Tape Recordings of the ECG of Active Men
Limitations and Advantages of the Holter-Avionics Instruments

By Lawrence E. Hinkle, Jr., M.D., Jerome Meyer, B.S., Michael Stevens, and Susan T. Carver, M.D.

SUMMARY
The electronic and mechanical characteristics of the Holter-Avionics instruments for recording and analyzing the electrocardiogram of active men have been measured in the laboratory, and during carefully standardized 6-hour recordings of 385 active subjects. Although late model recorders have a cumulative timing error of less than 1%, the frequency response of the system is limited at both the upper and lower ends of the range, producing significant distortion of the complex. Scanning the taped data at 60 times real-time is a helpful screening procedure, but accurate analysis of records requires photographic write-out of R-R intervals with real-time scanning and analysis of all potential areas of abnormality. If records are made with subjects under constant observation and stop-watch timed, they can yield significant data on phenomena of rate, rhythm, and conduction, under a variety of circumstances and over long periods of time; but changes in the shape of the ST segment and T wave must be interpreted with great caution because of distortions produced by the recording system and by changes in position and activity.

Additional Indexing Words:
Electrocardiography Instrumentation Coronary disease

The small portable cardiac recorder developed by Holter and Glasscock has made it feasible to obtain large samples of the human electrocardiogram under many conditions of ordinary activity. Production models of the Holter system, manufactured by the Avionics Research Products Corporation, are already being used rather widely for the study of ambulatory subjects over long periods, for the detection of transient arrhythmias and conduction disturbances, for the investigation of anginal pain, and for the study of the possible cardiac effects of various activities and situations in which people may become involved. It has been recommended by some that this system be used for determining the employability and work assignments of people thought to have heart disease.

The Holter system is different from the standard electrocardiographic system in a number of important respects: (A) The recorders ("Cardiocorders") and the playback mechanisms ("Electrocardioscanner" and "Electrocardiocharter") do not have the same electronic characteristics as the standard electrocardiograph. (B) The representation of the electrocardiogram is limited to a single lead in one plane. (C) The lead system used is not the same as that used in standard electrocardiography. (D) The records are obtained while the subject is in a variety of bodily positions, in a variety of metabolic states, and engaged in a variety of activities. (E) The number of complexes in a single sample is large, being of the order of 50,000 in 10 hours. Each of these features of the system may have an important influence on the data that

From the Division of Human Ecology of the Departments of Medicine and Psychiatry of Cornell University Medical College, New York, New York.
Supported by Grant HE-07796, U. S. Public Health Service.

Circulation, Volume XXXVI, November 1967
it produces, and gives these data a meaning significantly different from that of the data produced by the standard ECG.

The purpose of this paper is to consider some of the electronic and mechanical characteristics of the Holter-Avionics system that affect the interpretation of the data obtained from this system. In succeeding papers we shall consider some of the new variables that are introduced when electrocardiographic recordings are made under the conditions of daily life and describe some observations that bear on the usefulness of this system in the diagnosis of a number of common cardiac disorders, and especially coronary heart disease.

Methods

The equipment used in the studies consisted of four "Electrocardiocorders" Model 350A, four "Electrocardiocorders" Model 350C, one "Electrocardioscanner" Model 450B, and one "Electrocardiocharter" Model 550A, manufactured by the Avionics Research Products Corporation; a Multitrace Oscilloscope Photographic Recorder Model DR8 Rapid Writer manufactured by the Electronics for Medicine Corporation, and a Dual Beam Oscilloscope Model 502 manufactured by Tektronix Incorporated.

The "Electrocardiocorder," a small battery-powered tape recorder operating at 7.5 inches per minute, is designed to be carried by a subject and to record electrocardiographic signals for a period of 10 hours. This is a direct recording system (fig. 1).

The "Electrocardioscanner" is a unit that allows for the simultaneous monitoring on separate cathode ray tubes of heart rate and individually displayed ECG complexes. The rate representation is accomplished by generating saw-tooth voltages whose heights are proportioned to the R-R intervals. These voltages are displayed on a rate-calibrated cathode ray tube with an independent time base. This is called the "Arrhythmia-graph" trace (fig. 2). The ECG complexes are displayed on another cathode ray tube whose time base is the saw-tooth voltage initiated by the R wave of each complex. The analysis is carried out at a tape speed of 7½ inches per second, which converts minutes in real-time into seconds in analysis time. The play-back of the superimposed complexes on this oscilloscope screen at 60 times real-time provides a "moving picture" of the changing electrocardiogram (the "AVSEP") (fig. 3).

