The Effect of the Frequency Response of Electrocardiographs on the Form of Electrocardiograms and Vectorcardiograms

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The spectrum of frequencies making up the cardiac potential has not been fully explored. Limitation in the high frequency response of most electrocardiographs suppresses in some tracings QRS components whose significance is at present obscure. Using the cathode ray oscillograph it was found that frequencies as high as 1300 cycles per second reveal characteristics not shown at lower frequencies. Frequencies as high as 6000 cycles per second are under investigation. Limitation of the low frequency response by the use of a condenser-resistor network to abolish extraneous potentials produces serious distortions of the RS-T segment.

SCANT ATTENTION has been paid to the effect of the capabilities of the recording equipment on the form of the electrocardiogram. Until recently the inherent limitations of most electrocardiographs, particularly with respect to frequency response, have been such that investigation of this problem was not easy. Moreover, with the best available apparatus, records seemed to be satisfactory and indeed often showed (and still do show) characteristics beyond the limits of our ability to interpret them.

For two reasons interest in this problem has recently been stimulated. The first is the introduction of the direct writing instruments. Some of the records, particularly of the early models, showed "smoothing" out of the curves and low amplitudes, attributable to limitation of high frequency response. In order to accept the direct writer as a satisfactory recording instrument, it is necessary to show that even with its limited range, all or nearly all of the components of physiologic or pathologic significance are detected. This is indeed a formidable task and even if it proved to be so in the present state of our knowledge, future progress in some directions might be hampered by the widespread use of such instruments in research.

The second reason for our interest is that the development and improvement of cathode ray apparatus has enabled us to investigate a much wider band of frequencies than was heretofore feasible. It should thus eventually be possible to determine (1) whether the present instruments are satisfactory for routine clinical use, and (2) whether a greatly increased frequency range is of value in research. There are of course other recording characteristics capable of improvement, but our attention will be directed only to the frequency response. No attempt has been made to study the problem of phase shift.

In late years, there has been almost no interest in the low frequency characteristics of electrocardiographs. The advent of the amplifier type of recorder some years ago raised the problem of the amount of distortion of slow waves introduced by the time constant factor. It was finally agreed that a time constant of 2.0 seconds or more would give almost distortionless reproduction of slow components and this standard is achieved by practically all commercial instruments. Recently an attempt has been made to minimize low frequency potentials from sources outside the heart by decreasing the time constant. Certain of the tracings thus recorded showed characteristics which appeared to be caused by too short a time constant.
was thought advisable to re-investigate this problem.

**High Frequency Response**

Little work has been done to determine the relative magnitudes of the various harmonics of the cardiac potential. Einthoven was certainly aware of the problem because he succeeded in reaching a frequency response of 300,000 cycles per second by the use of a fine string less than 1 mm. in length.1 In 1912 he wrote,2 "If the string reaches its new position of equilibrium within about 0.01 second or less, the instrument is rapid and at the same time sensitive enough for recording E.K.G. s with sufficient accuracy. The deviations from an ideal E.K.G. which a curve recorded under these conditions exhibits are so small that in the great majority of cases they may be neglected. . . . We are now justified in making the following conclusion. If the movements of the string could be made 10 to 100 times faster, the sensitiveness remaining the same, or even if, theoretically spoken, an instrument were available with an infinitely small deflection time, the form and dimensions of the recorded E.K.G. s would not be thereby perceptibly changed."

Einthoven's conclusions appear to have been generally accepted without much question. Wiggers3 in 1929 seems to have suggested that a frequency response of about 20 cycles per second was sufficient for practical purposes. In 1933 Reid and Caldwell4 re-investigated this problem using an oscillograph and amplifier having a much higher frequency response than the string galvanometer. Harmonic analysis indicated that the more rapid frequency components had significant magnitude and that the one hundredth harmonic was twice as large as the fundamental.

In May 1947 the Council on Physical Medicine5 of the American Medical Association laid down minimum requirements for electrocardiographs and specified that the amplitude response to a 1 mv. alternating (or sinusoidal) signal must be not less than 50 per cent at 40 cycles. In June 1950 this was revised6 so that the response “. . . up to 40 cycles per second shall not fall below 80 per cent of the square wave response to equivalent voltage variation.” This specification is low enough to make acceptable most of the popular makes of instruments. Some of the early models of direct writers barely reached this level of performance; the later ones are better, but it is evident that the inertia of the writing apparatus is a limiting factor which will never permit it to approach the frequency capabilities of the cathode ray oscillograph.

