Recently, the introduction of solid-state microprocessors, microcomputers, and integrated circuits has allowed even more flexible and versatile handling of data.

Recorders

The recorder for ambulatory ECG data has bipolar skin electrodes that record the difference of potential at two electrode sites. The conventional Holter recorder samples ECG data comparable to data recorded by leads V1 and V5 of the standard 12-lead ECG. The skin electrodes are usually disposable, pre-jelled, and self-adhering, and contain a silver-chloride-sensing element. Electrode adhesiveness and degree of skin irritation are extremely important determinants of ECG signal quality in regard to baseline wandering, degree of artifact, and duration of performance. The electrode leads and the shielded cable that connects the leads to the recorder are generally reusable. The leads may contribute to artifact, and the cable may be a source of artifact or recording malfunction. The 5-lead system, which has a separate negative electrode for each exploratory electrode in addition to an external ground, is preferable, particularly because if an electrode dislodges at least one ECG channel often will still be recorded.

The recorder itself is usually compact and is powered by either a disposable alkaline or rechargeable nickel cadmium battery. A varying DC current from a signal re-

cording head is recorded directly onto magnetic tape in the recorder. The tape is driven by a hysteresis-synchronous motor and the electrical signal of 0.05 to 100 Hz (at -3 dB) is recorded on either a reel-to-reel or cassette magnetic tape. Cassette recorders are generally lighter than reel-to-reel recorders and thus more convenient for technicians and less obtrusive for patients. Reel-to-reel recorders, however, have better signal-to-noise ratio, dynamic range, and speed stability, with less wow and flutter and fewer recording failures. Reel-to-reel recorders use tape of either chromium dioxide or ferric oxide that is 6.4 mm wide and usually 4 to 5 mm thick. Wide two-track recording heads and, frequently, three-phase motors are used. In contrast, cassette recorders use tape that is 3.2 mm wide and typically 2 to 3 mm thick, usually of ferric oxide. Narrow four-track recording heads and less stable motor transmissions are used. Internal millivolt calibration is important in the recorder, particular if ST-segment changes are to be measured. Two channels of ECG recording are used by most recorders, and it is possible to adapt one of these channels to augment the pacemaker stimulus to facilitate evaluation of pacemaker function. Other recorders now available can also simultaneously record ambulatory blood pressure, electroencephalographic data, and respiratory rate. In clinical settings cassette recorders are predominantly used, because of their light weight and more convenient size. Reel-to-reel recorders are preferred for research purposes, particularly for the evaluation of the effects of new antiarrhythmic drugs. Some of the available Holter ECG recorders are compared in Table 2.

Recording Modes

Three types of recording modes have been developed in the last several years: continuous; intermittent or patient-activated recording; and real-time analytical or event recording. Continuous Holter recording is, as the name implies, the process of recording continuously the ECG without alteration by the patient or a change in the ECG signal. Thus, all ECG data are recorded during the recording session. Continuous recorders allow for 24 hours of recording; after 24 hours of use, the tape and battery must be replaced. These recorders usually have a 1-mV calibration signal and a timing reference that the patient can use to mark an event on the tape. Usually the patient also notes these events in a diary.

Intermittent recording allows the patient to initiate recording manually or by automatic time-activation. This system has been used less in recent years than previously, because of significant improvements in the continuous and real-time event models. Intermittent, patient-activated recording may be used telephonically, by transmission of one channel of ECG data over the telephone to a strip chart recorder. Whereas earlier devices had no internal storage and therefore had to be used in "real time," current technology allows for storage of ECG data for later telephonic transmission. Shortcomings of this system are that ECG data on events before activation of the recorder are not obtained, and if the memory becomes filled before the patient can telephone to transfer the information, im-

portant data can be lost.

Real-time event recorders contain a microprocessor that analyzes one or two channels of ECG data as they are being recorded and stores only those abnormal patterns that it is programmed to store. These recorders usually weigh 50% to 100% more than continuous recorders and cost three to five times more, but the playback system is considerably less complicated. The event recorder stores only about 30 minutes of selected information for subsequent printout. Disadvantages of this recorder include that it will cease to record if the memory is full and that all information in the memory can be lost if the battery fails. The accuracy of the final analysis, of course, depends on the appropriateness of the algorithm used for initial ECG event detection, including its ability to recognize artifact. The accuracy and reliability of real-time event recorders have been questioned, in regard to their ability to detect important transient ECG events, such as single ventricular triplets. Direct comparison of event recorders with continuous recorders, however, has not yet been made (15).