The "Electrocardiocharter" is an instrument designed to write out in real-time the ECG recorded by the Electrocardiocorder. It consists of a separate tape deck traveling at 7½ inches per minute and an amplifier that feeds the input of a Standard Burdick EK III Electrocardiograph.

"Scanning" the complex on the "AVSEP" screen and the rate representation on the "Arrhythmia-graph" screen at 60 times real-time is the method customarily used for analyzing the bulk of the data provided by this system. The real-time write-out through the Burdick EK III is intended primarily for the study of relatively small and selected samples of the complexes.

In the present study a Tektronix Oscilloscope #502 was coupled with the "Electrocardioscanner" to provide an additional means for the scanning of complexes at 60 times real-time; and an Electronics for Medicine Photographic Recorder was used to provide a calibrated record of the Arrhythmia-graph trace and real-time scanning and photographs of individual complexes in series.

The characteristics of the Holter-Avionics system in actual use were investigated by the study of a stratified random sample of all the men aged 55 to 60 who were on the active payroll of the New Jersey Bell Telephone Company on No-

Figure 1
Subject wearing tape recorder ("Electrocardiocorder") with a "modified Lewis lead."
November 1, 1962. The manner in which this sample was drawn and the men in it were examined has been described elsewhere.\textsuperscript{11}

Every man in this sample of 301 spent a full day at our laboratories, where he was put through a carefully standardized 6-hour routine of ordinary activities while wearing a cardiac recorder. Beginning at 9 a.m. in the resting, fasting state, he was guided and stop-watch timed by a technician as he went through a series of activities designed to test the effects of body position, graded physical exercise, the ingestion of food and fluids, various states of digestion, exposure to hot and cold air, anxiety, subjective states of rest and fatigue, and smoking. The precise details of this routine will be described in a subsequent paper.

To investigate the reliability of rapid scanning as a method of analyzing the data on the tapes, a standard schedule was devised and two trained observers were used. One observer watched the chronometer and the subject’s diary, and verbally reported each change in position or activity. A second observer watched an enlarged image of the AVSEP screen on the Tektronix #502 Oscilloscope. Following a fixed schedule he made drawings of the AVSEP images as they appeared under various conditions, and he made note of any important phenomena that he detected on the screen. After scanning the complexes, he systematically scanned the ArrhythmiaGraph trace in the same manner, observing and recording the rate at specified times, and attempting to estimate the number and type of premature contractions and other arrhythmias that appeared in each part of the record. When the scanning had been completed, the results were compared with the information obtained from the clinical examination of the men and with the data from the photographic write-out of the records.

Because of the obvious inaccuracies of rapid scanning, a method of photographic write-out was devised for the precise study of the taped data. The entire ArrhythmiaGraph trace was photographed by the photographic recorder, and 1-minute time lines were superimposed. Each period of activity was located precisely on the record by comparing these time lines and landmarks in the record created by changes of position or activity with the actual elapsed recording time as measured by the chronometer. By making an appropriate adjustment based on the cumulative timing error of the tape, mean heart rates were calculated for each period of activity, and rates were obtained before, during, and after various exercise periods. A series of four or more complexes were written out with the subject in each of the routine positions, and before, during, and after each of the routine activities. The record was visibly scanned before the photographic analysis and any significant change in the form of the complex that was observed on scanning was also written out. From the ArrhythmiaGraph trace all potential periods of arrhythmia were located. If there were fewer than 50 of these, each was scanned at real-time and an example of each type of arrhythmia or conduction disturbance encountered was written out for direct study. If the number of possible periods of arrhythmia in a record was greater than 50, a random sample of 6 minutes from each hour was drawn, and each of these minutes was scanned completely at real-time, with the number and type of premature contraction and other arrhythmias and conduction disturbances carefully noted. The actual number in the record was estimated from the real-time write-out of this random sample.

The initial analysis of the Cardiocorder tapes was carried out by observers who had no knowledge of the medical data relating to the men.

Figure 2
The “ArrhythmiaGraph” display: R-R intervals as vertical bars on a calibrated screen.

