

**COMMENTS ON
PROGRESS IN BALLISTOCARDIOGRAPHIC RESEARCH
AND THE CURRENT STATE OF THE ART**

by William R. Scarborough, M.D.

Reprinted from Proceedings of the
3rd EUROPEAN SYMPOSIUM FOR
BALLISTOCARDIOGRAPHY
Belgium, 1962

Comments on progress in ballistocardiographic research and the current state of the art (*)

by William R. SCARBOROUGH, M.D. (**)

Introduction :

I would like to express my pleasure at being able to attend, for the first time, your society and to discuss with you the type of cardiovascular research which is of interest to us all. During the last few years, I have been impressed and greatly gratified at the volume and quality of work relating to ballistocardiography which has been carried out in Europe. My remarks during this discourse will be of a general nature and will concern what I feel to have been significant advances in the field. I propose to indicate those areas in which it seems to me more research effort is needed. I cannot, of course, include the more recent work you have been doing in Europe but by the end of this meeting I hope to be better informed about it.

Instrumental Considerations :

First, I would like to turn to instrumental considerations. In an earlier paper, Dr Starr discussed the history and development of ballistocardiography and therefore I need not repeat the evolution of the method. However, I would like to emphasize the fact that the two earliest « adventurers » in this field, Gordon (1) in 1877 and Henderson (2) in 1905, intuitively selected methods for supporting the human body which were the proper ones, a fact which emerged

(*) Presented before the Society for Ballistocardiographic Research in Brussels, Belgium, on April 16, 1962 (Third Symposium).

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Supported in part by a research grant (H-327) from the National Heart Institute, National Institutes of Health, U.S. Public Health Service.

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many years later as a consequence of the rigorous physical analyses by Burger and his group (3-5), by von Wittern (6) and by Talbot and Harrison (7). As is known to all of you here, the efforts by the early investigators were not sustained and it remained for Starr (8) with his development of the rugged, reliable high-frequency bed to excite the continued interest of investigators in this field. Dr Starr recognized at the outset that the records from this bed were distorted but, and I think rightly, he chose to use it, for it permitted him to study a large number of subjects with many different kinds of disease states. The results of the several physical analyses referred to already can be rather briefly summarized and illustrated in fig. 1. This demonstrates the distortion which is due to the stiff coupling to « ground », heavy platform mass and/or excessive

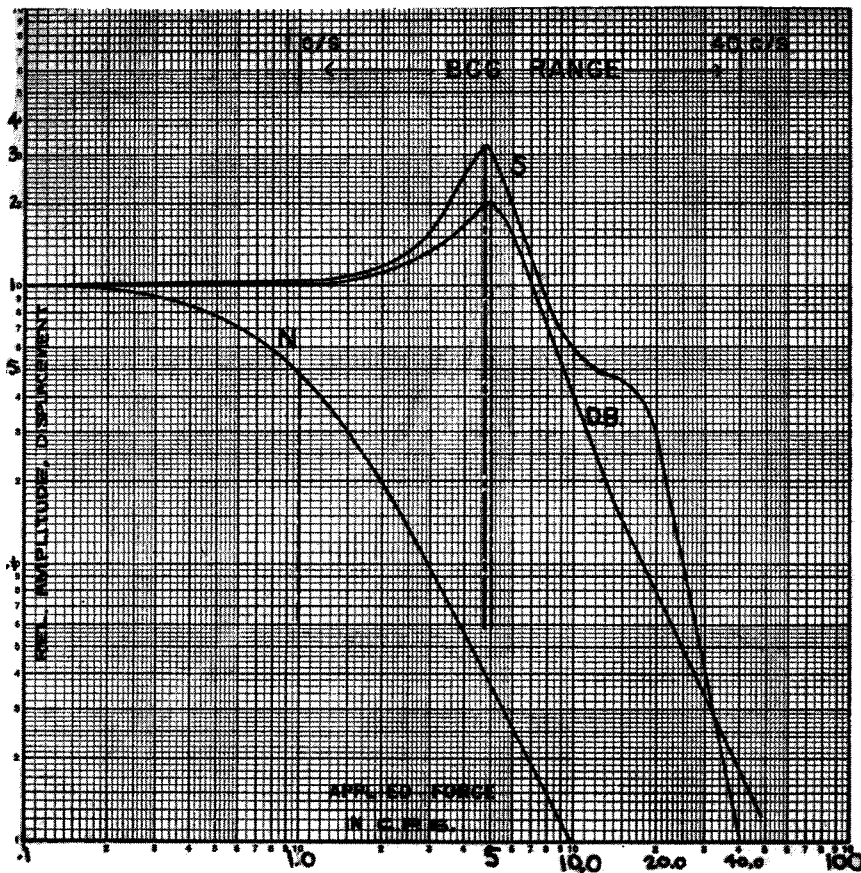


Fig. 1.

Frequency Response Characteristics (F.R.C.) for 3 Ballistocardiographic Systems. N : Nickerson low-frequency. S : Starr high-frequency. D.B. : « Direct-body » (with stiff footboards). Displacement amplitude values when applied force is held constant but varies in frequency.

damping and shows the frequency-response characteristics of a Starr high-frequency bed, a Nickerson low-frequency bed, and a « direct-body » (shin pick-up type) system. With the « direct-body » and Starr systems there is a large resonance peak in the vicinity of 5 cycles/second, with marked attenuation thereafter. For the Nickerson method there is a loss of most of the high-frequency components.