Analysis Systems

Although Holter recorders tend to be fairly similar in design and performance, the analysis systems differ greatly in their hardware configurations, capabilities, and prices (Table 3). Significant improvement in integrated computer processors has given rise to sophisticated digital analysis systems. Future improvements in memory and logic chips will increase storage density, and analysis systems will soon become faster, more accurate, and more cost-efficient.

The hardware-based analog scanners that use superimposed ECG technology were the mainstay of ECG analysis until just a few years ago. These systems are now essentially outmoded. A modern analysis system includes a playback deck for reel-to-reel or cassette tapes and an oscilloscope for operator interaction with the system. Recently, playback scanners have incorporated analog-to-digital converters and electronic memories. With these features, the ECG can be memorized at high speed and segments can be played back through digital-to-analog converters to provide real-time ECG strip documentation. The oscilloscopes can show superimposed sinus complexes at one location on the screen, ectopic ventricular complexes at a second, and ectopic supraventricular complexes at a third (Figure 1 Top). Other systems use the oscilloscope to spread out ECG data over time on the screen for direct analyst interaction (16). A freeze memory display of real-time data ranging from 15 to 180 seconds can be shown. Also incorporated into playback systems are an ECG chart printout that can provide real-time, trend, or graft presentations of data. The playback deck can read, and the oscilloscope display, data at 30 to 480 times real time.

Older equipment had an audiospeaker that emitted a buzz whose tone would change with heart rate and ectopic interval to alert the operator to an ECG change. The outmoded hardware-based systems examined primarily the RR interval for prematurity, width, amplitude, and

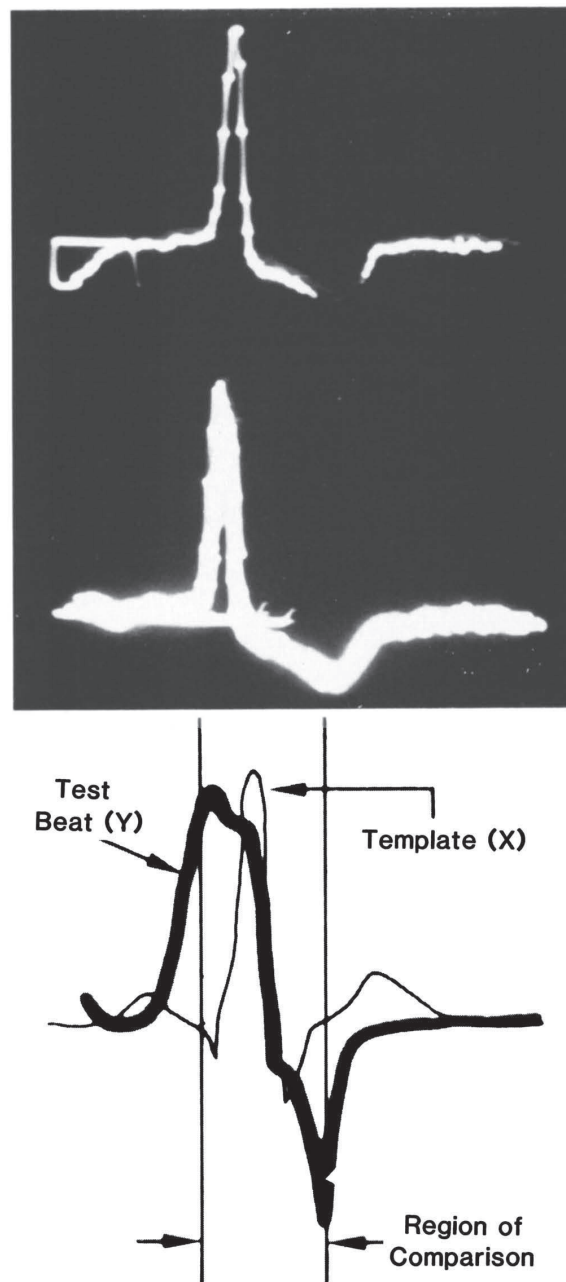


Figure 1 Top. Audiovisual superimposed electrocardiographic presentation (AVSEP). Ectopic beats are identified by change in the structure or audio tone generated by superimposition of ongoing QRS complexes. **Figure 1 Bottom.** Computerized "template" of the underlying normal QRS complex (X) and an ectopic complex termed a "test beat" (Y). Beat Y is matched to beat X by the computer during the region of comparison by cost correlation algorithms.