Figure 3
Photograph of the “AVSEP” display: ECG complexes superimposed at 60 times real-time.
whose tapes were being examined; and the detailed analysis of the photographic write-out of the tapes was made without reference to the data from the initial scanning.

The recorders had been reconditioned and given a new instrument warranty by the manufacturer immediately before they were tested and used.

Results

Timing Characteristics of the System

Speed Constancy of the Recorder and Scanner

In the laboratory, a 10-hour test tape was made with a Model 350A recorder powered by a freshly charged battery. The test recording consisted of 100 millisecond, 2 millivolt pulses at a repetition rate of one pulse per second. The pulses were generated by a Tektronix 161 Pulse Generator, which was triggered once per second by a Tektronix 180A Time-Mark Generator, whose stability is rated at 3 parts per million in 24 hours. An attenuator at the output of the pulse generator provided for the recorder a source impedance of about 2,000 ohms. The time stability and the shape of the pulses were monitored at the input terminals of the recorder with a Tektronix 531A Oscilloscope. The temperature variation in the room was no more than 2 C during the recording.

The test tape, when completed, was run on the scanner and the Arrhythmia graph trace was observed. At the end of 1 hour there was an apparent rate speed-up (tape slow-down) of about 4%. At the end of 5.5 hours this apparent speed-up had risen to about 6%, where it remained fairly constant to the end of the run. There were rather frequent transient apparent rate slow-downs (tape speed-ups) lasting about 0.3 minute (real-time). In the most pronounced cases, these produced a 10% variation in apparent rate. Throughout the run there was an apparent rate jitter of about ± 2%.

Test tapes were made in a similar manner, with use of two Model 350C recorders, and were analyzed in the same way. At the end of 10 hours there was an apparent rate speed-up of 0.5% for one recorder and 1.0% for the second recorder. The transient tape speed-ups

Figure 4

Example of photographic write-out of R-R intervals with superimposed rate indicator.
apparent in the Model 350A recorder were absent from these two recorders. There was a constant apparent rate jitter of ± 0.8% in one recorder and ± 2.4% in the second.

Rate Linearity of Arrhythmograph Presentation

A test tape consisting of 100 millisecond, 1 millivolt pulses at rates of 120 per minute, 80 per minute, 60 per minute, and 40 per minute was made on a 350A recorder powered by a freshly charged battery. Each rate was recorded for 10 minutes. The ambient temperature varied less than 1 °C during the recording.

The pulses were generated by a Tektronix 161 Pulse Generator triggered by a Tektronix 162 Wave Form Generator. The pulse duration and the rates were set by monitoring the output with a Tektronix 531A Oscilloscope whose time accuracy had been calibrated to within 1% in the necessary ranges by use of a Tektronix 180A Time-Mark Generator. The time stability and pulse wave form were monitored during each run at the input of the recorder. Tape was run for 5 minutes before each recording to allow the recorder to warm up to full speed.

The completed test tape was run on the Scanner, and the Arrhythmograph presentation was observed at the auxiliary Arrhythmograph output with a Tektronix 531A Oscilloscope by means of a type-D plug-in unit in the differential DC mode.

At the rate of 120 per second (analysis time) the scope deflection was set at 2 cm. This scale setting should produce deflections of 3, 4, and 6 cm, respectively, for rates of 80, 60, and 40 per second. The observed deflections were about linear through 80 per second. At 40 per second the deflection was 5.7 cm, giving an error of about 5%. The observed wave shape at 40 per second was distinctly rounded at the high end. Since this saw-tooth signal is also used as the time basis for the “AVSEP” ECG display, the nonlinearity of the saw-tooth introduces some time distortion in the display of the complexes on the “AVSEP” scope.

Timing Error of the System in Actual Use

Four Model 350A recorders and four Model 350C recorders were used to study subjects undergoing the standardized 6-hour routine of activities. Standard Avionics electrodes were used, with the recorder supported by a shoulder strap, as in figure 1. The procedures were timed by a Huer 12-hour chronometer. Cumulative timing error was obtained by comparing the total time of the recording as obtained from the chronometer with the total time indicated by a photographic write-out of the Arrhythmograph trace made by playing back the tape through the Scanner and feeding the Arrhythmograph output into an Electronics for Medicine Photographic Recorder that had been calibrated with a 60-cycle signal (fig. 4).

