Preparation of Electrocardiographic Data for Analysis by Digital Electronic Computer

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DIGITAL electronic computers are finding increasing applications in the analysis of medical and biologic data. The principal advantages are high speed, relatively great accuracy, and extreme versatility, especially for analytic operations that are too tedious and time-consuming for routine clinical use. Large amounts of data can be processed on a completely objective basis in a relatively short time. Thus computation by commercially available machines should facilitate extensive statistical studies, mass screening of the population, and the data handling of patient records in large organizations such as the Veterans Administration.

The electrocardiogram was chosen for a pilot study in automatic data processing, since it has important clinical applications as a diagnostic aid. The electrical signals from the heart are repetitive and relatively well adapted for objective mathematical treatment. Once the feasibility of the method is established in electrocardiography, only minor modifications of the equipment would be required in other applications such as phonocardiography, ballistocardiography, hemodynamic pressure and flow curves, electronecephalography, and electromyography.

Several efforts have been made in recent years to apply analog computers to the analysis of the electrocardiogram. For example, McFee, Sayers et al., and Abildskov et al. have proposed conversion of signals from 3 orthogonal electrocardiographic leads into curves of spatial magnitude and orientation. Such a conversion does not necessarily lead to automatic analysis, since the newly obtained tracings must be interpreted in fashion similar to the original records. Although a few specific procedures are readily and economically accomplished by analog computation, the examination of large quantities of data for relationships that may never have been precisely formulated seems a task better suited to the digital computer. The problem of interpreting electrocardiographic wave forms is believed to be primarily one of recognition of pattern. Analog devices adapted for this use are likely to be single-purpose, and the probability is strong that a continuing development of equipment would be needed to meet drastic changes of processing procedures.

On the other hand, if the researcher has access to a general purpose digital computer, an almost infinite variety of measurement and analysis can be had merely by writing a new set of instructions for the machine. Then conversion of electrical heart signals to numbers and their storage in a form acceptable to the computers becomes an essential preliminary step. In the present report, a pilot facility for accomplishing this purpose automatically is described.

Materials and Methods

Three corrected, orthogonal electrocardiographic leads (Schmitt's SVEC III system) were recorded simultaneously on magnetic tape through FM (frequency modulation) channels, with use of a tape recorder. Differential preamplification with a gain of 1,000 and a frequency response flat from 0.1 to 1,250 c.p.s. was used. A fourth direct (voice) channel permitted recording of verbal information including identification of each

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Supported in part by a grant from the American Heart Association.

Equipment for the conversion of electrocardiographic data from their original analog into digital form. The control unit with a display oscilloscope is seen on the right. The electrocardiographic signals are retrieved from the analog tape recorder (on the left) and re-recorded through a digital magnetic tape recorder (second from the right, with the analog-to-digital converter in its lower section). The remaining equipment used in the automatic data conversion process is built into the unit which is seen second from the left.

Figure 1

Circulation, Volume XXI, March 1960

patient. The electrocardiographic tracings were monitored on a cathode-ray oscilloscope both before and during recording. Calibration was obtained by recording periodically a 2-millivolt peak-to-peak square-wave signal on all 3 FM channels of the tape recorder. Tracings of approximately 20 cardiac cycles from each of about 100 patients have been recorded on each tape reel.

The equipment for conversion of analog-to-digital data was operated by a technician sitting at the control unit (figs. 1 and 2). The electrical heart signals were retrieved as voltages from the magnetic tape by using the play-back mechanism of the analog recorder. The operator examined these records on an oscilloscope screen, a high-speed electronic switch providing him with simultaneous displays of all 3 leads automatically timed to the heart rate and synchronized successively to show similar intervals of as many beats as might be desired. In cases with normal sinus rhythm, each cycle will comprise the familiar P-QRS-T complex. The operator, after viewing several cycles to check the essential uniformity of successive complexes, pressed a "record" switch that initiated the conversion of the next cycle, and monitored it on the oscilloscope. If it appeared to be non-typical (e.g., an extrasystole), he backed up the analog tape drive and recorded an earlier cycle.
The remainder of the process was completely automatic, requiring no further manipulations by the operator.

The control unit first sets the digital tape transport into motion. After a brief delay to bring the tape up to proper speed, the format control is activated. This apparatus fulfills several functions: (1) by controlling the analog switch it samples each of the 3 leads X, Y, and Z 1,000 times a second; (2) it initiates the operation of the analog-to-digital converter* which converts the analog voltages to binary digits represented by sets of pulses, and feeds these pulses to a buffer which amplifies them and feeds them back to the format control unit; (3) the latter delivers them serially to the digital "write" electronic unit for re-recording on digital magnetic tape.

The digital write electronic unit provides proper data form and power level for energizing the "record" heads of the digital tape recorder. At the end of a cardiac cycle the conversion equipment receives a stop signal from the control unit, and is then ready for the next patient's record. Records of 1 cardiac cycle of each of approximately 1,000 patients can be stored on one reel of digital magnetic tape.

The digital tape format was designed to be compatible with one of the digital computers available at the National Bureau of Standards.** Consequently, the information thus stored can be fed directly into any digital computer of this type for further processing and analysis of the electrocardiographic data as may be desired.