The problem remained in abeyance until it was taken up by Gilford of the United States Bureau of Standards. Preliminary results7 were reported in 1948 and his tentative conclusions may be reasonably summarized as follows: (1) The necessary frequency response characteristics of electrocardiographs have not yet been accurately specified, but probably should be flat to 200 cycles per second, a figure not attained by most available instruments. (2) Research demands instruments with a wider frequency range than heretofore used. An interim report8 of further work was made in 1949. Simultaneous tracings were made with several standard models and compared with that of a wide-band cathode ray recorder whose response was down 3 decibels at 1200 cycles. As we shall see, this is somewhat better than we had arbitrarily selected as our highest response. Gilford felt that the direct-writer was adequate for routine purposes but that research required high fidelity apparatus with a frequency response up to 200 cycles.

It has been customary to make instruments only slightly better than good enough to meet the presumed requirements, partly because of cost and partly because operating complications are introduced at higher frequencies. It is obvious that previous assumptions about frequency response requirements are not based on exact information and that further investigation is indicated.

**Method**

The ability of the recording instrument to respond to signals of different frequencies may be tested by putting in a sinusoidal signal of constant voltage and measuring the amplitude of the recorded deflections at each selected frequency. When
the frequency of the signal is increased a gradual and then a more abrupt decrease in the magnitude of the response takes place as the limit of the instrument is reached. (See fig. 1.)

It was pointed out above that determination of the necessary frequency response characteristics of an instrument can be achieved by the harmonic analysis of records taken with very high frequency apparatus and by estimating the relative amplitudes of the various harmonics of the complex action current. An adequate frequency limit may then be set at a point just above where the amplitude of

![Graph](the fast components is found to be too small to affect the shape of the curve visibly. This method is time-consuming and requires special apparatus and considerable mathematical skill. For these reasons, in this investigation we used the more practical method of taking records with different frequency response limitations and comparing them with one another in respect to amplitude and form. A definite change at a given level of response was taken to indicate suppression of more rapid components.

The cathode ray electrocardiograph used in these experiments had its high frequency response adjustable by a tap switch to six different settings, identifiable on figure 1 by the numbers one to six, position one having the highest response. The different responses available were chosen to represent to a first approximation the following conditions:

Position 1. Considerably better than any conventional electrocardiograph.

Position 2. Commercially available cathode ray electrocardiograph.*

Position 3. Typical string galvanometer type electrocardiograph.


Position 5. Minimum requirement as stated by Council on Physical Medicine of American Medical Association.†

Position 6. Appreciably worse than position 5. (The data for determining positions 3 and 4 were obtained from the paper by S. R. Gilford.)‡

It was, of course, not always possible to make the response curves of the cathode ray unit agree exactly with the curves for the other types of electrocardiographs, but in general the curves are reasonably representative. In particular, Gilford’s curves for string galvanometers actually fall between positions 2 and 3 above. In most cases the response curves on the cathode ray unit do not fall off as steeply as the curves for the other types of electrocardiograph. Table 1 shows the actual frequencies in cycles per second at which certain specific responses were obtained.

A large number of records were taken on a variety of normal and abnormal individuals. No attempt was made to study a particular type of case but many examples of congenital heart disease were utilized because high frequency components were common in this group. From 6 to 12 complexes were recorded for each tap position. Where there was variation in the form and size from complex to complex, the patient was asked to hold his breath during the recording. If the variation was not thereby abolished, the record was discarded. It was considered that a frequency response greater than

* At that time the response of the cathode ray electrocardiograph was deliberately limited to diminish possible amplifier noise and muscle potential. Current models are slightly better than position 1. Muscle potentials are largely eliminated by placing the electrodes on the upper arm and amplifier noise has not proven to be a problem.