The mean cumulative timing error for 72 6-hour recordings with the Model 350A recorder was 1.3%, but the standard error was ± 4.6%. A 5% standard error in 6 hours is an error of 18 minutes (fig. 5). The more recent models (350C) had a mean error of 2.1% and a standard error of 0.7%, indicating that the tape drive and timing mechanisms of the recent model recorders had been substantially improved over that of the early models.

<table>
<thead>
<tr>
<th>MEAN ERROR</th>
<th>STANDARD DEVIATION</th>
<th>RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>72 RECORDS USING MODEL &quot;A&quot; RECORDERS</td>
<td>+ 1.32</td>
<td>± 4.59</td>
</tr>
<tr>
<td>79 RECORDS USING MODEL &quot;C&quot; RECORDERS</td>
<td>+ 2.13</td>
<td>± 0.69</td>
</tr>
</tbody>
</table>

Figure 5

Cumulative timing error of recorder read-out system based on 6 hours of recording during a standardized routine of activity.
ECG OF ACTIVE MEN

**Frequency Characteristics of the System**

*Frequency Response of the Recorder-Scanner and of the Recorder-Charter Systems*

The frequency responses of these systems were first measured in the laboratory with a square wave in order to obtain a comparison with the Veterans Administration specification for low-frequency response of direct-writing electrocardiographs. These specifications call for a deviation from the initial amplitude of not more than 5% at the end of 100 milliseconds. This is in substantial agreement with the American Heart Association recommendation of 1954. This recommendation has recently been revised to provide for an even lower frequency response. The frequency responses were measured a second time with a variable frequency sine wave to obtain an overall frequency response including a high-frequency cut-off. A recent study by Dower and associates indicates that the minimum acceptable upper 3 db point is 100 cycles per second.

Whenever the Burdick EK III was involved in these tests, it was calibrated for an over-all gain of 1 millivolt per centimeter. The overshoot of the stylus in response to a square wave generated by actuating its internal standardization switch was less than 5%.

(a) **Response to Square Wave for Recorder-Scanner and Recorder-Charter Systems.**

The rate linearity test tape was used. The square waves were 100 milliseconds long, 1 millivolt in amplitude, and were generated once every 1.5 seconds.

For the Recorder-Scanner response the tape was run on the Scanner and read out both on the ECG Display Monitor and on a Tektronix 531A Oscilloscope, with a type-D plug-in unit in the DC single-ended connection, whose input was taken from the auxiliary ECG output of the Scanner.

For the Recorder-Charter response the tape was run on the Charter and written out on the Burdick EK III.

Both the Scanner output and the Charter output showed a decay of about 27% from the initial amplitude at the end of 100 milliseconds.

(b) **Response to Square Wave for Burdick EK III.**

To ascertain if the Burdick instrument was responsible for any of the decay in the square wave response of the Recorder-Charter system, the same instruments and procedures were used that were used in making the rate linearity test tape. In this case, however, the output of the pulse generator was fed directly into the ECG input of the Burdick. The Burdick showed a decay of less than 5% at the end of the 100 milliseconds.

(c) **Over-all Frequency Response for Recorder-Scanner and Recorder-Charter Systems.**

A tape of sine wave frequencies from 0.05 cycles per second to 205 cycles per second in steps of one octave was made on a Model 350A recorder. A Hewlett-Packard Low Frequency Function Generator 202A was used with an external attenuator to bring the peak amplitude to 1 millivolt and the source of impedance to about 2,000 ohms. The input of the recorder was monitored with a 531A Oscilloscope using a type-D plug-in unit in the DC mode. The ambient temperature varied less than 1 C during the recording.

For the Recorder-Scanner response the tape was run on the Scanner and observed with the 531A Oscilloscope using the D plug-in unit in the DC mode with the input taken from the ECG output of the Scanner. The results are plotted in figure 6 on the same coordinates as the manufacturer's specifications.

![Figure 6](image)

**Figure 6**

Typical recorder-scanner system frequency-response curves.
For the Recorder-Charter response the tape was run on the Charter and written out on the Burdick EK III. The results are plotted in figure 7 along with the manufacturer’s specifications.

