AN EXTRAORDINARY increase in knowledge of circulatory physiology has taken place relatively recently. This has largely been due to the introduction of improved methods for the accurate measurement of various hemodynamic events. There remains, however, an important gap that badly needs to be filled. There is no reliable method available for assessing the myocardial element of over-all cardiovascular function that is sufficiently simple to be applied to routine clinical practice. The need for this is most urgent in the management of patients with overt or incipient coronary artery disease. It is toward the goal of correcting this deficiency that much of the investigation in ballistocardiography is directed.

Several years ago an editorial prepared by us appeared presenting an evaluation of ballistocardiography at that time. It pointed out that there were several serious objections to the adoption of the technic as a trustworthy tool in clinical practice. Three important objections were discussed and emphasized. The first of these was that conventional instruments supplied partially distorted and rather limited information about forces impressed on the body and that the new, improved instruments, which largely eliminated these differences, required more development to make them sufficiently practical and dependable for clinical utility. The second objection was that although empirical clinical correlations were of stimulating interest, they were not sufficiently complete to permit clinical conclusions from the records of an individual case. A final objection was that there were no controlled studies upon animals that demonstrated correlation between known hemodynamic events and ballistocardiograms.

The purpose of this editorial is to record what progress has been made over the intervening years. In our previous review it was stated that records obtained from the high frequency, low frequency, and direct body systems then in common use were greatly distorted and dominated by passive body oscillations that arose from a resonant coupling of the body and the structure supporting it. Since that time considerable progress has been made in the development of systems that lessen these important mechanical errors. It has been shown that the main source of artifact can be reduced or eliminated by the use of a supporting system that allows the body to move rather freely in space with minimal coupling to the earth. This was accomplished by several different methods, all of which for practical purposes, yield the same result. These methods are termed "ultralow frequency systems," since the natural frequency of the body and support is extremely low. The methods are not really new, since the two earliest workers in ballistocardiography, Gordon in 1877 and Henderson in 1905, used systems of this sort. That the most important design characteristics arrived at intuitively by
these pioneers were physically sound has been established by recent analytical studies.

Whereas the waveform of the records from the older ballistocardiographic methods is significantly determined by passive body vibration, this is not true when the newer instruments are employed. As might be expected, these records are considerably different in waveform and contain meaningful information over a much wider frequency range. Records of the body’s displacement, velocity, and acceleration have been obtained with various direct body methods, but the physical meaning of these records is obscure. However, displacement, velocity, and acceleration records from the ultra-low frequency systems have definite physical meaning.

Ballistocardiography is concerned, in the broadest sense, with measuring mass movements of the body in response to movements in the circulation and, by so doing, giving objective information about the over-all performance of the circulatory system. In this sense the term mass movements refers to movements not only of the mass of circulating blood but also of such masses as the heart itself during the cardiac cycle.

When the human body is supported in such a way that it in effect floats without restraint, then any motion of mass within that body will be reflected by oppositely directed motion of the body itself, so that the center of gravity of the whole system remains unchanged. If one records the displacement of the instrument’s platform and the body it supports, with the onset of systole there is a headward displacement of the cardiovascular mass. This is followed shortly by a prolonged footward displacement that lasts until early diastole, after which there is a slow return in a headward direction until the beginning of the next beat. This agrees in general with what is known from physiologic studies by other methods regarding the direction and flow of blood in the arterial and venous systems during the cardiac cycle. Similarly, velocity records yield information about cardiovascular momentum (mass × velocity) since, ideally, cardiovascular mass times its velocity is equal to body mass times its velocity. Acceleration records, in like manner, yield information about cardiovascular force. Each of these types of records supplies a different and complementary kind of information about cardiovascular mechanical behavior. However, the fidelity with which these records reflect actual blood flow within the body has not been determined but is under active investigation.

Much of the recent biophysical effort in this field has been expended in attempting to extend the recording technic from the single longitudinal axis to other axes. Although lateral (or side-to-side) records have been obtained from conventional ultra-low frequency systems, these appear to contain a mixture of information, part of which is due to translation and part to body roll from rotation about the longitudinal axis. Evidence now available suggests that this sort of distortion can be eliminated only when the body is suspended so that it is free to roll, thereby yielding a roll-free lateral translational record.