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**Table 1.**—Frequency Response Characteristics (in Cycles per Second) of Tap Positions of Cathode Ray Electrocardiograph (see Fig. 1)

<table>
<thead>
<tr>
<th>Position</th>
<th>Frequency for 90% response (1 db. down)</th>
<th>Frequency for 70% response (3 db. down)</th>
<th>Frequency for 50% response (6 db. down)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300</td>
<td>760</td>
<td>1300</td>
</tr>
<tr>
<td>2</td>
<td>74</td>
<td>135</td>
<td>220</td>
</tr>
<tr>
<td>3</td>
<td>37</td>
<td>74</td>
<td>140</td>
</tr>
<tr>
<td>4</td>
<td>27</td>
<td>47</td>
<td>78</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>31</td>
<td>43</td>
</tr>
<tr>
<td>6</td>
<td>---</td>
<td>---</td>
<td>15</td>
</tr>
</tbody>
</table>
1300 cycles would probably not be useful due to limitations in the resolving power of the recording system at the standard speed of 25 mm. per second. This has also been pointed out by Gilford. In more recent experiments a variety of faster speeds has been employed.

For purposes of direct comparison simultaneous records were taken on four different types of instrument, (a) a cathode ray electrocardiograph set at position 1, (b) a popular amplifier type of mirror galvanometer recorder, (c) a recent (1950) model of a direct writer, and (d) a string galvanometer. Since the first three have a high impedance they were connected to common patient electrodes while a separate set had to be used for the string galvanometer. With the latter a chest lead on the same site could not, of course, be taken at the same time as on the other recorders. Identification of simultaneous complexes was achieved by pressing the four standardization switches at the same time.

Since the above investigation was completed a new cathode-ray, four channel, biologic recorder has become available.* It is capable of taking four simultaneous electrocardiograms or two simultaneous vectorcardiograms. The high frequency response can be limited by means of filters which decrease the response at a rate of 6 decibels per octave. The maximum frequency available was 6400 cycles per second for 6 decibels down (50 per cent voltage response); and the other tap positions were one octave apart at frequencies of 3200, 1600, 800, 400, 200, 100, 50, 25 and 12.5 cycles per second. At each of the levels the voltage response was 50 per cent (down 6 decibels). The slopes of the frequency response curves are similar to those of positions 2 and 3 in figure 1. In the examples shown later, frequency levels of 50, 100, 200 and 6400 cycles were selected so as to represent a rough approximation the earlier American Medical Association requirement, the performance of a string galvanometer, the level suggested by Gilford and finally the maximal presently available with this apparatus.

It must be appreciated that an increase of frequency response invites difficulties in the way of tube noise and high frequency interference. These may be reduced to a great extent by careful selection of tubes and proper preparation and placing of the patient and instrument, but some allowance must be made for minor irregularities of the base line particularly at high gains.

Results

No attempt has been made to study systematically a large series and determine statistically at what level of frequency response the form

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* Manufactured by Smith and Stone Ltd., Georgetown, Ontario, Canada.

of the electrocardiogram would show all the necessary harmonics. It is, however, clear that many routine electrocardiograms appear to be satisfactory in this respect at a level of 135 cycles per second (3 decibels down). Some others show little change even at 74 cycles per second (3 decibels down). Below this level practically all records are distinctly altered.

![Electrocardiograms](http://circ.ahajournals.org/)

**Fig. 2.** Electrocardiograms of five different subjects (from above downwards) showing the tap positions numbered 1 to 6 as in figure 1, the highest frequency response being at the left and the poorest at the right. In this and in figure 3 time and horizontal lines have been removed from some of the records. Standardization 1 mv. = 1 cm.

These remarks apply of course only to tracings taken at standard speed.

The records seen in figure 2 were selected to show the type of changes encountered. The character of these changes is similar to those noted by Gilford, namely, decreased amplitude, "smoothing out" of splintering and notching, and disappearance of small amplitude waves. In most of the waves measured only slight decrease in amplitude is noted at posi-
tion 2, but becomes more marked as the frequency response is decreased. Apart from amplitude differences, inspection of the records shows progressive loss of beading and notching, and increasing density and hence slowing of the trace from left to right. Since the electrocardiographic lead is but a scalar projection of the vector which is the resultant of a multitude of vectorial quantities, it is obvious that rapid reversals in the direction of the vector are visible on the electrocardiogram as notches which are minimized or wiped out in some types of apparatus with limited capabilities. In small animal records very rapid waves form an important part of the complex, but whether they have any physiologic or pathologic significance in man is apparently unknown. It is our impression that young individuals with normal hearts are most likely to show these features. It would be interesting to know if there is a progressive loss of these fast waves in serial electrocardiograms in man over a period of years, particularly where the cardiac muscle is diseased.

In some cases progressive decrease and eventual obliteration of small amplitude waves were noted. In figure 2c this is well exemplified in the S and S' waves. In figure 2c the Q is well preserved but the S decreases considerably at position 4 and disappears at position 5.