duration of the QRS complex. Thus the QRS-complex area was used to distinguish normal sinus complexes from ectopic complexes and artifacts. In some analysis

Table 2. Features of Holter Recorders*

	Hittman Comp Act 4	ICR 7200	Marquette 8500	Oxford MR-10/ MR-14	United Medical CT-I
Record mode	Continuous cassette	Continuous cassette	Continuous cassette	Continuous cassette	Continuous cassette
Approximate weight, kg	0.6	0.8	0.5	0.4	0.5
Channels, <i>n</i>	2	2	2	2	4
Patient event marker	Yes	Yes	Yes	Yes	Yes
Lead signal test	Yes	Yes	Yes	Yes	Yes
Battery type	9V	6V or recharge	9V	5.4V	5.4V
Internal calibration signal	Yes	Yes	Yes	No	No
Compatible with other systems	Yes	Hittman only	No	Hittman only	Yes
Clock display	Yes	Yes	Yes	No	Yes

* Manufacturers of the respective recorders are as follows: Hittman Corporation, Columbia, Maryland; ICR, Inc., Liverpool, New York; Marquette Electronics, Milwaukee, Wisconsin; Oxford Medilog, Inc., Clearwater, Florida; United Medical Corp., Haddonfield, New Jersey; Del Mar Avionics, Irvine, California; Scole, Culver City, California; Circadian, Inc., Sunnydale, California; Datamedix, Sharon, Massachusetts; Aegis Medical Systems, Inc., Mt. Laurel, New Jersey.

systems, the complexes to be identified were fixed; in others, the operator could specify them depending on initial recordings. It is obviously impractical to preset such equipment to detect all or most forms of ectopic complexes and to distinguish them from artifacts. Currently available systems are more accurate, in that their microprocessor playback systems can store QRS-complex waveforms and create "templates" that can be used for data correlation (Figure 1 Bottom). The normal QRS template is continuously updated and can be compared with templates of new events to distinguish them as artifacts or ectopic complexes; thus, separate template counts for each event can be made. The operator may program the computer to recognize and thus quantitate these various templates.

The use of a few measurement features to differentiate between the types of QRS complex is called feature ex-

traction. When QRS complexes are grouped into templates and a cross-correlation algorithm is used to determine the type of complex, a more accurate analysis results if data reduction is used. Cross-correlation techniques require a much more sophisticated computer system.

The high-speed data-reduction processors that use semi-automated modes of processing are described in Table 3. Of the seven examples chosen, the first three use powerful 16-byte microcomputers as the central processing unit, which is buffered with a rigid-disk drive. Their costs range, depending on the options selected, from \$60 000 to \$90 000. The next three are microprocessors but do not use a rigid-disk system and lack the flexibility afforded by such a feature. Their costs, depending on the options selected, range from \$40 000 to \$100 000. The Oxford Medilog 2 (Oxford Medilog, Inc.; Clearwater,

Table 3. Features of Holter Analysis Systems*

	Accelerated Analysis via Processor-Technician Interface						
	United Medical CT-240	Marquette 8000	Cardio-Data MK III	Avionics Trendsetter	Hittman Compu- scan III	ICR 6201	Oxford Medilog 2
Rigid disk microcomputer	Yes	Yes	Yes	No	No	No	No
Digital analysis	Yes	Yes	Yes	Yes	Yes	Yes	No
Simultaneous analysis	Yes	Yes	No	No	No	No	No
Can print out all 24 h of data from tape	Yes	No	No	Yes	No	Yes	No
Automated wave-form analysis done in sequential page mode	Yes	No	No	No	No	No	No
AVSEP analysis	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Display separation of arrhythmias	Yes	Yes	Yes	No	No	No	No
Scanning speed	240X	60-240X	120X	60-120X, 240X	60-120X, 240X	60-120X	60X, 120X
Heart-rate display	Yes	Yes	Yes	Yes	Yes	Yes	No
Static display content, s	10, 80, 160	10	8, 30	120	64	32	120
Adjustable arrhythmia criteria	Yes	No	Yes	Yes	Yes	Yes	No
Automatic arrhythmia detection	Yes	Yes	Yes	Yes	Yes	Yes	No

* Manufacturers of the respective systems are as follows: United Medical Corp., Haddonfield, New Jersey; Marquette Electronics, Milwaukee, Wisconsin; Cardio-Data Corp., Marlboro, Massachusetts; Avionics Del Mar, Irvine, California; Hittman Corp., Columbia, Maryland; ICR, Inc., Liverpool, New York; Oxford Medilog, Inc., Clearwater, Florida; Zymed, Camarillo, California; American Edwards, Santa Ana, California; Circadian, Inc., Sunnyvale, California; Datamedix, Sharon, Massachusetts; Aegis Medical Systems, Inc., Mt. Laurel, New Jersey. ECG = electrocardiogram; AVSEP = audiovisual superimposed ECG presentation; NA = not applicable.