The effects of the distortion introduced by these systems is illustrated by the next diagram which simply shows what would happen if the electrocardiogram were distorted in a way similar to that in which the internal cardiovascular forces are distorted by the older classical methods of ballistocardiographic recording. Fig. 2,

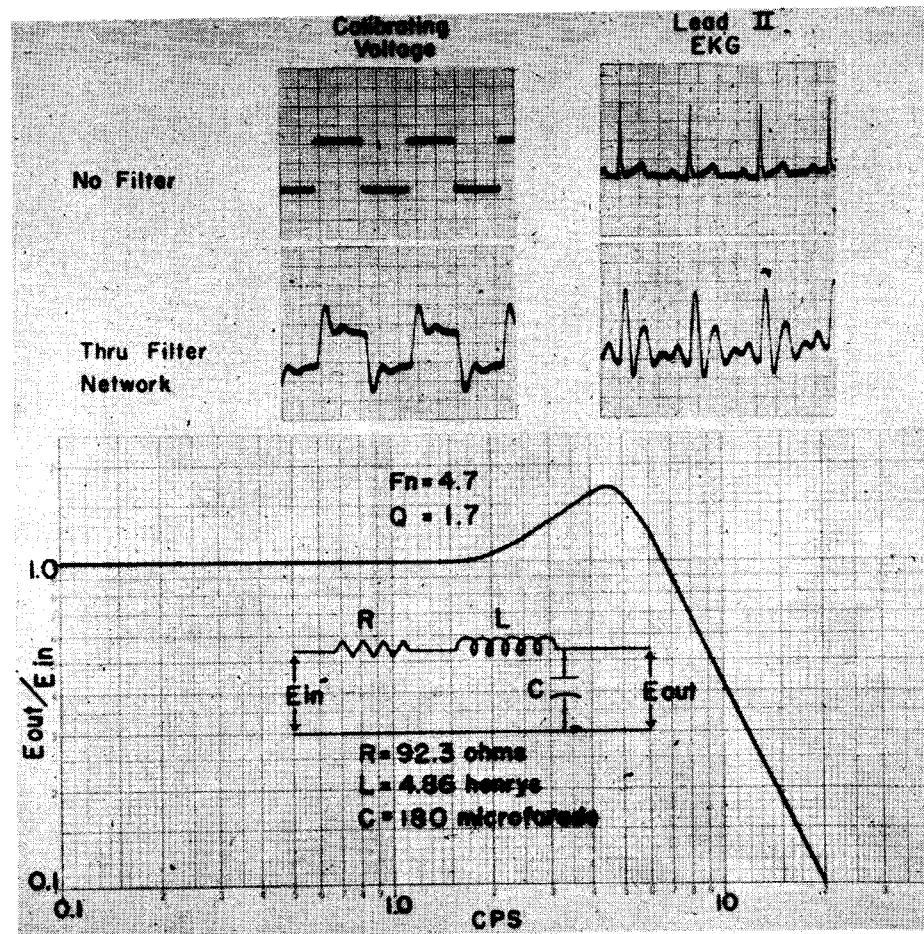


Fig. 2.

Simulation by R-C-L filter of distortion introduced by body's « Dorsal Spring ». This filter was designed to demonstrate the appearance of an ECG if it were distorted in the same way as internal cardiovascular forces are distorted if body's support is too stiff and/or heavy. At bottom : F.R.C. curve of the filter; note similarity to D.B. in Fig. 1. At top, right : At the extreme top is a standard ECG lead and immediately below it is the same lead after it is run through the R-C-L filter; the marked distortion of the latter is evident.

at bottom, shows the frequency-response characteristics of a « high-cut » R-C filter designed to simulate the body's own passive characteristics. Above, on the right, is a normal lead II electrocardiogram. Immediately below it is the record of this electrocardiogram after it had been passed through this filter; the marked distortion is obvious.

It has been rather clearly demonstrated that ultra-low frequency ballistocardiographic systems largely circumvent the errors inherent in the older methods. The ULF systems may be characterized by the following attributes : 1) low natural frequency or « soft » coupling to earth; 2) low platform mass; 3) minimal damping. To this should be added a fourth at least; 4) a support structure for the body so designed that parasitic oscillations of an extraneous nature do not interfere.