In figure 3 are shown simultaneous records on the four instruments, in order from above downwards, cathode ray, string galvanometer, amplifier and direct writer. In the complex denoted by x the S is clear in both cathode ray and direct writer records, present but small in the amplifier tracing and frequently absent in that of the string galvanometer. It is fair to assume that the cathode ray traces represent the maximum voltages obtainable with the frequency response at position 1. Overshooting of course cannot be a factor with a beam of electrons. The amplifier type revealed consistent defects of amplitude throughout. The direct writer showed up very well in the actual measurements and fairly well in the minor notchings too small to be calculated. It must be emphasized again that in a number of records the differences among the various recorders were of minor degree and not of significance in our present state of knowledge.

It cannot be denied that factors other than frequency response may have accounted in some degree for the variations in simultaneous complexes taken with different types of apparatus. Elimination of other possible factors was achieved by simultaneous recording of four
complexes on the same apparatus with the added and not inconsiderable advantage of increased paper speed to spread out and render more easily visible the rapid oscillations. In figures 4 and 5 are shown several series of such complexes at various recording speeds. In be noted that in fig. 4c only the P wave and QRS complex are shown and in fig. 4d only the QRS complex. The difficulties of labeling the various parts of the QRS complex are demonstrated in figure 4c. At frequencies of 50, 100 and 200 cycles, the main upward de-

![Figure 4](http://circ.ahajournals.org/)

**Fig. 4.** Four simultaneous records of lead V1 of a normal subject taken at different frequency responses and different speeds. Top row 50 cycles per second, second row 100 cycles, third row 200 cycles, bottom row 6400 cycles (see text). Speeds: (a) 25 mm. per second, with time and height lines, (b) 25 mm. per second, without time or height lines, (c) 100 mm. per second, (d) 250 mm. per second. Standardization 1 mv. = 8.5 cm. (5N). In c only P and QRS are shown and in d only the QRS.

figure 4a and b, even at standard speeds, marked differences are quite evident. These are plainly seen between the records at 50 and 100 cycles and between 100 and 200 cycles but are not so obvious between 200 and 6400 cycles. Visibility is improved by increasing the paper speed to 100 mm. per second (fig. 4c) and is best at 250 mm. per second (fig. 4d). It should flection would be called the R wave. But at a frequency of 6400 cycles the first downstroke returns to below the baseline and becomes an S wave and the process is immediately repeated. Hence, among other variables, the capabilities of the recording instrument influence the labeling of the complex.

As previously noted, the amplitudes of the
components of a complex are greatly affected by restriction of the frequency response. Thickening and slurrings of the trace become well defined notches at higher frequencies, especially when spread out (fig. 5a and 5b). In figure 5c are shown the comparative deflection times of a standardization signal impressed on each channel at different frequency responses. At 6400 cycles the deflection time is practically zero, at 200 cycles it is about 0.002 second, at 100 cycles about 0.005 second and at 50 cycles, about 0.008 second.

Figure 6 demonstrates the effect of differences in frequency response on the form of the vectorcardiogram. In figure 6a the upper vectorcardiogram was taken at 6400 cycles and the lower simultaneously at 50 cycles. Considerable change in contour is evident. In figure 6b the upper vectorcardiogram was taken at 6400 and the lower at 200 cycles.

Differences, though less marked, are still obvious. If any useful information is to be obtained from the vectorcardiogram other than the axis and the direction of the loop, high frequency apparatus should be utilized in the investigation.

**Fig. 5.** Four simultaneous records of lead V1, taken at the following frequency responses (see text): top row 50 cycles per second, second row 100 cycles, third row 200 cycles, bottom row 6400 cycles. Speeds: (a) 25 mm. per second, (b) 250 mm. per second. Standardization 1 mv. = 8.5 cm. (5N). In b only QRS is shown. (c) Effect of frequency response on deflection time of standardization signal. Frequencies 50, 100, 200, 6400 cycles, from above downward. Speed 500 mm. per second. (The figure has been reduced to one-half original size.)

**Fig. 6.** Simultaneous frontal plane vectorcardiograms. (a) Upper, frequency 6400 cycles; lower 50 cycles. Standardization 1 mv. = 2 cm. (b) Upper, frequency 6400 cycles; lower 200 cycles. Standardization 1 mv. = 5 cm. (The figure has been reduced to one-half original size.)