Table 2. (Continued)

Avionics 445	Scole	United Medical CT-II	Circadian Circamed	Datamedix Peggysys	Aegis	
Continuous reel-to-reel	Continuous reel-to-reel	Continuous reel-to-reel	Time, event, or patient activated	Event activated	Event activated	Record mode
0.8	0.6	0.3	0.9	0.6	0.9	Approximate weight <i>kg</i>
2	2	2	1	2	2	Channels, <i>n</i>
Yes	Yes	Yes	Yes	Yes	Yes	Patient event marker
Yes	Yes	Yes	Yes	Yes	Yes	Lead signal test
9V or recharge	9V	9V	Two size-AA	Two 9V	Five size-AA	Battery type
No	No	Yes	No	Yes	Yes	Internal calibration signal
Yes	Avionics only	Yes	No	No	No	Compatible with other systems
Yes	Yes	Yes	No	Yes	Yes	Clock display

Florida) is an example of the older analog-based processing systems and usually costs less than \$40 000.

The rigid-disk systems are the most advanced and filter original two-channel analog ECG tape for frequency and voltage artifacts localized in software. Analog-to-digital conversion takes place, and data are stored on a hard disk. During a second pass of the ECG tape, digital QRS data are analyzed in core memory by an algorithm to detect ectopic complexes using both feature extraction and cross-correlation techniques. Templates and special forms, such as salvos of ventricular tachycardia, are printed out as examples on an ECG strip and then can be edited and formatted or numerical data generated (Figures 2-4). The algorithm driving the system is complex and written in both low- and high-level computer languages; it is significantly more adaptable for higher-quality interpretation than the non-rigid disk systems. In the hard-disk systems, the patient's normal QRS complex is used as a reference and the 16-byte resolution enables a

more accurate digital QRS representation to be constructed than is achievable with systems that do not use rigid disk systems or with real-time analyzers that have only 8-byte processors. Thus, better template matching with few adaptability problems can be accomplished with the disk systems. Within these disk systems, the ability to analyze both ECG leads simultaneously is helpful in detecting artifacts. Non-disk systems lack full disclosure capability and are capable of only limited graphics and limited display separation of arrhythmias.

Another type of Holter analyzer performs no automatic ventricular arrhythmia detection but rather simply displays the entire ECG recording on a monitor or prints it out in miniaturized form, or both (Figure 5). This mini-ECG presents all recorded data but does not accurately quantitate the data. Manual quantitation is possible but tedious and possibly imprecise. Whereas these systems are inexpensive and can be used in physicians' offices for arrhythmia screening, they are probably inadequate for

Table 3. (Continued)

Manual Analysis of Miniaturized ECG Complexes		Real-Time Analysis by Holter Recorder			
Zymed	American Edwards Eliminator	Circadian Circamed	Datamedix Peggasy	Aegis Medical	
No	No	No	No	No	Rigid disk microcomputer
Yes	No	Yes	Yes	Yes	Digital analysis
No	No	No	No	No	Simultaneous analysis
No	Yes	No	No	No	Can print out all 24 h of data from tape
No	No	No	No	No	Automated wave-form analysis done in sequential page mode
No	No	No	No	No	AVSEP analysis
No	No	No	No	No	Display separation of arrhythmias
Page mode	480X	Event	Event	Event	Scanning speed
No	No	No	Yes	Yes	Heart-rate display
120	NA	NA	NA	NA	Static display content, s
No	NA	No	No	No	Adjustable arrhythmia criteria
No	No	Yes	Yes	Yes	Automatic arrhythmia detection