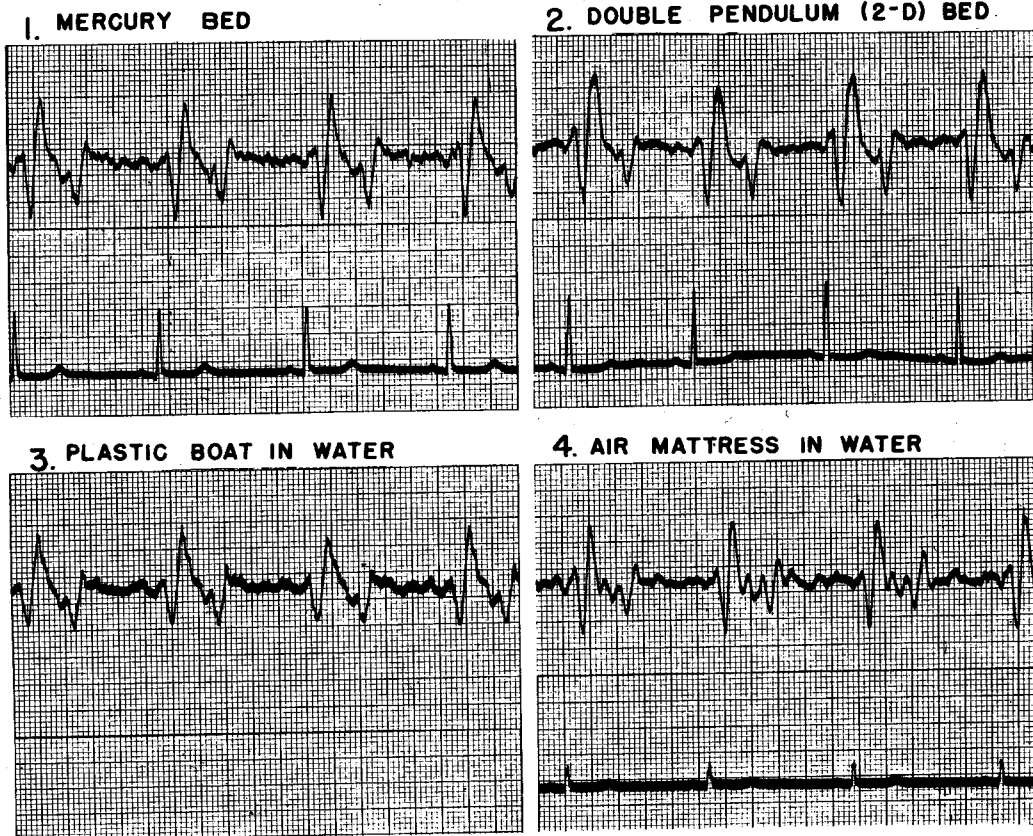


Fig. 3.

Ballistocardiograms from same subject using different types of highly-compliant suspensions. Note similarities. Lower two tracings, 3 and 4, were obtained with temporary experimental suspensions in which accelerometers were not well mounted; this probably accounts for most of the differences between them and tracings 1 and 2.

A variety of methods for attaining suitable performance characteristics has been used. These include very long simple pendular systems, shorter simple pendular systems with lateral offsets (similar to Henderson's original design), differential-pendulum systems with balancing legs, horizontal-pendulum systems of the « swinging door » variety, floatation in mercury or other liquids (these have been experimental only), « airbearing » systems (*), and others of mixed mechanical design. Fig. 3 illustrates acceleration ballistocardiograms

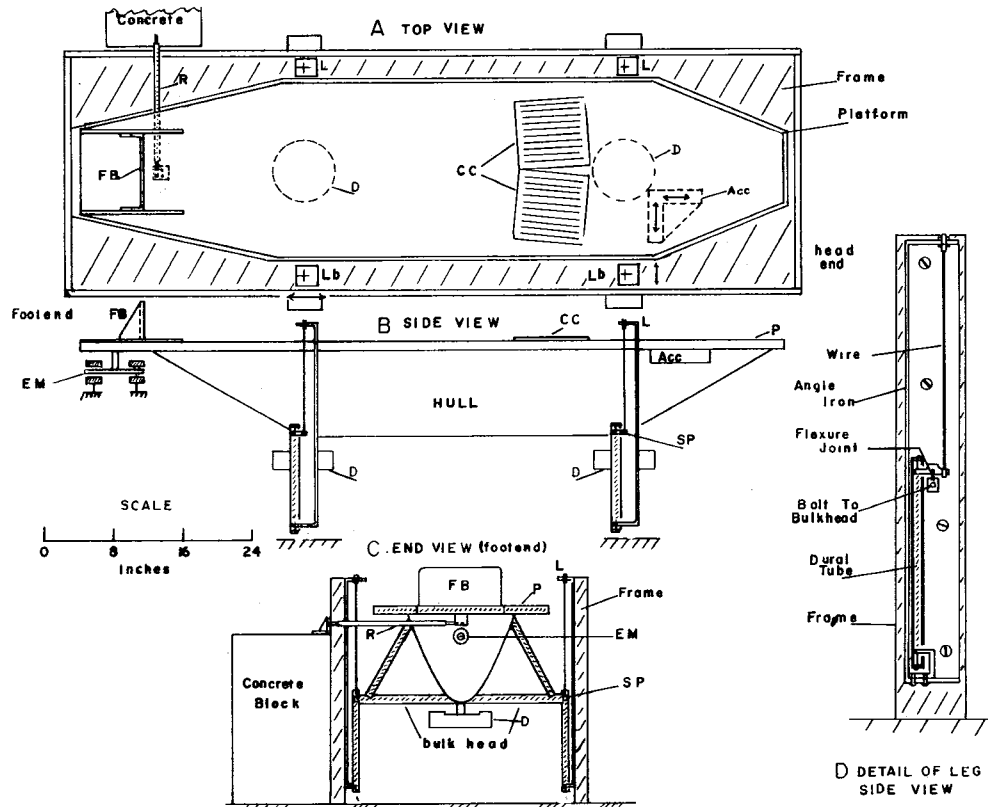


Fig. 4.