**LOW FREQUENCY RESPONSE**

Low frequency components of the cardiac potential are accurately represented by the string galvanometer. The introduction into the field of electrocardiography of moving coil galvanometers requiring valve amplification aroused considerable controversy in the beginning as to the possibility of introducing distortions into the record. The property of a resistance-capacitance coupled amplifier usually termed "low frequency response" or "time constant" governs the amplifier's ability to reproduce faithfully a sustained departure of the wave form from the baseline. It is well recognized that if a steady direct current sig-
nal is applied to such an amplifier, the output will eventually return to the baseline,* following a curve which is usually logarithmic in shape. The time constant of an amplifier having such a decay curve is defined as the time required for the output response to fall to 36.8 per cent of its initial value when a steady direct current signal is applied.

Since the decay curve is logarithmic from the start Miller⁹ modified the circuit so that decay did not begin for 0.1 to 0.2 second. The standard laid down by the Council on Physical Medicine¹ states that “the response of the instrument at 0.2 second after the application of a direct current of 1.0 millivolt shall not deviate more than ±10 per cent from the response at 0.04 second.” If the shape of the decay curve is assumed to be truly logarithmic this corresponds to a time constant of approximately 2.0 seconds (see figure 7c).

In this respect, most instruments in use today are presumably satisfactory.

Dock¹⁰ found that capacitance in the circuit produced changes in the amplitude of S and T waves and displacement of the S-T segment. The distortions varied directly as the voltage of the QRS complex and inversely as the resistance and capacitance of the circuit. Ernstene and Levine¹¹ compared the records taken on 25 patients with both the amplifier type and the string galvanometer and found some decrease in amplitude with the former, but did not regard the difference as significant in most cases. Pardee¹² denied that the distortions found by Dock¹⁰ could be due to capacitance. A detailed study of the effect of condensers in the patient-instrument circuit was made by Schwarzschild and Kissin.¹³ They pointed out that “a capacitance represents an impedance to the flow of electric current inversely proportional to the frequency of alternation of the current. It offers a practically infinite impedance to low frequency currents which are evidenced by a drift (‘skin current’), whereas it offers little impedance to currents caused by the rapidly fluctuating heart voltage.”³ It was concluded that the important distortions introduced by the use of condensers lay in the amplitude of the R and deviation of the RS-T segment. They calculated that a time constant of 2.0 seconds would be sufficiently long to avoid most distortions and still permit reasonably rapid compensation for drift and similar effects. Recently this subject has been reviewed in detail by Lepeschkin.¹⁴

It is often difficult to obtain satisfactory esophageal leads because of extraneous low frequency potentials which cause considerable wandering of the base line. A condenser inserted in series with the patient will decrease low frequency potentials in the electrocardiogram.¹⁴ Recently¹⁵,¹⁶ an attempt has been made to minimize these potentials by placing a condenser-resistor network having a time constant of approximately 0.1 second between the exploring electrode and the amplifier of the recording instrument. It was claimed that this attenuated frequencies of 1.5 cycles per second and less and had little effect on frequencies greater than 2.5 cycles per second. Records made with and without this filter were said to be similar. From the values for the condenser and resistor used, it is calculated

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* Strictly speaking, the level to which the waves decay is the “mean value” or the level having equal areas above and below it. With the wave forms of the type found in electrocardiography there is rarely any significant difference between the baseline and the mean value.
that the time constant of this network would be 0.1 second. Thus the output signal would fall to 36.8 per cent of its original value in only 0.1 second.

In the case of the steady direct current input signal previously mentioned, if the input is suddenly reduced to zero before the output has decayed completely to the base line, the output will be driven in the opposite direction by the full value of the original signal. If the duration of the signal is very short, the sloping top of the wave is often not obvious and only the overshooting below the base line is evident. However, the sloping top must actually be present if the overshooting is observed. The effects of high frequency and of low frequency response are interrelated insofar as the shape of the resultant record is concerned. If the high frequency response is limited, the upward deflection will be sufficiently slowed so that the downward slope at the summit will be minimized.

These distortions are demonstrated in figure 7. In figure 7a a 1.0 mv. standardizing signal of very short duration with a time constant of 2.0 seconds is shown. The top of the record is flat and the return to the base line is exact (see footnote on page 105). In figure 7b the time constant has been changed to 0.1 second and there is an obvious downward slope at the peak and a dip below the base line. Both of these records were made with the high frequency tap at position 1. (See fig. 1.) In figure 7c the high frequency has been reduced to position 4 (fig. 1) which slows the upstroke near the peak and the downstroke near the base line. In figure 7d both the low frequency and high frequency responses have been restricted. Compared with figure 7b the downward slope at the summit has been minimized while the base line depression has been little affected.