GENERAL PROFILE										
TIME ENDING	HEART LO MEAN	RATE HI	TOTAL BEATS	RHYTHM	SVPB TOTAL	SVPB PER 1000 HB	VPB TOTAL	VPB PER 1000 HB	TIME ANALYZED	
10:00.BA1	52	61	96	inus	38	8.52	334	94.94	10:57.0	
11:00.BA1	52	78	116	inus	49	18.35	1159	245.03	11:00.0	
12:00.BA1	54	77	109	inus	45	12.91	1898	544.77	12:00.0	
1:00.BP1	64	77	109	inus	28	6.35	130	38.58	1:59.5	
2:00.BP1	56	63	84	inus	74	19.42	301	79.02	2:59.5	
3:00.BP1	54	61	88	inus	50	12.42	425	114.09	3:59.5	
4:00.BP1	54	58	72	inus	27	6.66	541	151.56	4:59.5	
5:00.BP1	50	57	70	inus	30	5.74	347	99.65	5:59.5	
6:00.BP1	50	54	72	inus	16	4.04	238	102.22	6:59.5	
7:00.BP1	48	51	76	inus	28	8.92	367	115.62	7:59.5	
8:00.BP1	52	51	70	inus	41	12.35	298	89.78	8:59.5	
9:00.BP1	50	54	70	inus	47	14.32	307	117.91	9:59.5	
10:00.BP1	50	55	66	inus	31	6.30	600	182.47	10:59.5	
11:00.BP1	54	63	84	inus	77	20.09	578	150.07	11:59.5	
12:00.BA2	54	63	84	inus	59	15.41	873	228.05	12:59.5	
1:00.BA2	54	77	109	inus	48	9.92	749	175.34	1:59.5	
2:00.BA2	50	57	82	inus	28	8.13	562	163.22	2:59.5	
3:00.BA2	52	59	86	inus	48	11.18	822	229.53	3:59.5	
4:00.BA2	54	71	116	inus	45	9.92	964	218.30	4:59.5	
5:00.BA2	70	87	114	inus	86	16.28	829	157.00	5:59.5	
6:00.BA2	66	88	120	inus	119	22.25	484	75.54	6:59.5	
7:00.BA2	66	90	120	inus	99	18.07	391	71.38	7:59.5	
8:00.BA2	64	81	122	inus	125	25.68	465	94.78	8:59.5	
8:31.2AZ	64	75	98	inus	36	15.92	321	142.03	9:30.1	
SUMMARY:	48	67	122		1241	13.18	14596	155.05	23:21.7	

Figure 2. A suggested format for presenting data derived by quantitative analysis of Holter data. The top represents a general profile, and the bottom, a specific profile of ventricular ectopic beats. See Figure 3. SVPB = supraventricular premature beat; HB = heartbeat; VPB = ventricular premature beat; VT = ventricular tachycardia.

VENTRICULAR ECTOPY PROFILE										
TIME ENDING	HEART LO MEAN	RATE HI	VPB TOTAL	VPB'S SINGLE	VPB'S PAIRED	VT BEATS	VT EVENTS	VPB'S R ON T	MULTI FORM	TIME ANALYZED
10:00.BA1	52	61	96	334	243	66	25	8	VEC	10:57.0
11:00.BA1	52	78	116	1159	713	292	54	16	VEC	11:00.0
12:00.BA1	54	77	109	1898	1279	566	53	18	VEC	12:00.0
1:00.BP1	64	77	109	635	375	226	34	10	VEC	1:59.5
2:00.BP1	56	63	84	301	251	38	12	4	VEC	2:59.5
3:00.BP1	54	61	88	425	251	38	12	4	VEC	3:59.5
4:00.BP1	54	58	72	541	318	100	13	4	VEC	4:59.5
5:00.BP1	50	57	70	347	245	73	8	8	VEC	5:59.5
6:00.BP1	50	54	72	238	161	12	3	8	VEC	6:59.5
7:00.BP1	48	51	76	367	236	16	3	8	VEC	7:59.5
8:00.BP1	52	51	70	298	296	12	3	8	VEC	8:59.5
9:00.BP1	50	54	70	307	226	12	3	8	VEC	9:59.5
10:00.BP1	50	55	66	600	303	12	3	1	VEC	10:59.5
11:00.BP1	54	63	84	578	358	88	22	16	VEC	11:59.5
12:00.BA2	54	77	109	749	458	88	19	16	VEC	12:59.5
1:00.BA2	54	77	109	749	458	72	19	16	VEC	1:59.5
2:00.BA2	50	57	82	562	344	18	20	9	VEC	2:59.5
3:00.BA2	52	59	86	822	544	28	20	9	VEC	3:59.5
4:00.BA2	54	71	116	964	745	38	20	24	VEC	4:59.5
5:00.BA2	70	87	114	829	537	228	22	24	VEC	5:59.5
6:00.BA2	66	88	120	484	289	98	22	24	VEC	6:59.5
7:00.BA2	66	90	120	391	275	104	22	4	VEC	7:59.5
8:00.BA2	64	81	122	465	304	72	9	3	VEC	8:59.5
8:31.2AZ	64	75	98	321	282	38	9	3	VEC	9:30.1
SUMMARY:	48	67	122	14596	11014	2256	526	160	#	23:21.7

accurate detection of infrequent but potentially important complex ECG forms, such as ventricular triplets, or for accurate measurement of the frequency of ventricular arrhythmias, which is required to determine the effects of therapeutic interventions.