Results

Records of 988 patients with a variety of electrocardiographic abnormalities were processed through the described analog-to-digital conversion equipment and a digital computer.* An obvious test for the proper functioning of the automatic equipment is the conformity between the original records and graphs of the 3 processed electrocardiographic

*Epsco "Datrac."

**IBM Type 704.
Figure 3
Record shown in figure 4 after processing through conversion equipment and digital computer. The tracing was printed out in numerical form and re-plotted on the basis of this digital information. Amplitudes, wave forms, and time relationships were maintained satisfactorily. This time scale is expanded more than that of figure 4.

leads on the basis of the digital print-out received from the computer. Figure 3 is a graph of a 3-lead electrocardiogram (patient C-21), after its conversion from the analog record on magnetic tape, its read-in to the digital computer, and its print-out as a column of numbers at millisecond intervals. Except where greater resolution was required accurately to delineate the curve, only every fifth number was plotted. The original electrocardiogram was a sequence of 22 successive beats but the pattern of figure 3 was sufficiently distinctive to permit a single beat to be selected from the original record of 22 cardiac cycles. When the graph was overlaid by the film record of that original, enlarged 12 times as in figure 4, the amplitudes of the 2 diagrams were found to coincide within a trace width—a discrepancy far less than the beat-to-beat variability of an average electrocardiogram. A number of other patients’ digitized records, plotted at 10-millisecond intervals, showed equally good correspondence. Thus, it has been demonstrated that the facility used for conversion and digital storage of electrocardiographic data performs satisfactorily and reliably.

Discussion
As pointed out above, logical and mathematical operations on electrocardiographic data in digital form afford a high degree of flexibility. Once the signals are stored on digital magnetic tape in a suitable format, only proper programming of a digital computer is required to provide a great variety of analytic procedures. This flexibility appears especially important for the establishment of clinical norms and the discovery of new diagnostic
Computer for Electrocardiographic Data

by Guest, July 25, 2017

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from the patient’s history and physical examination, which can be entered into the digital computer on punched cards. There are no instrumental limitations, therefore, for providing a more broadly based computer program as an aid in electrocardiographic diagnosis. The total information thus available would greatly facilitate statistical correlations of various parameters.

Magnetic tape provides a convenient medium for recording and storing electrocardiographic tracings. The original analog tape can be used at any time for the display of old records either on an oscilloscope in scalar or vectorial form or, if so desired, for re-recording old tracings on paper. Considerably less storage space is required for magnetic tape than for conventional recording media.

The described equipment requires only minor changes to make possible the inclusion of other diagnostic methods for cardiac evaluation. Modifications for phonocardiography, respiratory volume curves, and pulse tracings are presently being made.

Summary

A pilot facility for automatic processing of electrocardiograms leading to their analysis by digital computer has been described. Wave forms from orthogonal electrocardiographic leads were recorded on magnetic tape. By means of newly designed conversion equipment these records have been converted from their original analog form into digital form. The further processing and analysis of the data thus becomes feasible through the use of commercially available digital electronic computers. It has been demonstrated that the electrocardiographic tracings as recorded from patients can be reproduced from the resulting numerical print-outs in their original and undistorted form. The further analysis of these records then requires only proper programming of a digital computer. The same equipment with minor modifications can be used for automatic processing of other analog data such as phonocardiograms, pulse tracings, and ballistocardiograms.

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In a series of experiments it was demonstrated that chlorothiazide potentiates the ganglion-blocking agents (as exemplified by pentolinium) by causing a reduction in plasma volume. A negative sodium balance was observed in 11 patients, but the extent of this did not correlate well with the development of increased sensitivity to pentolinium. There was better correlation with the changes in plasma volume. In 8 of 13 patients studied, 3 days’ treatment with chlorothiazide produced a fall in plasma volume and all of them showed an increased sensitivity to pentolinium. In 4 out of 5 in whom there was no significant change in plasma volume, the effect of pentolinium was unchanged. Replacement of the calculated loss in plasma volume with salt-free Dextran in 7 patients was followed by reduction in sensitivity to pentolinium to about the pre-chlorothiazide level in all except 1. It was thought unlikely that chlorothiazide had any direct hypotensive action, since no change in blood pressure nor potentiation of ganglion blockade was observed after intravenous injection of large single doses. The sensitivity to pentolinium did not develop until the second day. This was not true with the non-quinuaternary ammonium compounds such as Mecamylamine and Pempidine. Since there was a slight shift of the urinary pH toward the alkaline side on first giving chlorothiazide, there was a resultant reduction in the renal excretion of these latter drugs, and therefore an increased hypotensive effect. The potentiating effect of chlorothiazide on pentolinium particularly affected the postural drop of blood pressure. Some postural hypotension was observed as a response to chlorothiazide itself in 4 of 13 patients. Three of these had a considerable fall in plasma volume while the fourth had an extensive sympathectomy previously. The postural response was abolished in each case by the infusion of sufficient Dextran to replace lost plasma volume.

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Circulation. 1960;21:413-418
doi: 10.1161/01.CIR.21.3.413

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1960 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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