Frequency Analysis of the Electrocardiogram

By Allen M. Scher, Ph.D., and Allan C. Young, Ph.D.

The body surface electrocardiogram is generally recorded with direct-writing galvanometers capable of responding linearly to signals at frequencies up to 20 to 40 c.p.s. The mirror galvanometer recorder, not widely used at present, can have a frequency response to 200 c.p.s., and the cathode ray oscillographic equipment, used for vectorcardiographic recording, is responsive to much higher frequencies. In previous reports on the high-frequency recording of the electrocardiogram, notching, slurring, and other rapid movements of the oscilloscope beam are mentioned, and it is implied that recording of high frequencies can increase the amount of significant electrocardiographic information. One paper contains indications that the amount of high-frequency information is limited, but a detailed frequency analysis of electrocardiographic leads has not been performed to settle this question. In connection with another study, a large number of oscillographically recorded electrocardiograms were available, and these furnished the opportunity to perform a rather complete frequency analysis.

Methods

Conventional limb-lead and chest-lead electrocardiograms were recorded in 17 normal persons and 8 patients; in addition, some records were taken between adjacent chest lead positions. The number of leads recorded in each individual totaled 8 to 20, the average being 12. These records were obtained with an amplifier-oscilloscope system which has a frequency response of well over 20,000 c.p.s. In some cases, the Rycom oscilloscope was used; this instrument has a frequency response of over 10,000 cycles per second on each channel. The electrocardiograms were recorded with a paper speed sufficient to resolve 0.5 msec. This speed implies that deflections with frequencies well over 1,000 c.p.s. could have been seen had they existed. Photographic records were enlarged so that 1 msec. equalled 1 mm. The QRS complex, generally about 80 msec. (mm.) long, was carefully cut out of each photographic print so that it could be mounted on the wave analyzer described below.

To analyze the waves, a conventional oscilloscope was placed so that the face of the cathode-ray tube was focused on a photo cell connected to a small amplifier. The electrocardiographic curve being studied was pasted on the cathode-ray tube face. The output of the photo cell amplifier was connected to the vertical scope input so that an increase in the amount of light falling on the phototube tended to direct the oscilloscopic beam below the opaque curve. A decrease in the amount of light directed the beam up. The photocell amplifier was so connected that the oscilloscope beam traced the curve being studied. The input to the oscilloscope thus duplicated sequentially all amplitudes in the electrocardiogram being analyzed, but the speed at which the record was repeated depended on the sweep frequency of the oscilloscope. Similar equipment to this has been described previously. The output of the phototube amplifier was fed into a General Radio waveform analyzer connected to a Sanborn amplifier and a two-channel Brush penwriter. The motor-driven waveform analyzer was connected to a pen channel and the various frequencies were recorded as the analyzer passed through them. The amplitude of the wave at that frequency was recorded on the other channel. In general, the sweep frequency used was the reciprocal of the duration of the QRS complex, but a correction was always made so that the results were in terms of the actual frequency content. In general, the analysis was continued to well past the tenth harmonic. This frequency technique gives the relative amplitudes of the fundamental frequency and of each harmonic, but does not separate the sine and cosine terms, as would be required by a complete Fourier analysis.

From the Department of Physiology and Biophysics, University of Washington School of Medicine, Seattle, Wash.

Supported by a grant from the American Heart Association and by a research grant (H1315) from the National Heart Institute of the National Institutes of Health, Department of Health, Education, and Welfare.

Received for publication October 5, 1959.
Amplitude of the voltage due to each frequency in electrocardiograms of 17 normal individuals and 8 abnormal individuals. Amplitude is indicated as percentage of amplitude at the fundamental. The fundamentals fell between 6.5 and 12 cycles/sec. As can be seen, the voltages have fallen below 10 per cent of the fundamental at 80 cycles and are generally at 5 per cent of the fundamental, or below, at 90 cycles and 100 cycles. Components above 100 cycles were negligible in all individuals. The net contribution by frequencies 80 cycles and above to the total amplitude in all of these individuals is less than 3 per cent.

Results

The results of all the studies were plotted as amplitude at a given frequency in figure 1. It can be seen that none of the curves has a sizable frequency component at 100 cycles. In none of the curves studied was the amplitude at 100 c.p.s., or at any higher frequency greater than 4 per cent of the amplitude of the fundamental. In each individual studied, and in the entire data, the contribution by frequencies over 90 c.p.s. was less than 2 per cent of the total curve area.

Discussion

It appears from these studies that frequencies above 100 cycles do not contribute significantly to the electrocardiogram. These results indicate that it is at present feasible to build a "perfect" direct-writing electrocardiographic amplifier and, indeed, that such is probably now available. Certain of the newer transistor-driven pen recorders have a flat response to well over any frequencies encountered in this study and have a paper speed which is adequate to spread electrocar-
diographic curves for accurate reading. It appears that a paper speed of 50 mm. or, better, 100 mm./sec. with a trace width of 0.5 mm., or less, would be adequate for all the data in the electrocardiogram.* The high-frequency notching and slurring previously reported by Langner has not been seen in our experiments. Although we believe that these high frequency components were present in Langner's records, we believe that they would have been below 2 per cent of the total area of any lead, and we believe further that any clinical significance of these small high frequency components remains to be demonstrated. Our results are consistent with those of Gilford. 4

Summary
The frequency analysis of the electrocardiogram reveals that contributions by frequencies of 100 cycles, or higher, per second are less than 10 per cent of the amplitude of the fundamental of the QRS complex, and it thus appears that transistor-driven amplifier-pen recorders presently available are adequate to record all the information contained in the electrocardiogram, if the standard paper speed is doubled, or quadrupled.

References

Behavior of the Right Ventricle Following Acute Constriction of the Pulmonary Artery—pp. 315-318

Summario in Interlingua
In 15 anesthesiate canes, le constriction del passage del arteria pulmonar per minus que 50 pro cento produceva nulle significative alteration in le tension intraventricular o in le rendimento cardiac. Constrictiones additional causava un augmento progressivo del tension dextero-ventricular. Usque al valor de 62.3 ± 3 mm de Hg pro le tension dextero-ventriculare, nulle alteration occurreva in le rendimento cardiac. Quando le tension systolic del ventriculo dextere excedeva le mentionate nivello, il occurreva un reduction del rendimento cardiac, un reduction gradual del tension systolic sed un augmento del tension diastolic in ambe ventriculos, e ultimemente un dilatation del corde e arresto o fibrillation ventricular.
Frequency Analysis of the Electrocardiogram
ALLEN M. SCHER and ALLAN C. YOUNG

Circ Res. 1960;8:344-346
doi: 10.1161/01.RES.8.2.344

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circres.ahajournals.org/content/8/2/344