

of his heart to the fourth intercostal space is considerably lower than the average (Fig. 1). The equivalent recording of Leads V_1 and V_2 in this patient may be in the fifth or even sixth intercostal spaces (Fig. 2). The R' recorded in the standard positions for Leads V_1 and V_2 represents normal depolarization of the posterior basal segment of the heart. This can be confirmed by simultaneous esophageal lead tracing.

Similarly, a Q wave in Leads V_4 , V_5 , or V_6 in the standard positions, or slightly above, does not necessarily indicate lateral wall myocardial infarction, but more likely is recording the potential from within the left ventricle and should be regarded as a normal complex.

If these patterns present without concomitant evidence of right bundle branch block or myocardial infarction, investigation of the physical features may enable more accurate interpretation.

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Ballistocardiography as a Result of Cooperation Between Sciences

The early investigators in the field now known as ballistocardiography, who conducted their studies in various European and American cities without, for the most part, any knowledge of each other's work, devised methods and made observations which were so diverse that it would be difficult to put together the information secured. The aim of these investigators was to obtain physiological and clinical information about the human circulation with the aid of physical methods and recording apparatus; however, the obstacles they encountered were great and, to some extent, of a new kind. Their research may be considered an extension of that done in the old European schools by physiologists and clinicians who, with some success, tackled problems such as the determination of stroke volume and the clarification of pulse wave transmission.

The study of the biophysics of the human circulation, now approached from another angle and by different means, began to attract general attention after the physiologist-clinician Starr was able to show how much the ballistocardiogram depends on the state of cardiac and vascular performance. Starr's own interest had been aroused by Yandell Henderson, also a physiologist. Once again, general attention was focused on a biophysical problem by the medical profession, although some of the early students of ballistocardiography were of different backgrounds altogether; among them was a geophysicist, and Gordon, one of the founders, does not seem to have been a physician either. At this time, physicists (among others Burger and Talbot) became intrigued by these problems, formulated them properly, and initiated in the field the systematic application of physics, and, making use of the developments in instrumentation, bridged some of the gaps the old schools had to deal with. It gradually became clear that neither the physicians nor the physicists could independently solve problems such as those concerned in ballistocardiography, and an intensive cooperation got under way.

When Starr first began his work in ballistocardiography, he used Henderson's (and Gordon's) bed of ultralow natural frequency (ULF) and recorded its displacement, but, in order to avoid the necessity of having the subjects and patients hold the breath—a procedure that some patients find impossible, that some perform differently than others, and that is well known to affect appreciably the abnormal circulation—he soon designed his high-frequency (HF) table, again recording displacement. Some years later, Dock introduced his direct-body technique, which proved to be simple enough for immediate clinical application insofar as the handling of the instrument was concerned.

Starting out from Newton's laws, the physicists could interpret quantitatively why these three types of ballistocardiographs give different results on the same person. First, because of the difference in mechanical properties of the ULF and HF instruments, different aspects of the circulatory events, namely, displacement and acceleration of the center of gravity inside the body, are represented quantitatively by the displacement tracings. Second, the motion of the subject on his own tissue layer, on which the Dock ballistocardiogram is based, affects records secured from the HF instrument, and slightly affects those from the ULF instrument as well. This evaluation of two mass systems indicated that the ULF instrument gives the smallest distortion, and that by recording its acceleration a force ballistocardiogram can be obtained just as free of respira-

tory effects as that from the HF instrument. Other results are that ballistocardiograms secured from different types of instruments can be transformed into each other, and the clarification of why a striking resonance is visible in direct-body tracings.

However, some of the complications affecting the high-frequency components of ballistocardiograms need additional clarification, such as the transmission from the cardiovascular system to the body frame, the movement of body parts relative to one another, and the movement of tissue caused by the changing volume of the heart and of the blood vessels. The available evidence suggests that these effects are of minor importance for the longitudinal components of the movement, that is, only insofar as notches and slurs are concerned.

The development of lightweight ULF ballistocardiographs, with up to six degrees of freedom, made possible animal experiments on a ballistocardiograph. Such experiments had up to that time been very crude, although focusing attention once more on a basic problem: the interpretation of the record. Starr and Hamilton and associates had already been able to calculate the force ballistocardiogram, starting out from ejection curves. These approximations provided strong evidence for the theory that the greater part of the ballistocardiogram is originated by movement of blood in the large vessels. Cossio, however, concluded from animal experiments in which he occluded both inflow and outflow of the heart that most of the curve is due to movement of the heart inside the body. More recent experiments on dogs (Scarborough and Honig), carried out on ULF ballistocardiographs, did not support Cossio's view. They do suggest, however, that motion of the heart contributes appreciably to the ballistocardiogram. This conclusion was also reached by Burger and Noordergraaf in their calculation of the normal ULF displacement, velocity, and acceleration ballistocardiogram from the changing distribution of blood in the large and small arteries and in the heart, and the latter's motion as derived from other information concerning the heart's behavior. This calculation, which includes several assumptions that have to be checked, results in predicted curves closely resembling the average normal experimental ballistocardiograms.

The quantitative evaluation of the effects of aging, tortuosity, and of an abnormally performing circulatory system has scarcely been started.

Attempts to interpret the ballistocardiogram have greatly stimulated the search for methods to measure not only local pulsatile blood flow itself, but also the elastic properties of blood vessels *in vivo*. New methods for continuous determination of the ejection curve (the "force of the heart") and thus of the stroke volume, and of the latter directly are being developed, while characteristics of the records of use in recognizing definite clinical abnormalities are emerging gradually. All this could result because of the unity of method attained through a straightforward formulation of the underlying problems.

One can hardly imagine that the growth in, and dissemination of, understanding of circulatory phenomena could have evolved so rapidly without this cooperation, the scope of which is fortunately still widening and deepening.

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Essential Hypertension

In 1954, Hamilton, Pickering, Fraser Roberts and Sowry¹ published their study of the frequency distribution of blood pressure in the general population. For each age-group they obtained a single curve, Gaussian or skewed; there was no evidence that any one of the age-groups contained two populations, one with "normal" pressure and one with "hypertension." Again, when they studied the relatives of those subjects who (by conventional criteria) had hypertension, the curves were not bimodal. The authors concluded that "hypertension" may consist merely of the upper end of a continuous distribution, and that no exact demarcation between normal and high blood pressure exists.

This important study had considerable bearing upon the conventional concept of essential hypertension as "a disease," and it seemed that this concept might have to be rejected. Sir Robert