Diagrams of the construction of the differential-pendulum ULF bed. Portions of the wooden frame are indicated in A, C, and D but are not included in B for reasons of clarity. Symbols : L : differential-pendulum leg; Lb : legs used for balancing platform; R : restraint rod to prevent lateral motion; FB : footboard; Acc : accelerometers; P : platform; EM : electromagnetic transducer; SP : suspension point for platform; D : dampers; CC : rubber pads with grooves for seating the postero-lateral chest constraints. (Courtesy American Journal of Cardiology.)

(*) A bed based on this principle is now commercially available in the United States from the Cordis Corporation, 241 N.E. 36th St., Miami 37, Fla. In Europe, two types of beds based on different principles are being produced commercially.

obtained on the same subject with four different systems. The similarity among them is apparent and such differences as do exist probably relate more to the manner in which the accelerometer was coupled to the supporting system than to the characteristics of the system itself. Fig. 4 shows a differential-pendulum bed design which permits the recording of head-foot and lateral (side-to-side) motions—displacement, velocity, and acceleration. This bed has been proven rugged and reliable through five or six years of routine work. Fig. 5 shows displacement, velocity, and acceleration records obtained with it from three normal subjects; this illustrates some of the individual

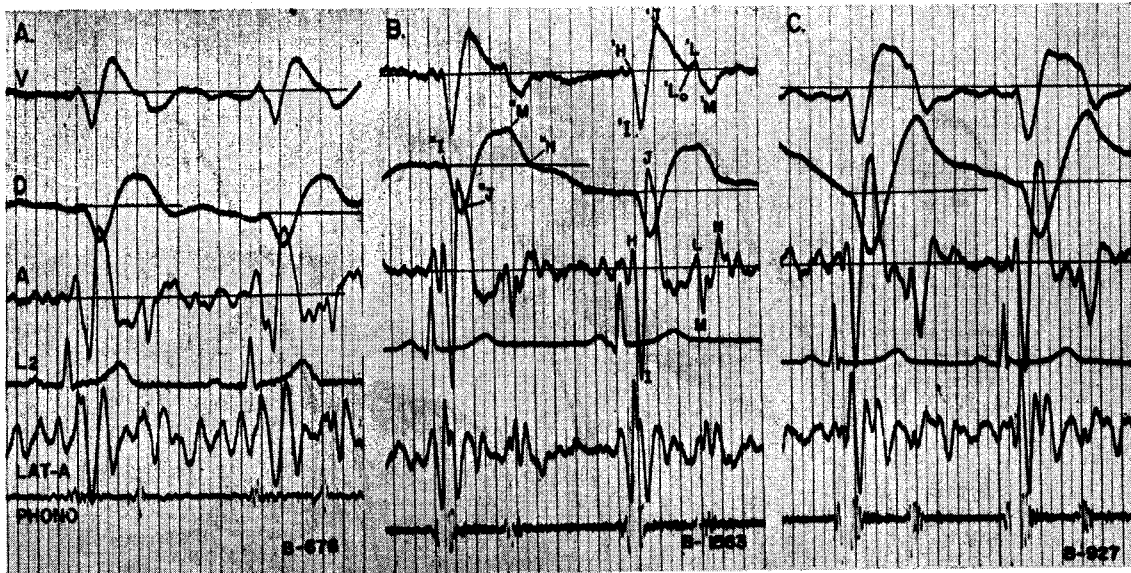


Fig. 5.

Normal ULF ballistocardiograms from three young females. Baselines are drawn in to indicate the manner in which they are placed. (Courtesy American Journal of Cardiology.)

variation normally observed. Fig. 6 shows the simultaneously recorded displacement and acceleration ballistocardiograms in the head-foot and lateral axes in one subject. There is ample reason to believe that the records in the longitudinal axis are relatively free of distortion but this probably is not the case for the lateral records from beds which do not permit « roll » (rotation about the longitudinal or y axis). The evidence indicates that the records in the lateral mode represent a mixture of rotations and translations.

In an attempt to eliminate distortion of the type referred to above, efforts have been made to develop ULF-BCG systems with multiple degrees of freedom, each independent of the other. Talbot's 3-D (three directional) bed is an experimental one and is quite complicated, but it does permit the recording of three translations

and three rotations independently (14). Such a bed has been duplicated in no other laboratory with which I am familiar and a rugged tri-directional design which is relatively simple to operate is yet to emerge. This is a long-sought-for hope for the future, as is a design which permits upright, sitting or standing recordings which allow a study of circulatory function under normal gravitational forces.

