ED 125 876   SE 020 334

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TITLE   Clinical Application of Electrocardiography.
PUB DATE   Jun 75
NOTE   12p.; Paper presented at the Annual Meeting of the
                American society for Engineering Education (Ft.
                Collins, Colorado, June 16-19, 1975)

EDRS PRICE   MF-$0.83 HC-$1.67 Plus Postage.
DESCRIPTORS   *Biomedical Equipment; Clinical Diagnosis;
                *Engineering; Human Engineering; *Man Machine
                Systems; *Medical Education; Medical Evaluation;
                *Medicine

ABSTRACT
        The scalar electrocardiogram (ECG) is one of the most
important and commonly used clinical tools in medicine. A detailed
description of the recordings of cardiac electrical activity made by
the ECG is presented, and the vast numbers of uses made with the data
provided by this diagnostic tool are cited. Clinical applications of
the ECG are listed. More emphasis is placed on the fact that advances
in the biomedical engineering aspects of clinical electrocardiography
will require improved and on-going communication between the engineer
and the clinician. (Author/EB)

Event Number: 2505

AMERICAN SOCIETY FOR ENGINEERING EDUCATION

ANNUAL CONFERENCE, JUNE 16-19, 1975

COLORADO STATE UNIVERSITY

FT. COLLINS, CO   80521

CLINICAL APPLICATION OF ELECTROCARDIOGRAPHY

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The standard scalar electrocardiogram (ECG) is composed of 12
to 14 separate recordings of cardiac electrical activity: each one
from a distinct electrode configuration (lead). This tracing is one
of the more frequently requested laboratory tests in clinical medicine.
Thousands of these examinations are done daily not only on patients
with known or suspected cardiovascular disease but on patients for
whom screening or clearance is desired, e.g. prior to elective
surgery, entry into a physical conditioning program, or as part of
a routine evaluation. For patients with cardiovascular disease the
ECG is a necessary part of any evaluation and changes that occur in
the ECG over time may be an important indicator of improvement,
deterioration, or impending difficulty. As necessary as the ECG is
to good patient evaluation and clinical problem-solving, it is but
one of several pieces of information that is required for an accurate
and rational clinical diagnosis. The other parts of the cardiovascular
evaluation include a careful history and physical examination, a chest
x-ray, and special procedures indicated by the information obtained
from the basic evaluation techniques. Special procedures such as
cardiac catheterization, exercise stress testing, certain blood studies
or long term ambulatory monitoring might be indicated.

Many clinicians tend to think of the ECG as a precise diagnostic
tool; only occasionally is this so. Some rhythm abnormalities and
the presence of heart damage may be accurately detected, but most
often the ECG provides clues that might lead to a specific diagnosis

or shows quite non-specific abnormalities. The electrocardiogram is rarely diagnostically precise.

Four elements are required if the ECG's clinical usefulness is to be optimized. First, the recording device must have suitable characteristics providing the appropriate frequency response, a stable paper speed, and must be equipped with simple maintenance checks so that machine performance can easily be evaluated. Second, electrodes must be properly positioned and the recording must be of good technical quality. Third, appropriately detailed information regarding each specific patient must be recorded. Fourth, if the goal of assisting in patient care is to be achieved, the information from the ECG tracing must be integrated with the specific knowledge regarding the patient and an optimal interpretation of the electro-cardiogram must be made. At the present time, it would appear that well-trained cardiologists are capable of an acceptable interpretive performance, but that the computer will be able to greatly enhance the capability of the cardiologist through the application of techniques too complex, laborious, and time-consuming to otherwise be considered.

In a single ECG lead, some more than others, can be found useful information regarding heart rate, rhythm, hypertrophy of any one of the four cardiac chambers, conduction time from the atria to the ventricles, conduction time through the ventricles, specific abnormalities of the conduction system of the heart, and the presence of

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myocardial injury, ischemia or damage. In addition, a lead may
suggest specific metabolic or electrolyte abnormalities, and at
times may suggest the presence of important disease in other body
systems -- for example, the lungs and occasionally the central
nervous system.