Real-time analyzers, or event recorders, are digitally based and use microprocessors to detect automatically arrhythmias during the recording mode, while the recorder is being worn by the patient. The accuracy and reliability of its arrhythmia-detection algorithm—the basis of the system—for quantitation of infrequent but important events have yet to be formally compared with those of continuous recording and analysis systems. Real-time systems do not analyze the P-wave and may have difficulty with the ST segment. An advantage is that little or no technical personnel are required for analysis, which reduces the cost of the procedure, although the recorder itself is more expensive. Only limited data are presented to the physician, depending on the quality of the ECG algorithm. A disadvantage is that because only a single channel ECG is analyzed, the ability to quantitate normal or abnormal data and to identify artifact may be poor. The frequency response of event recorders is not as good as that of continuous recording systems, and no assessment of the patient's normal ECG or trend data are obtainable. Data validation is not possible, and event recorders tend to be bulkier.

"Sampling" recorders record ECG data automatically every few seconds or minutes. In addition, the patient

may activate a button to initiate recording. This system requires little technical help and may be quite valuable for patients with infrequently symptomatic arrhythmias.

Quality Control of Analysis

Holter analysis systems should be subjected to standard external and internal quality control programs to evaluate their accuracy compared with that of a fully recorded and counted ECG printout at 25 mm/s. The American Heart Association provides Holter tape databases for quality control; these tapes are more useful for intensive care unit monitoring systems than for high-speed, interactive, tape-playback analysis systems. Also, these databases tend not to have sufficient examples of artifact to provide an excellent test for this important problem. Thus, each analysis system and Holter laboratory must have individual quality control standards, using 24-hour tapes that have had ECG abnormalities counted by hand in real time. Physicians must be wary of data from Holter monitors that have not been subjected to a rigid quality control program to ensure accuracy and repeatability of the quantitative data. The user should inquire whether such a program is used in the laboratory and understand its nature. Reports of quality control programs should be reviewed to determine the level of accuracy.

Data Formatting

Characteristics measured by Holter systems should in-

clude precise details of any supraventricular and ventricular arrhythmias that are detected and heart rate. This information should be presented in terms of the low, high, and mean frequency of these events over 24 hours and for each hour of the recording. Specifically, these items should include heart rate, supraventricular premature complexes, ventricular premature complexes, ventricular couplets, and ventricular tachycardia (both beats and events) (Figures 2, 3 and 4). The time actually analyzed should be noted for each hour. In addition, important changes in the PR, QRS and JT intervals should be noted.

Other measurements that should be noted include the frequency and degree of ECG pauses, including second- and third-degree atrioventricular blocks, bradyarrhythmias and tachyarrhythmias, R-on-T phenomena, and changes in the ST segment. Pauses can be clearly defined as the absence of any ECG data over a period of time. A heart rate exceeding a low or high limit signals a bradycardia or tachycardia. Missed beats can be analyzed as to whether they represent blocked ectopic complexes or atrioventricular block. The R-on-T phenomena can be identified by analysis of the RR interval. Because T waves are not recognized by these systems, all R-on-T phenomena must be verified by the technician. ST-segment changes can be identified by using certain timing and voltage references and identification of the electrical baseline and J point. ST-segment changes are usually measured in terms of the amount of negative deflection of the isoelectric level at 60 to 80 ms after the J point. The slope of the ST segment can be described as flat, upward, or downward. Most commercially available systems record only the deflection of the ST segment, not its slope. It is important that the system used meets the American Heart Association standards for frequency response. Trend records of heart rate and ST-segment change are of potential value when correlated with clinical events.

Because of the variety of phenomena that can be detected and classified with the new arrhythmia analysis systems, formatting has become important for understanding the data. Almost all systems should show samples of various abnormalities, such as R-on-T phenomena, ventricular couplets, ventricular tachycardia, and degrees of atrioventricular block, so that the physician reviewing the Holter report will be able to assess the degree of confidence and quality of the technician-computer interaction. Although there are no standards for reporting such details, the display of ECG examples recorded while the patient was having symptoms (as recorded in the diary), graphic or tabular representations of heart rate and ST-segment changes, and a quantitation of the various forms of atrial and ventricular arrhythmias are of great value to the clinician.