Finally, one other specific design should be referred to and this is the system described by Babskii and his Russian colleagues (15). This is a chest support device which behaves as though there were a small bathroom scale under each of four corners. The pressures applied to these scales are recorded in such a way that longitudinal

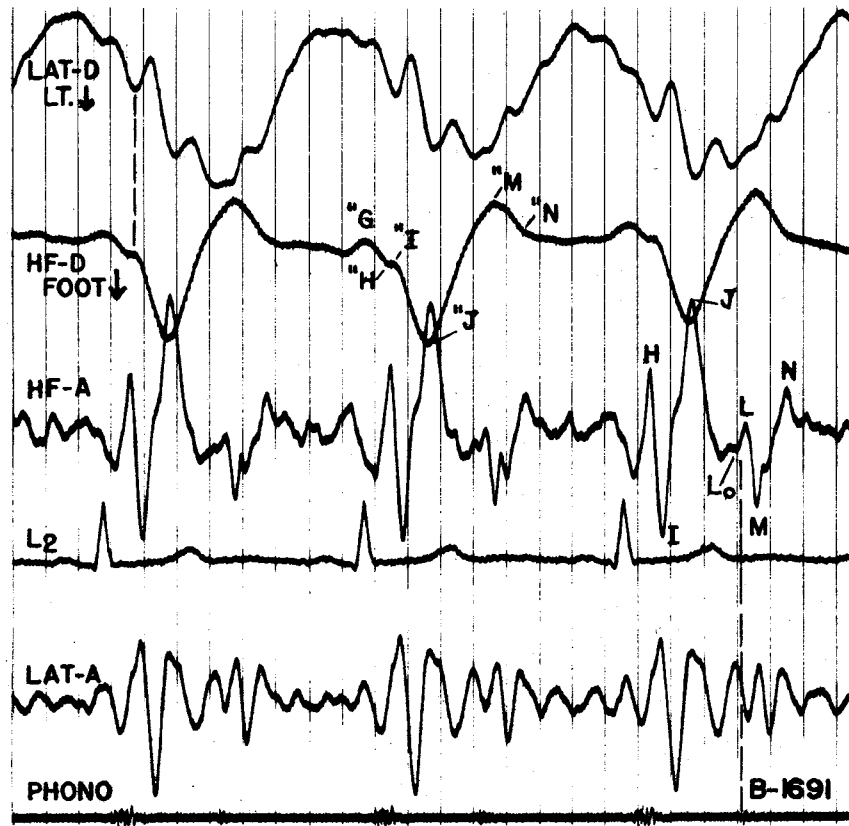


Fig. 6.

Simultaneous head-foot displacement (HF-D) and acceleration (HF-A) records and lateral displacement (LAT-D) and acceleration (LAT-A) records. From a young normal female. Polarity of the tracings is indicated by the arrows. (Courtesy American Journal of Cardiology.)

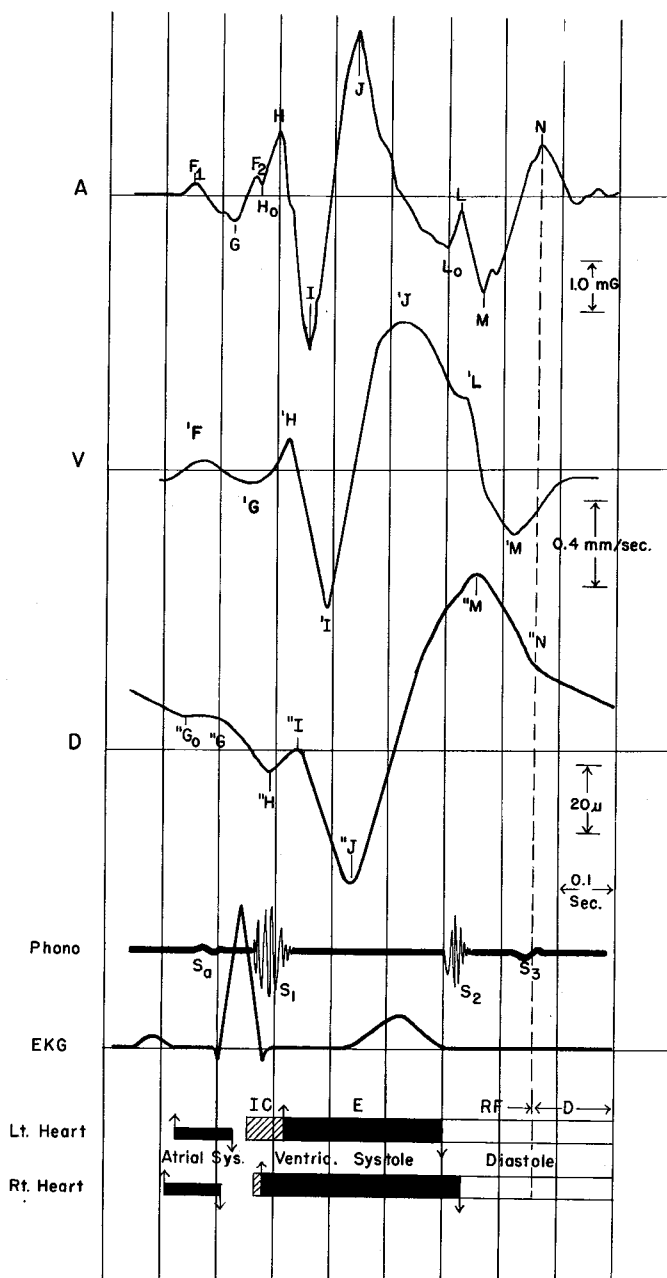


Fig. 7.