The electrocardiographic complex is made up of several wave
forms (Figure 1).
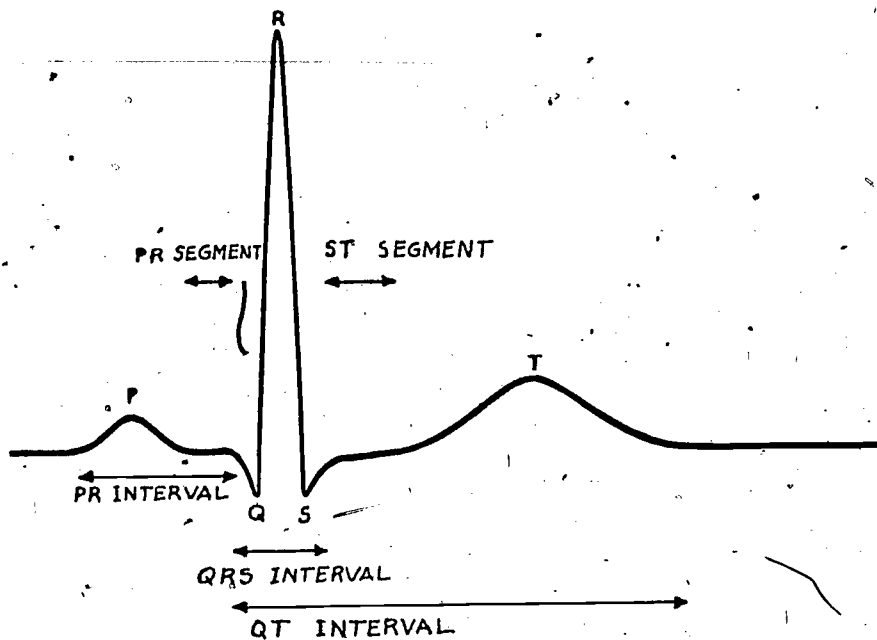

Figure 1. The Normal ECG Complex. (See text for details.)

The P wave represents atrial depolarization. The PR segment reflects
the time from initial atrial depolarization until the electrical
activity reaches the ventricles and generates the QRS complex which
represents ventricular depolarization. The ST segment and T wave are
inscribed during ventricular repolarization or recovery.

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Examination of all portions of the complex may suggest important clinical events which may in turn lead to a correct diagnosis and appropriate management. The height, duration and shape of the P wave in certain leads may reflect enlargement of the right or left atrium, or that the heart is being commanded from an abnormal atrial site. Alterations in the duration of atrio-ventricular conduction, as reflected in the PR segment, may be the result of drug effects, heart block rhythms (due to a variety of causes), normal variants, or abnormal conduction pathways from the atria to the ventricles bypassing the normal conduction route. The QRS complex must be examined carefully. The initial 0.04 seconds reflects myocardial damage if present. The direction of the terminal 0.04 second electrical activity indicates the presence or absence of specific intraventricular conduction problems or may reflect (in the proper clinical setting) acute stress of the right ventricle. The magnitude and direction of the mean QRS vector in at least two planes are noted and reflect the presence or absence of enlargement of the right or left ventricle. ST segment and T wave abnormalities may indicate the presence of potentially reversible inadequate oxygen supply to a portion of the heart muscle but such changes are commonly non-specific and may be produced by eating, anxiety, a change in body position, certain drugs, or volume or pressure loads on the left ventricle. In addition, the ST segment and T wave, PR interval, P wave, and QRS complex may be significantly altered by metabolic and electrolyte

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abnormalities. It is necessary, then, to study each portion of the

ECG complex carefully, to integrate that information with what is

learned from other portions of the complex, and finally to relate that

information to the patient from whom the recording was made.

At the present time, common clinical applications of the electro-

cardiogram include:

1. A screening device for disease detection and disease
   prevention programs.

2. Monitoring the acutely ill patient.

3. Monitoring a patient undergoing a stress test.

4. Following the natural history of a disease.

5. Diagnosing a specific abnormality of cardiac rhythm.

6. Detecting and following the natural history of
   myocardial damage.

7. An adjunct in detecting and following metabolic and
   electrolyte abnormalities.

Some of these uses require a single lead only, others multiple leads.

Regardless of the reason for which the electrocardiogram is obtained,

accurate interpretation of the electrocardiogram is virtually impos-

sible if at least some key patient characteristics are not known: age,

height, weight, body build, body position during recording of the

electrocardiogram, time from eating to recording of the tracing,

relationship of the tracing to the last cigarette smoked, the patient's

emotional state, drugs taken by the patient, the time the drugs were

taken in relation to the recording of the electrocardiogram, the

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underlying disease or diseases, the individual's metabolic status,
and position of the ECG leads on the patient. Each patient is a
multivariate object, and each ECG is a result of the total effect of
the variables. Recent work by Pipberger et al[1] has shown that when
a multivariate approach to the computer application of the standard
ECG is used, the diagnostic accuracy of the computer exceeds that of
a well trained cardiologist as well as other available computer pro-
grams which are programed to observe and integrate standard criteria
in a decision-tree fashion.