(d) The Over-all Frequency Response for the Burdick EK III. The same instruments and procedures were used that were used in making the frequency response tape. In this case, however, the output of the function generator was fed into the ECG input of the Burdick. For comparison, these results are also plotted in figure 7.

Since the manufacturer’s specifications indicated that there had been no significant change in the frequency characteristics of the Model 350C recorders, the tests described in section (a) through (d) previously were not repeated with recorders of this model.

Effect of the Electronic Characteristics of the System on the ECG Signal

The frequency characteristics of the system as determined in the laboratory were quite close to those specified by the manufacturer (fig. 6). The −3 db points for the Recorder-Scanner were at approximately 0.2 cycles per second and 50 cycles per second. However, the unusual shape of the low frequency roll-off, in effect, set a lower limit to the accurate response, at about 0.5 cycles per second. It is generally agreed that accurate representation of the very low frequency components of the ECG complex, including those represented by the so-called “ST segment,” requires a low-frequency response down to approximately 0.08 cycles per second or below; and that the accurate representation of the major high-frequency components of the QRS requires an upper limit of response at approximately 100 cycles per second. Therefore, one would expect that some distortion of the complex might be produced by this system.

To test this, a simulated ECG signal produced by a Telemedics EKS 70 simulator was reproduced on the Electronics for Medicine Photographic Recorder, which has a frequency range from 0.05 to 2,000 cycles per second, and the form of the signal was compared with the form of the same signal after it had been passed through a Model 350A Cardiocorder (fig. 8). The amplitude of the R wave was

![Figure 7](image-url)

**Figure 7**

Typical recorder-charter system frequency-response curves.

![Figure 8](image-url)

**Figure 8**

Distortion of a simulated ECG complex produced by early model recorder.
ECG OF ACTIVE MEN

reduced by the limited high-frequency response of the Holter-Avionics system, and a definite “ST segment depression” and “Post T sag” of the baseline were produced by its limited accuracy at low frequencies. Similar tests with a Model 350C recorder produced similar results (fig. 9). A gross distortion of the complex was produced by changing the polarity of the lead—a device that is sometimes suggested as a feasible way to introduce a signal into the tape.

Reliability of the Recorder

The over-all reliability of the system in actual use was estimated by comparing the number of complete 6-hour records technically adequate for analysis that were finally obtained, with the number of recordings initially attempted. The reliability of the system in use was 92% with the early model recorders. With the later, “Model C” recorders, the reliability increased to 97%. This was largely the result of the correction of defects in the tape drive and take-up mechanisms, which had a tendency to break down in the early model recorders.

Comparison of the Results of Analysis by Rapid Visual Scanning and by Photographic Write-Out

When this system is used to make long-term electrocardiographic recordings under the conditions of ordinary life, many changes in the shape of the complex are observed.16 Some of these are related to changes in position, activity, and food intake, and some appear to be produced by the electronic characteristics of the system, as noted above. For these reasons it was evident that it would not be profitable to make minute measurements of the degree of deflection of the ST and T waves from the baseline during the course of a day. However, it was of some interest to determine the reliability with which the most striking changes in the configuration of the complex that would be relevant in the study of coronary heart disease—specifically, inversion of the T wave and the presence of “ischemic” ST depressions as described by Mattingly17—could be recognized on rapid scanning. It was also of interest to determine with what accuracy premature contractions and conduction disturbances could be recognized and counted.

The comparison of the findings reported from visual scanning with those obtained from the complete photographic write-out of 74 records showed that there was approximately 85% agreement between the two methods on the presence or absence of changes in the ST segments and T waves (fig. 10). However, the disagreement affected roughly half of the records that were called “positive” on scanning. The disagreement arose partly in borderline cases in which ST segments that had been

<table>
<thead>
<tr>
<th>&quot;ISCHEMIC ST SEGMENTS&quot;</th>
<th>WRITE-OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YES</td>
</tr>
<tr>
<td>SCANNING</td>
<td>4</td>
</tr>
<tr>
<td>NO</td>
<td>4</td>
</tr>
<tr>
<td>AGREEMENT</td>
<td>67/74 = 91%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INVERTED OR DIPHASIC T WAVES</th>
<th>WRITE-OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YES</td>
</tr>
<tr>
<td>SCANNING</td>
<td>8</td>
</tr>
<tr>
<td>NO</td>
<td>7</td>
</tr>
<tr>
<td>AGREEMENT</td>
<td>63/74 = 85%</td>
</tr>
</tbody>
</table>

Figure 9

Distortion of a simulated ECG complex produced by a later model recorder.