Normal human displacement (D), velocity (V) and acceleration (A) ballistocardiograms from an ultra-low frequency (ULF) system and their temporal relation to events in the cardiac cycle. The BCG, heart sounds (phono), and EKG tracings were based on the measurements from 25 males, 20-29 years of age. The block diagrams at the bottom represent the timing of cardiac events on the two sides of the heart and are based on data supplied by Braunwald and by Wiggers (see text). IC = isometric contraction (Crossed-hatched), E = ejection phase (solid black), RF = rapid filling, and D = diastasis. Calibrations for the three ballistocardiograms are shown on the right. mG represents milli-G; 1.0 mG (0.001G) is approximately equal to 1.0 cm/sec²; μ represents micron; 20 μ is equal to 0.02 mm. (Courtesy American Journal Cardiology.)

changes in the center of gravity are recorded. However, there are a number of complicating factors which makes a biophysical evaluation of this kind of system extremely difficult.

To summarize my views about instrumentation, I would say the following : rugged, reliable ultra-low frequency systems are available for head-foot or longitudinal recording but the lack of commercial instruments which can be obtained by competent research groups has hindered progress; simpler, more practical, 3-D beds for clinical work are in development but are not yet available.

Physiologic Significance of the Ballistocardiogram :

A few comments seem in order about the physiologic significance of the ballistocardiogram. My own view is that the principal aim of research in this area is to provide ballistocardiography with a sound physiologic basis. Those of you who have worked in this field are clearly aware of the difficulties which exist in quantitating, in any exact fashion, the various determinants of the ballistocardiogram. These determinants are multiple and are often mutually dependent; they are often inaccessible in the human subject. Some of the quantities which are needed cannot be obtained because no adequate method of measurement exists, either in man or animal. Nevertheless, the determinants which are known, or believed, to be important can be listed. These include : 1) motion of the heart's mass; 2) stroke volume; 3) acceleration of blood from the heart during systole; 4) velocity of blood flow through the major arteries; and 5) size, spatial orientation, and elasticity of the larger vessels. Fig. 7 shows normal ULF ballistocardiograms aligned in time with various events in the cardiac cycle in man. Although there is a certain amount of overlap and mixing, three series of events in the acceleration ballistocardiogram are distinguishable. These are motions associated with : 1) atrial contraction and ventricular presystole (wave-tips preceding the H wave); 2) ventricular ejection (H and successive waves to but not including the L tip); and 3) early ventricular filling (wave tips L, M & N). Fig. 8 shows what is considered to be a reasonably representative normal acceleration ballistocardiogram from a dog plotted along with measurements of the phases of the cardiac cycle, the latter published by Moskovitz and Wilder (9). Our own results (10), in which simultaneous ballistocardiograms and specific events during the cardiac cycle were obtained, are similar to these. You will note the similarity, both in general waveform and in relation to events in the cardiac cycle, of the acceleration ULF ballistocardiograms in man and dog, even though in the latter the duration of systole, and of ejection, is considerably shorter than in man. In this record from a dog, the duration of systole is 0.22 sec. while the interval between the H and L wave is 0.26 sec. In the previous figure the duration of systole was 0.34 while the H-L interval was

0.33 sec. Systole is shorter in the dog but so is the duration of the systolic ballistic complex; thus the relationship between specific ballistic waves and the events which mark the onset and termination of ventricular contraction is retained. In the humans there is a highly significant correlation between the H-L interval and the duration of systole; there are, however, systematic differences when men and women are considered separately (11). With respect to the dog ballistocardiogram, our impression remains that, in general, a dog

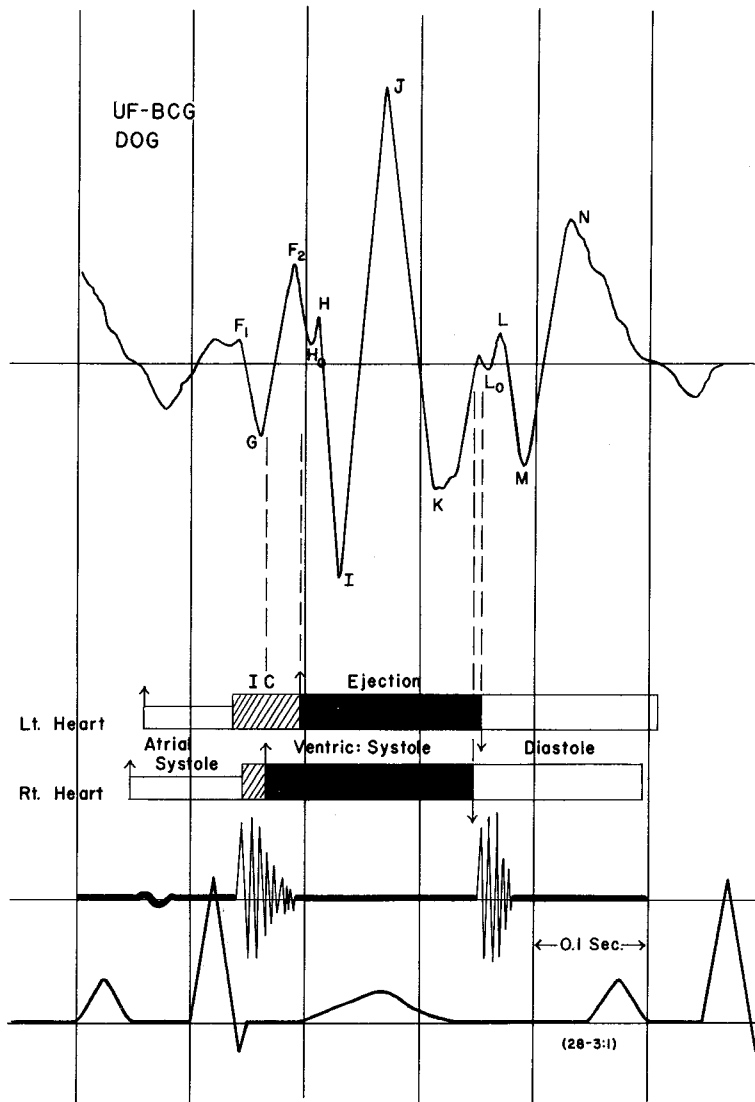


Fig. 8.