Although the study of one lead may give much useful information,
it is important to recognize that no single ECG lead gives all of the
available useful information. For example, left atrial enlargement
is not diagnosed by frontal plane lead aVR, and inferior myocardial
damage is not reflected in standard lead I. For common clinical
purposes, twelve leads are recorded. Standard leads I, II, III,
aVR, aVL and aVF reflect activity in the frontal plane, that is,
parallel to the anterior chest wall, and perpendicular to the floor.
The precordial leads V_1 through V_6 record electrical activity in the
horizontal plane, parallel to the floor, and perpendicular to the
frontal plane. Usually, in order to make many electrocardiographic
diagnoses, combinations of leads are required very often from both
frontal and horizontal planes. Whether this will still be necessary
in future years is uncertain. Clinical research utilizing the three

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mutually perpendicular orthogonal leads X, Y, and Z recorded in scalar fashion is underway, and all useful clinical information may ultimately be available from these three leads.

It should be apparent from the preceding discussion that advances in the biomedical engineering aspects of clinical electro-cardiography will require improved and on-going communication between the engineer and the clinician. This is not always easy to accomplish. Each speaks a different professional language, and all too often neither has a clear understanding of the needs or capabilities of the other. Clinicians are more likely to recognize that the human organism does not lend itself well to controls, and are therefore more tolerant of variation in outcome from research programs than is one trained in the physical sciences. The clinician also tends to guage the performance of engineering equipment or programs by conventional standards when actually the storage capability and speed of a computer permit improved outcome from ECG analysis provided the proper variables are programed into the machine. In other words, the standards of performance should not be those standards or guide-lines which the clinician has used for many years. New, more complex multivariate approaches must be sought which should improve upon old diagnostic standards. In addition, the clinician does not, and often cannot tell the engineer precisely the information, display, or ultimate outcome desired from a specific bioengineering program. In

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order to achieve an end product that is of clinical practicability
and application, the clinician and engineer must communicate through
all stages of the project -- planning, construction, and clinical
trial -- and each must be willing to make appropriate modifications
throughout. Both clinician and engineer must recognize that the
final goal of the combined effort is to benefit a patient. This
may require program or instrumentation modifications that at times
offend the sensibilities of either investigator; however, if a
patient is not ultimately well served, then the total effort is
without clinical merit.

One of the greatest problems in the development of clinically
useful programs using the ECG is the presentation of data. There
are many ways that the engineer can handle the ECG wave forms.
Contemporary computers can handle large volumes of data rapidly and
reliably, but too often the presentation of the data is more meaning-
ful to the engineer than it is to the clinician. The data must be
clearly presented so that it is readily understood and directly
applicable to patient care. A pictorial representation of the data
is best. In this regard, the engineer needs to think like a clinician,
since the practicing physician or staff nurse has little time to
figure out a complex plot or presentation. Indeed, many data
presentations will be seen more often by nursing personnel who will
be responsible for the first and perhaps most important decisions
regarding patient care.

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Because all patients are different it may be desirable to develop computer programs for handling the electrocardiogram that can be readily modified to provide information regarding a specific and particular clinical situation. For example, in an arrhythmia detection program some patients will have a very narrow coupling interval of their ectopic beats to the normal complexes, others will have a very long coupling interval, almost as long as the normal R-R interval. In the latter instance an arrhythmia detection program designed to include only those beats that represent a change in R-R interval of 25% or more may not be detected. Looking at the specific wave form may be useful, but nevertheless the computer would not record these as premature beats when indeed they are.

Development of the human engineering aspects of biomedical engineering is one of the most important and one of the most difficult tasks. Very often a clinician does not know precisely what he wants to see and trial and error in the actual clinical situation is often necessary. It seems most appropriate if the information which is presented to the clinician is presented for clinical interpretation and action without providing a dogmatic diagnosis or single management outline. It is acceptable to give diagnostic probabilities and therapeutic options, but the responsibility for interpretation and action in the patient's behalf must remain with the clinician.

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In summary, the scalar electrocardiogram is one of the most important and commonly used clinical tools in medicine. The opportunities for the biomedical engineer and the clinician to work together in this area are vast. Many strides have been made in this area already. Further work will require improved communication between the clinician and the engineer with good patient care being the ultimate goal of each.

Reference

[1] Pipberger, Hubert V.; McCaughan, Donald; Littmann, David; et al. Clinical Application of a Second Generation Electrocardiographic Computer Program. American Journal of Cardiology 35: 597-608, 1975