Although electrocardiographic wave forms are not composed of idealized square waves, one can make certain generalizations from what is known about the performance with square waves. Any interval in which the electrocardiographic wave is appreciably removed from the base line should be considerably shorter in duration than the time constant of the amplifier if the above type of distortion is to be avoided. The exact factor required obviously depends on how much distortion can be tolerated. On an idealized square wave a duration of time-constant/5 or longer would certainly produce noticeable distortion, whereas any duration less than approximately time-constant/20 would probably be accepted as free from distortion. Wave components very much shorter than the amplifier time constant (rapid, nearly vertical components) will be unaffected by the time constant and will be reproduced at their correct amplitude, provided of course that they are not so rapid that high frequency factors affect them.

The two most important types of wave in electrocardiography which are affected by a time constant as short as 0.1 second are the QRS and the T. In QRS complexes of average duration, say 0.08 second, some distortion may be expected since they are shorter than the amplifier time constant by a factor of less than 2. This will show up partly as a decrease in amplitude because during the rising interval the output will be decaying slightly, and even more noticeably as an overshooting of the base line at the completion of the QRS. Such components as T waves represent relatively long intervals of sustained deflection from the base line. Because these components do not even approach the time-constant/5 standard mentioned above for slightly noticeable distortion, one might expect to find severe distortion occurring with such waves. If the T were truly a square wave and of 0.3 second duration, distortion might be expected in an amplifier system having a time constant of 0.1 second. In the case of a component as long in duration as this example, even the American Medical Association requirement of a 2.0 second time constant might be considered as inadequate for completely distortionless amplification. Thus with the usual wave forms encountered in electrocardiography, the general effects of an inadequate time constant are premature return to the base line and overshooting.

Inspection of the records in the article by Scherlis and co-workers\textsuperscript{13} suggested that some of the abnormalities were due to deficient low
frequency response. There are obvious advantages in such a circuit to facilitate the taking of esophageal electrocardiograms but it was felt necessary to investigate the possibility of having introduced distortions which Scherlis and associates\textsuperscript{15} in their input circuit. Figure 7f shows the cathode ray amplifier output when a square wave is applied to the input. The time constant is seen to be very close to the 0.1 second value.

Figure 8 shows a series of complexes taken from a large number of patients, some of whom had cardiac infarction. The upper of each pair is the complex taken with the usual time constant while the lower is taken with the filter in the circuit, the resulting time constant being 0.1 second. Usually they were not recorded simultaneously but were taken on the same strip, the filter being inserted by turning a convenient control. In some cases simultaneous records were taken on two cathode ray electrocardiographs connected to the same electrodes, one having a "normal" low frequency response and the other a poor low frequency response.

\textbf{Method}

To simulate the performance of an electrocardiographic system incorporating a filter of the type described, one of the coupling circuits in the cathode ray electrocardiographic amplifier was modified to give an over-all amplifier characteristic having a time constant of 0.1 second, the same as used by
Results

Depression of R-T or RS-T segment is well demonstrated in figure 8a and b. Elevation of S-T is seen in figure 8k (premature beat), i, j and k. Gross distortions of T wave are evident in figure 8o, c and d, and in figure 8f, g, h and j. While most of these deformities are of such a type as to simulate those associated with myocardial ischemia, the opposite change may be present. In figure 8l, the S-T depression caused by cardiac infarction is nearly abolished by the introduction of the filter.

Attention is drawn to figure 3 in the article by Scherlis and his colleagues. The esophageal lead before exercise shows elevation of the S-T segment and an almost straight downward slope similar to that seen in our figure 8k. Leads E₈ and E₁₀ in figure 2a of the paper by the same group appear to show the same distortion. Esophageal lead E₉ in figure 1a of another report by the same authors resembles our figure 8l. In another article lead E₇ of figure 2 shows a resemblance to our figure 8k. Further examples of distortion can be found in the above mentioned tracings. Of course some leads will show little if any alteration, and in others changes due both to disease and to poor low frequency response will be present. It is possible to calculate the amount of this distortion and to make allowance for it, but this seems an unnecessarily laborious procedure. With practice one can estimate visually the degree and kind of distortion introduced, but because the alterations in repolarization produced by ischemia of cardiac muscle have certain resemblances to those of defective low frequency response, the interpretation of such records is made difficult or misleading by the use of such a filter in the circuit.