Representative normal ULF Acceleration Ballistocardiogram from a Dog and associated events of the Cardiac Cycle. Timing of right and left sided cardiac events from data by Moscovitz and Wilder.

ballistocardiogram which is « normal » resembles a normal human record and that when the dog's acceleration ballistocardiogram no longer resembles that in young normal humans, it is likely that some derangement in circulatory function has occurred, possibly as a consequence of the anaesthetic used, the nature of respiration, and the duration of the experiment (12). During a given experiment in a dog, it was found that while the initial records may be large and resemble the human ballistocardiogram in wave-form, yet as the experiment progressed but with no change whatsoever in the conditions of the experiment, there was often marked deterioration in wave form. In many of these cases the application of abdominal compression resulted in restoration of the normal wave-form. It seems apparent that the changes described represent acute and very real circulatory changes and it seems unlikely under these conditions that the alterations could be accounted for by the position of the dog on the BCG bed itself. I understand that Drs. Knoop and Pretorius will have another explanation to account for the differences between ballistocardiograms obtained on men and dogs.

Fig. 9 shows a simplified schematic outline of the circulation in the human. This simply shows the circulatory system divided into three lumped regional beds, the cerebral, the abdominal and the lower extremity. The sizes of the round or oval « beds » in this diagram were drawn to be roughly proportional to the relative quantity of total cardiac output going to these three regions. The displacement ballistocardiogram is a reflection of the mass-motions of the body and its support and this in turn is proportional in magnitude, but opposite in direction, to the mass-motions occurring internally, within the cardiovascular system. The internal mass-motions are obviously an algebraic sum of all of the internal motions of blood, so there is a certain degree of mutual cancellation by the uptake of blood in footward and in headward vascular beds. What this implies is that the size and shape of the normal ULF ballistocardiogram is determined by the spatial and temporal distribution, during the whole cardiac cycle, of the mass of blood ejected during each systole. (Spatial distribution, in this connection, is confined to the longitudinal axis since the validity of records taken along the other two axes is still questionable). Although there is the usual individual variability as in all biologic measurements, the consistency in magnitude and wave-form of the ULF ballistocardiograms from young, healthy individuals suggests that systolic stroke volume is distributed through the circulatory system in space and time in a similar fashion among these persons. When the ballistocardiogram from a single individual is **abnormal**, presumably reflecting abnormal changes in the «pattern» of distribution of blood mass, to what factor or factors may this be attributed? Here, we are groping in the dark on uncertain terrain.

It is known that such abnormal alterations in distribution do occur as a result of certain marked structural and functional changes

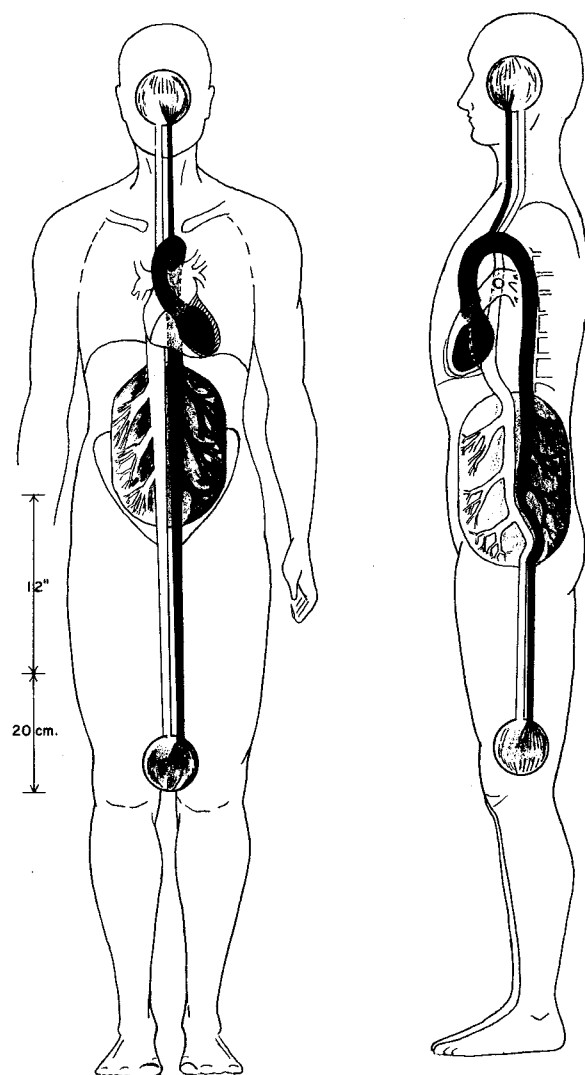


Fig. 9.