Problems in the Use of Holter Monitoring

Holter monitoring is a noninvasive procedure that has no immediate adverse effects. Although skin irritation or hypersensitivity from the electrode gel is possible, patients have been exposed to Holter monitoring for as

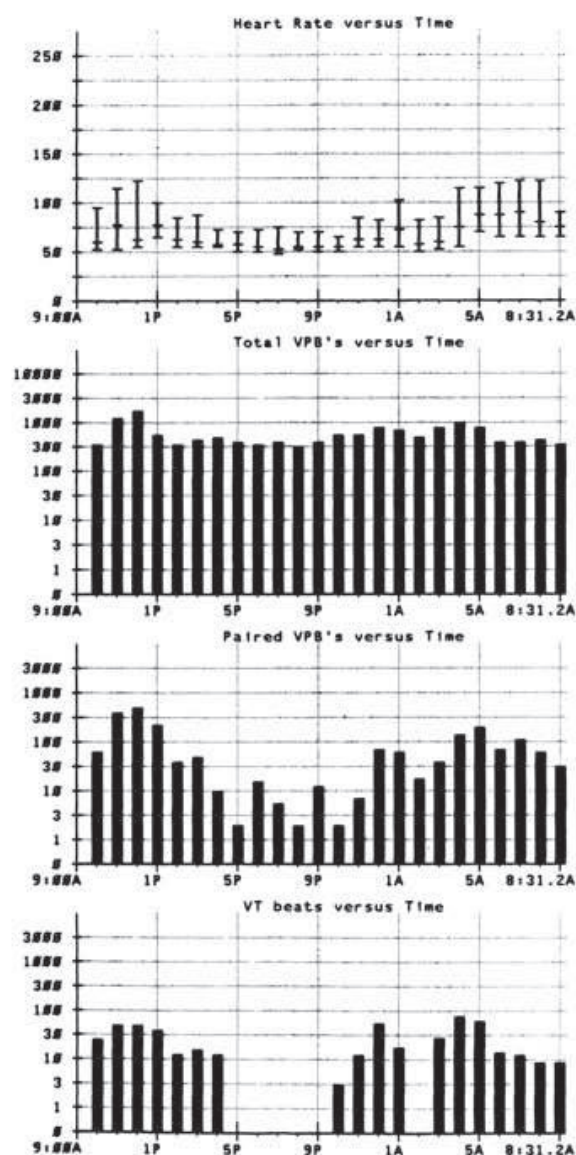


Figure 3. Data from quantitative Holter monitoring analysis presented in graphic form. VPB = ventricular premature beat; VT = ventricular tachycardia.

many as 14 consecutive days without major problems. The use of hydrocortisone cream can eliminate allergic or irritative reactions to the electrode gel or tape. Standard electrical safety requirements for Holter recorders should eliminate the possibility of electrical leak.

To avoid problems in analysis, the ECG data must be fed to the Holter monitor with sufficient voltage to "trigger" the system. Thus, ECG output should be sampled to ascertain that the lead system provides adequate voltage. Extraneous magnetic induction or demagnetization of the recording tape can occur and must be prevented. The speed of the charting-paper during analysis and the re-

cording speed are important, because errors may result in heart rate and ST-segment trends if changes in motor speed or timing are not detected. Artifacts on ambulatory recordings are important, because if they are not detected quantitative errors will occur that may lead to erroneous clinical diagnoses. Artifacts are primarily due to equipment malfunction or movement by the patient. The simultaneous use of two ECG channels has been valuable in helping to identify artifacts and also in distinguishing ventricular premature complexes from aberrant atrial premature complexes. Electrical, mechanical, and technician errors can produce pseudoectopic beats, pauses, bradyarrhythmias, and tachyarrhythmias. Knowledge of the previous occurrence of artifacts and the ability to measure cardiac rhythm through apparent artifact are clues to the presence of an artifact. Battery failure may cause pseudotachycardia or pseudobradycardia, but usually the ECG complexes become narrower or wider.