Summary

The depolarization and repolarization of myocardial fibers results in changes in electrical potentials which take place both consecutively and simultaneously throughout the cardiac muscle. These potentials may be represented as vectorial quantities which at present cannot be isolated and analyzed individually, but which, added together, give a composite vector representing the resultant of all these forces regardless of the magnitude, sense and direction of the unit components. The electrocardiogram is the scalar projection of this vector on a chosen axis (lead). The potentials are made up of a variety of frequencies having different amplitudes at various times during the electrically active portion of the cardiac cycle. The origin and significance of the different frequencies of the currents are unknown and appear not to have been investigated. For several technical reasons, much of the recording apparatus has been incapable of registering the higher frequencies. Moreover, in the past, there has appeared to be no sound clinical or experimental reason for demanding instruments having an extended frequency spectrum. Recent changes and improvements in recording methods (direct writer and cathode ray electrocardiographs) have suggested the investigation of the changes in the form and amplitude of the electrocardiogram (and vectorcardiogram) which might be revealed by using high fidelity apparatus.

In some cases, except for slight loss of amplitude of QRS, little or no change could be found when a frequency above 47 cycles per second (3 decibels down) was used at normal paper speed and standardization. In others adequate representation was achieved with a frequency of 74 cycles while some tracings required at least 760 cycles. Although measurements of amplitudes of various parts of the QRS have a limited value in diagnosis, particularly in an individual case, any set of normal values should take into account the capabilities of the recording apparatus. In addition to changes in amplitude, with high frequencies slurring of QRS was altered to beading and notching caused by rapid changes in the direction of the vector in one or more planes which were suppressed at lower frequencies. Minor changes are obscured by the use of the conventional speed, which fact has recently been emphasized by Langner.

The designation of different portions of the QRS by letters depends to some extent on the frequencies which are used (fig. 4e). Improvement in apparatus has permitted study
of frequencies as high as 6400 cycles per second, utilizing higher gains and speeds up to 500 mm. per second. Preliminary observations suggest that further investigation of this range is warranted. Langner\textsuperscript{9} believes that a frequency response flat to 330 cycles per second or probably higher is needed for faithful reproduction of the electrocardiogram. Our results indicate that frequencies as high as 6400 cycles (6 decibels down) may be required for research purposes.

Low frequency components of the electrocardiogram are adequately represented with a time constant of 2.0 seconds. Although low frequency potentials arising outside the heart are minimized or abolished by reducing the time constant to 0.1 second, distortion of the wave form, particularly the RS-T segment, is frequently introduced, rendering accurate interpretation difficult or impossible. To some extent the effects of high and low frequency responses are interdependent so that restriction of the former minimizes the distortion of the latter (fig. 7).

Conclusions

1. The high frequency response of most commercially available electrocardiographs is so restricted that in some records distortion is produced by the suppression of rapid components of the cardiac potential.

2. The investigation of frequencies as high as 6400 cycles per second is warranted. These may prove to be of particular value in research.

3. No attempt has yet been made to assess the practical significance of high frequency components with respect to pathologic processes.

4. Satisfactory resolution of these changes requires an increase of recording speed up to as high as 250 or 500 mm. per second. At these speeds the use of several times the normal gain aids visualization.

5. The use of a condenser-resistor network to eliminate extraneous low frequency potentials which are particularly troublesome in esophageal leads is contraindicated because serious distortions of the RS-T segment may be introduced.

Acknowledgments

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Sumario Español

El espectro de frecuencias que constituyen el potencial cardíaco no se ha explorado deteniamente. Limitación en el respondimiento electrocardiográfico a altas frecuencias evita componentes Q.R.S. en algunos trazados cuyo significado permanece obscuro en el presente. Usando el oscilógrafo de rayo cátodo se encontró que frecuencias tan altas como 6400 ciclos están bajo estudio. La limitación al respondimiento a bajas frecuencias mediante el uso de un condensador-resistencia para abolir potenciales extraños produce deformaciones serias del segmento RS-T.

References


The Effect of the Frequency Response of Electrocardiographs on the Form of Electrocardiograms and Vectorcardiograms

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