Figure 10

ST segments and T waves. Comparison of data from scanning and write-out.
called "ischemic" on scanning were described as "horizontal" or "concave" on the write-out; or when "ischemic" depressions were recognized on write-outs where they had not been recognized on scanning. Other instances of disagreement arose when apparent changes in the ST segments and T waves appeared during periods of exercise, when there was a good deal of artifact or baseline wandering, and these could not be confirmed on write-out; conversely, sometimes clear-cut ST deformities and inverted T waves were observed on the write-outs during periods of exercise, when they had been missed during scanning. Another source of disagreement arose from the question whether or not T waves were simply "notched" or were inverted. Here, too, the write-out did not always confirm the impression from scanning.

Scanning the Arrhythmigraph trace and the AVSEP screen at 60 times real-time also was not an accurate method of studying arrhythmias and conduction disturbances. Transient episodes of arrhythmia were sometimes missed by the scanner and their nature could not be accurately assessed. In more than half of the records that were studied, estimates of premature contractions based on scanning were grossly inaccurate as to number of premature contractions or as to type of premature contractions or both (fig. 11).

Although transient conduction disturbances

**Figure 11**

*Premature contractions. Comparison of estimates from scanning with results from write-out.*

**Figure 12**

*Subject #43: Burst of premature contractions at beginning of activity: Arrhythmigraph*
could be recognized by scanning, their accurate evaluation by this method was not possible.

**Data Obtainable with the Aid of Real-Time Scanning and the Photographic Write-Out**

The combination of real-time scanning and the photographic write-out proved to be time consuming, but it provided several kinds of useful data. When these procedures were combined with an accurate external timing procedure, and with precisely timed landmarks on the tape, it became possible to locate any event on the tape within approximately ± 10 seconds of its occurrence. Heart rate, for any R-R interval or over any unit of time, could be estimated with an error not greater than approximately ± 3% over the range of 40 to 120 beats per minute. Mean heart rates over extended periods of time could be calculated. From the Arrhythmigraph trace any potential premature contraction could be located (fig. 12) and its probable origin could be ascertained (figs. 13 and 14). In most instances ventricular premature contractions could be differentiated from supraventricular premature contractions with ease; but when there was no clear-cut P wave in the single lead of the record, it might be impossible to say whether a supraventricular premature contraction was atrial or nodal in origin. More complex arrhythmias could, of course, be identified also. Conduction disturbances could be identified with relative ease, depending upon their nature. When these originated above the ventricle and disturbed the cardiac rhythm, they were easy to detect. When they originated within the ventricle and produced a noticeable distortion of the QRS complex for several successive beats, they were also easy to detect. But when they were intraventricular in origin, did not produce a marked distortion of the QRS, and occurred sporadically for single beats (fig. 15), they might be picked up only during the real-time scanning or write-out of randomly sampled minutes.

The possibility of locating phenomena such as these in time, of identifying them, and of counting them, plus the availability of large samples of complexes (30,000 in 6 hours; 120,000 in 24 hours), made it possible to treat these phenomena statistically, to determine their frequency under various circumstances and in various subjects, and to investigate the statistical relationships that may exist between them.

The photographic write-out generally recorded the configuration of the complex just as it appeared on the oscilloscope. The many changes in the shape of the complex that occur during the day in the single lead that is recorded were readily documented. However, because of the frequency characteristics of
the system, the effects of changing positions and activity, and the difference between the chest leads that are used in this system and the standard electrocardiographic leads, one could not assume that changes in the shape of the complex necessarily had the same meaning that they have when they appear in the standard ECG. Often it was quite apparent that they did not.

Discussion

The Holter system of dynamic electrocardiography is a significant contribution to cardiovascular instrumentation. Its chief value appears to lie in its contribution to the study of phenomena of rate, rhythm, and conduction. It provides large samples of complexes that make possible a statistical approach to these phenomena. When the system is used in conjunction with carefully timed observations of the subject, and is coupled to an adequate mechanism for write-out and real-time scanning, it can make possible the detailed study of some of the effects of activities, metabolic states, medications, and the subject’s reactions to his immediate situation.