Definite progress has been made in the development of suspensions of this kind but none is yet available for routine clinical use. There is good reason to believe that multidirectional recording will be as important in this field as it is in electrocardiography and in both cases frontal plane recording seems to be a minimum requirement.

The accumulated clinical work, most of which has been carried out with the classical instruments of Starr, Nickerson, and Dock, has yielded some stimulating clinical correlations. In general, the waveform of the ballistocardiogram is definitely abnormal in the majority of patients with overt cardiovascular disease although the frequency of abnormality is partially dependent on age. There has been hope that correlations between the type of cardiovascular disease and the kind of abnormal ballistocardiogram might reveal specific and characteristic record patterns of diagnostic value. These correlations have not been impressive, but probably no less impressive than those between anatomic diagnosis and other individual measurements of cardiovascular function. On the other hand, there is now reason to believe that this apparently limited specificity may have been due, at least in part, to
the fact that the cardiovascular information in the older ballistocardiograms was confused and distorted by meaningless artifact. The new instrumental methods will doubtless increase the specificity and precision of the measurements, but it is to be expected that records from them will correlate much better with functional than with anatomic circulatory conditions.

In addition to the interest that stems from these considerations, much of the effort in clinical ballistocardiography has been directed toward an evaluation of patients with coronary artery disease because other objective methods employed for the diagnosis and management of this condition are of limited value. It has been clearly established that the majority of patients with either angina pectoris or a history of myocardial infarction have abnormal ballistocardiograms at rest and in many of these there is no other objective evidence of cardiovascular disease. This would suggest that the method has real clinical value were it not for the fact that abnormal ballistocardiograms are found to occur in normal individuals above the age of 40 more and more frequently with increasing age. In the age range below 40 abnormal records from normal subjects are unusual but normal records from patients with coronary artery disease are common. Although it seems fair to assume that many older normal individuals have subclinical coronary artery disease, there is not yet proof that this is the cause of their frequently abnormal ballistocardiograms. At present these considerations limit the diagnostic value of ballistocardiography in coronary artery disease and make necessary a thorough search for supplementary procedures that will increase the separation between subjects with and without this circulatory abnormality.

In support of the belief that ballistocardiography measures some circulatory function of real clinical importance in patients with coronary artery disease, one observation in particular should be emphasized. There are well-documented instances in which ballistocardiographic waveform has been observed to deteriorate acutely during an attack of angina pectoris and to improve promptly when the attack was terminated.

Interest continues in the effect of cigarette smoking on the form of ballistocardiograms of subjects both with and without known coronary artery disease. A larger experience with this stress test bears out the earlier observation that it serves to separate patients from controls more impressively than does any other objective measurement. Ballistocardiograms of roughly one half the patients with overt disease deteriorate after smoking a cigarette whereas only 7 per cent of normal controls show such a response.

The data from clinical studies to date are too meager to permit definite conclusions upon the value of ballistocardiography in the clinic. Time may provide an answer as to whether there is prognostic significance to an abnormal ballisto-cardiogram especially now that there are newer methods of recording that may give more accurate information. The ultra-low frequency ballistocardiographic methods are so recent that data relative to their use are few. The American Heart Association’s Committee on Ballistocardiographic Nomenclature, headed by Dr. Isaac Starr, recently published a recommended terminology for the several types of records from the ultra-low frequency systems. These new methods are now being explored by most of the research groups active in this field, but the only sizable clinical study yet reported appeared in an excellent monograph in Dutch by Elsbach, using the bed developed by Burger. Concentrating on younger individuals, he described characteristic or typical patterns in certain varieties of congenital and acquired cardiovascular diseases and showed that these could be correlated with specific hemodynamic alterations. This and similar work will in time undoubtedly demand revision of some of the previously held views that were based on results with the older methods.