Recommendations

The primary use of Holter monitoring is to detect supraventricular and ventricular arrhythmias and to assess whether therapeutic interventions have been effective or proarrhythmic. New analysis systems can more accurately measure the severity of an arrhythmia, thus providing useful medical information. The accuracy of Holter systems in quantitation of the type and severity of arrhyth-

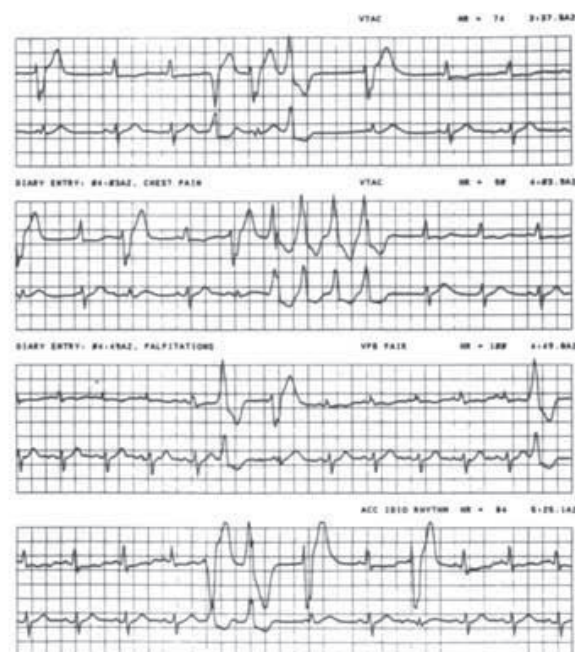


Figure 4. Four simultaneous pairs of electrocardiographic (ECG) strips, representing ECG leads V5 (top) and V1 (bottom) show events that are reported in numerical and graphic displays of Holter data. The time of occurrence of the simultaneous ECG strips, the heart rate, and the type of arrhythmia as determined by the technician-analysis system are noted. In addition, the second and third set of ECG strips show recorded rhythms that can be correlated with the patient's symptoms.

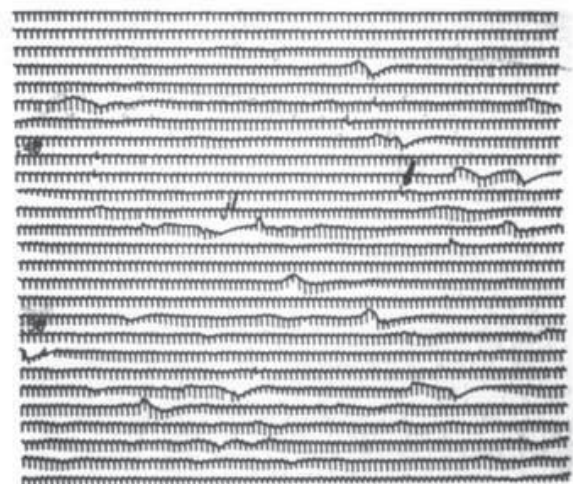


Figure 5. Mini-electrocardiographic (ECG) format representing the ECG recorded during a 24-hour Holter monitoring session. The single black arrow points to one of several ectopic complexes in this display. Frequent deviations in the ECG's baseline due to motion artifact can be seen.

mias and the accuracy and reliability of such data must be assured by the use of quality control programs. The use of commercial laboratories for analysis of Holter ECG data is becoming more popular, because expensive quality control measures and the availability of costly, constantly changing technology are often more likely to be present in competitive commercial services than in the usual hospital-based laboratory. High-quality data must be assured if the physician is to have confidence in the quantitative data and to assess the effect of therapy.

The use of sampling or event recorders may be most appropriate for the patient with an infrequently symptomatic arrhythmia that would be unlikely to be recorded during the usual 24 hours of Holter monitoring. An analysis technique that miniaturizes the entire 24 hours of Holter data may be useful for screening, but because of its lack of accurate quantitation it has limited clinical use. Thus, the standard recorder for Holter monitoring still is the traditional continuous recorder.

In summary, Holter monitoring provides an excellent, sensitive, and specific tool for detecting arrhythmias in various patient populations, particularly since the occurrence of arrhythmias is often undetected by the usual clinical tools. To ensure accurate differentiation of efficacy from proarrhythmic effects of a therapy, attention must be given to proper analysis technique and assurance that quantitation is accurate. The use of ambulatory ECG monitoring to correlate cardiac events with other physiologic events (for example, electroencephalographic events and blood pressure) may be of great future importance and is being actively investigated.

ACKNOWLEDGMENTS: The author thanks Robert Loring, Ph.D., for assistance in providing the data used in Tables 2 and 3.

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