The system has electronic and mechanical characteristics different from those of the standard electrocardiograph. These do not seriously interfere with its use for the study of arrhythmias and conduction disturbances, but they do greatly limit the extent to which empirical inferences can be drawn from the shape of the cardiac complex as it appears on the oscilloscope and in the write-out. The bipolar leads that are commonly used with this system are not “standard,” and there is no body of information about the “normal” range of variation of the ECG complex that may occur under the many and varied conditions of bodily position, activity, and food intake under which recordings may be obtained. It is clear that the high-frequency limitation of the system itself may cause it to reproduce a QRS deflection of smaller magnitude than that which would appear in a full-frequency range recording. The R wave and the S wave are not necessarily distorted to the same degree by this upper frequency limitation. Also, the low-frequency limitation of the system can distort the shape of the ST segment and T wave and cause them to deviate from the baseline. There are, therefore, many reasons why this is not now a suitable system for studying minor variations in the magnitude of voltage deflections of the cardiac complex. To put it bluntly, it is dangerous to draw any inferences about the presence or absence of heart disease because of deflections of the ST segment and T wave as recorded by this system.

On the other hand, there are many things that one can do with this system that one cannot do with the ordinary electrocardiograph. One can use it to study the relation of heart rate to various activities over long periods—and, since heart rate is related to cardiac work, one can obtain some estimates of cardiac work also. One can search over long periods for isolated arrhythmias (which are quite common), and one can identify the brief episodes of more complex rhythms that are often associated with premature contractions (which are much more frequent than used to be believed). One can study the circumstances under which these arrhythmias occur, and, in prospective investigations, one can study their meaning in relation to the subsequent development of heart disease. One can make similar studies of transient conduction disturbances. But all this cannot be done with ease by the use of the system as it now stands. With the present system an external source of timing, with carefully timed signals or landmarks inserted into the tape at intervals, is the only means by which a point on the tape can be located with accuracy in real-time. A trained observer, other than the subject, is necessary if one wishes to obtain accurate information about such important variables as the positions and activities of the subject. Although the analysis of the record by scanning at 60 times real-time is an ingenious and exceedingly helpful method of reviewing the data rapidly, it is not accurate enough for diagnostic or investigative purposes. A provision for accurate real-time scanning and immediate write-out of the data is essential. One cannot escape the necessity for a precise examination of all potential
areas of arrhythmia, and for the careful examination of a sample of each segment of the record.

Nor can it be expected that the computer will provide an immediate substitute for the human eye and mind in carrying out such an analysis. The pattern-recognition programs that have been developed for the analysis of the standard electrocardiogram on digital computers cannot be directly applied to the data from this device, because of the great variability in the shape of the complex under ordinary conditions of activity. Furthermore, the pattern-recognition programs that are now available operate at real-time, and would require 10 hours for the analysis from each of the 10-hour tapes that this system now provides. However, if the problem of recognizing and rejecting high-frequency noise can be conquered, it should not be too difficult to develop mechanisms that will provide for the accurate counting of complexes and the calculation of rates; nor should it be too hard to develop methods for the recognition of potential periods of arrhythmia and conduction disturbance, for writing them out automatically, and counting them. We are now attempting to develop such methods.

Recapitulation and Conclusions

The electronic and mechanical characteristics of the Holter System of Dynamic Electrocardiography have been investigated by means of laboratory studies of production models of the apparatus, and by investigations of the performance of this system when used to record the electrocardiograms of subjects engaged in carefully standardized routines of activity.

In the laboratory early model recorders showed a cumulative timing error of 6% in 10 hours, with transient speed changes during the recording that produced a variation in apparent rate as great as 10%. Two later model recorders showed a cumulative timing error of 1% in 10 hours. The transient tape speed-ups did not appear in these recently produced recorders, but there was an apparent rate jitter of ±2%. Under standard conditions of actual use, the early model recorders showed a cumulative timing error of 1.3%, with a standard error of ±4.6%. The later model recorders showed a standard error of less than 1% during a 6-hour recording.

Studies of overall frequency response of the system showed that both the “Recorder-Scanner System” and the “Recorder-Charter System” have an effective frequency range from 0.5 to 50 cps. The Burdick EK III, which is included as a part of the “Charter,” did not appear to be responsible for the frequency-response limitations of the Recorder-Charter System.