Final confirmation or denial of the clinical value of ballistocardiography will almost surely come from a more precise understanding of its physiologic significance as a result of controlled experimental study upon animals. Experimental work in the human has been limited in the past and will probably remain so in the future because only the simplest and most innocuous procedures are ethically justified.
Animal work now in progress in several laboratories has moved slowly but now promises to make a significant contribution. The differences between man and the dog in body build, weight, flexibility, and other physical characteristics required the development of special ultra-low frequency ballistocardiographic beds and other suitable electromechanical instruments. The technical difficulties encountered in working with anesthetized animals proved much greater than those with cooperative, unanesthetized human beings. The necessity for controlling respiration, for making several physiologic measurements simultaneously and for performing open chest surgery made it still more difficult to obtain consistent and reproducible ballistocardiograms from dogs. Anesthesia alone produces deterioration of the waveform of ballistocardiograms from otherwise normal dogs, a fact that seems a tribute to the sensitivity of the technic in detecting changes in circulatory function known to result from anesthesia. Methods have been found for obtaining normal ballistocardiograms in anesthetized dogs both with and without artificial respiration over periods of many hours and these records are remarkably similar to those from normal human subjects.

This experimental work must be considered preliminary at present because experience has been limited. However, certain correlations between the ballistocardiogram and other mechanical aspects of normal and abnormal cardiovascular activity have already begun to emerge. The dynamic circulatory effects of normal and artificial respiration have been under investigation and interesting differences between unanesthetized man and anesthetized dog have been found. Other studies undertaken to assess the relative contributions to the ballistocardiogram of blood flow in the pulmonary and systemic circulations promise to yield important information. Attempts to separate the effects of motion of blood in the great vessels from motion of the heart itself on the ballistocardiogram have yielded inconclusive results; however, a definite relationship has been demonstrated between ballistocardiographic force and cardiac contractile or ejection force as measured by the strain gage.

A considerable amount of information may be expected from indirect experiments of this sort, but the ultimate hope in determining the physiologic origin and significance of the ballistocardiogram lies in the direct measurement of pulsatile blood flow in various parts of the circulatory system in the animal. Definite progress is being made in the development of flow meters suitable for this work, and there is reason to believe that these measurements will be possible in the not too distant future.

The instruments and procedures used in the field of ballistocardiography are of considerable technical complexity and the problems involved in providing the method with a sound physiologic basis will not be easy of solution. However, the promise this technic holds for providing information of a new and entirely different type about the mechanical function of the cardiovascular system demands continued and intensified research efforts. As complex as the method may be, one should not lose sight of the fact that from the patient’s viewpoint it is a simple one, for the only thing required of him is that he rest quietly on a bed.

There is no denying the need for some objective method that will detect preclinical coronary artery disease. The hope for successful treatment by dietary, surgical, hormonal, chemical, and other measures makes this need an urgent one. It seems unlikely that an improved method suitable for routine clinical use will come from current research upon electrocardiographic, radiologic, and catheterization technics. Ballistocardiography is the only method now under study sufficiently simple from the patient’s point of view that holds out some promise for evaluating over-all circulatory performance. In addition to what has already been said a preliminary observation leads us to believe that this can be accomplished. The ballistocardiograms of a small group of patients with overt coronary artery disease whose dietary fats were considerably restricted for a year or more improved in form significantly when contrasted with those of a control group allowed to select their diets freely. To our knowledge this observation provides the only
objective evidence indicating that dietary lipid restriction may improve circulatory function in human beings with coronary atherosclerosis.

This review is an expression of faith in the further development of ballistocardiography. A few years ago we took a strong position that many unjustified claims were being made for the clinical value of the method and since then we have consistently advised a conservative attitude. Partly because progress in this highly specialized and technically complex field has seemed slow, there has arisen recently some rather harsh criticism of the method that we think is unwarranted, especially as it now seems likely that current research will provide, within the near future, a sound physical and physiologic basis for ballistocardiography.

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REFERENCE

Editorial: Ballistocardiography—Appraisal of Current Status
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_Circulation._ 1957;16:971-975
doi: 10.1161/01.CIR.16.6.971

_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231

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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:
http://circ.ahajournals.org/content/16/6/971.citation

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