When the system was tested to determine its capacity to reproduce a simulated ECG signal, the amplitude of the R wave was reduced by the limited high-frequency response of the system and a definite “ST-segment depression” and “post-T sag” of the baseline were produced by its limited accuracy at low frequencies. A gross distortion of the complex was produced by changing the polarity of the lead.

The over-all reliability of the system in actual use was 92% with the early model recorders, and with the later model recorders it was 97%.

A comparison of the findings obtained from rapid visual scanning of the taped records with those obtained from a complete photographic write-out of the same records showed an approximately 85% agreement between the two methods on the presence or absence of “ischemic” ST segments and inverted T waves. However, the disagreement affected roughly half of the records that were called “positive” on scanning. Transient episodes of arrhythmias were sometimes missed by the scanner, and their nature could not be accurately assessed. In more than half of the records that were studied, estimates of premature contractions based on scanning were grossly inaccurate as to number of premature contractions or as to type of premature contractions, or both. The accurate evaluation of transient conduction disturbances by rapid scanning was not possible.

When the system was used in conjunction with devices for the real-time scanning of
complexes and the photographic write-out of the data, and these data were combined with data from an accurate external timing procedure carried out by a trained observer constantly present with the subject, and with data from precisely timed signals or landmarks on the tape, it became possible to locate events on the tape within approximately ±10 seconds of their occurrence. Heart rate, for any R-R interval, or over any unit of time, could be estimated with an error no greater than approximately ±3% over a range of 40 to 120 beats per minute. Mean heart rates over an extended period of time could be calculated. Potential premature contractions could be located and their probable origin ascertained. More complex disturbances of rhythm could be identified with ease. Transient conduction disturbances could be located and studied also. All of these cardiac phenomena could be counted, studied statistically, and their relation to various activities of the subject could be investigated.

When it is used in the manner described, and when its limitations are recognized, the Holter System of Dynamic Electrocardiography is a significant contribution to cardiovascular instrumentation. Its primary value at its present stage of development lies in the study of phenomena of rate, rhythm, and conduction. It has very limited usefulness for the study of the configuration of the ST segment and T wave.

Acknowledgment

The authors wish to acknowledge the collaboration of Drs. Lee Winston, Bry Benjamin, William N. Christenson, Bernard W. Strone, S. B. Penick, James F. Casey, George McLemore, Edward Shepard, Thane Asch, and Theodore Robinson, who examined the men who were subjects for these studies, and participated in the examination of the x-rays and ECGs; to acknowledge with gratitude the collaboration of Dr. George Bisgeier, Medical Director of the New Jersey Bell Telephone Company, and the various officials of the Company who aided in the selection of men for this study, and made it possible for them to participate; and to acknowledge the collaboration of Norman J. Holter and William Glasscock of the Holter Research Foundation in providing research models for early studies of the equipment and the Avionics Research Products Corporation for making further studies possible.

References

12. Veterans Administration Specification for Electrocardiograph, Direct-Writing Type. Number 3272000a, March 11, 1959, Paragraph 3.2.6.3.
15. Dower, G. E., Moore, A. D., Ziegler, W. G., and Osborne, J. A.: On QRS amplitude and


---

**On Psychosocial Evolution**

... Perhaps this is why he believed in the inevitability of progress; or if his interpretation were true, social evolution would be cumulative and virtually irreversible. We know better: that we are all born into the Old Stone Age and in principle could stay there.

Psychosocial evolution differs from ordinary genetic evolution in three important ways: It is not mediated through genetic agencies; it is reversible, in the sense that what it has gained can in principle be wholly lost, and in one generation; and it is an evolution in the Lamarckian style, in the sense that a father's particular knowledge and skills and understanding can indeed be transmitted to his son, though not (as Spencer supposed) through genetic pathways. Common sense suggests that differences of this magnitude should be acknowledged by a distinction of terminology. The use of the word 'evolution' for psychosocial change is not a natural usage, but an artificial usage adopted by theorists with an axe to grind. If by any chance it had been a natural usage, people like myself on occasions like this would have said over and over again how wrongheaded it was, and how wise we should be to abandon it.—P. B. MEDAWAR: The Art of the Soluble. London, Methuen & Co. Ltd., 1967, p. 47; also distributed by Barnes & Noble, Inc., New York.