Diagram of the circulation to represent direction and distribution of blood flow. The systemic arterial system is in black, the venous and pulmonary arterial system in white. The size and shape of the cardiac chambers and intra-thoracic vessels were based on angiocardio-graphic measurements. Estimated distribution of blood flow to various parts of the body is represented by round or ovoid « lumped » vascular beds. (Courtesy American Journal Cardiology.)

in the circulatory tree. In coarctation of the aorta, nature has designed an experiment to demonstrate this point. Fig. 10 shows the pre- and post-operative records on a young man who had this condition. The records on the left were taken prior to resection of

the coarctation while those on the right were taken after recovery from the operation. In each case, from above downward, they are velocity, displacement and acceleration ballistocardiograms, respectively. In the displacement record, it is to be noted that a large footward displacement of the body, corresponding to a headward displacement of blood, occupies almost the whole of systole. This suggests that the major uptake of blood during systole occurs in a direction headward from the heart. It is evident that the lower part of the body cannot be long deprived of a blood supply, and it is, in fact, usually found to be reasonably adequate. The difference is that the obstruction at the arch does not permit the blood to flow beyond the constriction in a pulsatile fashion but allows only an almost steady flow to the lower part of the body by devious and circuitous routes. In this respect, the constriction of the aorta acts as a « high-cut »

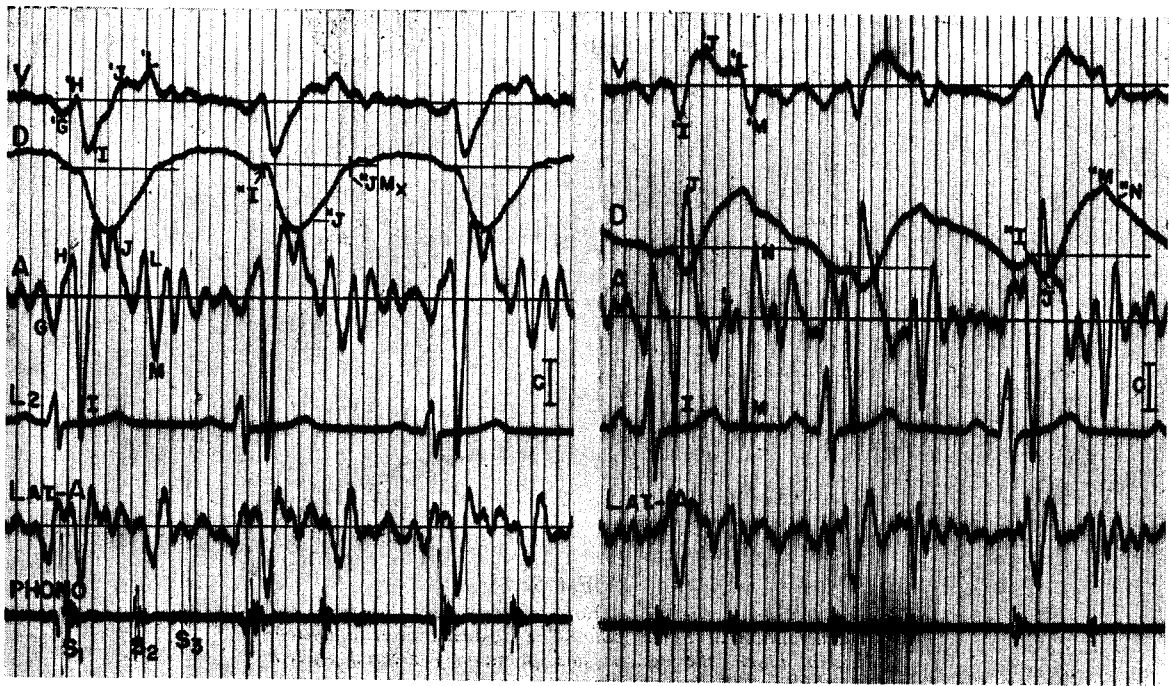


Fig. 10.

Pre- and postoperative ULLF ballistocardiograms from nine-year-old male with coarctation of the aorta. Left : Preoperative records. The most striking alterations are in the displacement record which shows a deep and greatly prolonged footward « J » occupying the whole of systole; the normal headward « M » is absent. This indicates that the displacement of blood during systole is predominantly headward. The normally large and rapid uptake of blood by the vessels distal to the arch cannot take place because of the obstruction and these vessels fill slowly through devious channels. This results in an unbalanced headward displacement of blood-mass during systole. The velocity and acceleration ballistocardiograms are also altered. Right : Records taken three weeks after operation. The ballistocardiograms have become normal. In the displacement record the large, broad « J » has been replaced by a normal, small « J » and this is followed by the large headward « JM » displacement. This suggests that the uptake of blood by vessels distal to the arch now takes place normally. The velocity and acceleration records have also become normal. (Courtesy American Journal of Cardiology.)

filter, as Elsbach pointed out earlier (13). The records on the right in Fig. 10 show the return to a normal ballistocardiographic configuration with re-establishment of normal aortic filling and distribution after the obstruction had been eliminated. This kind of alteration as been produced in our laboratory on dogs and Professor Klensch has simulated it in hydraulic models.

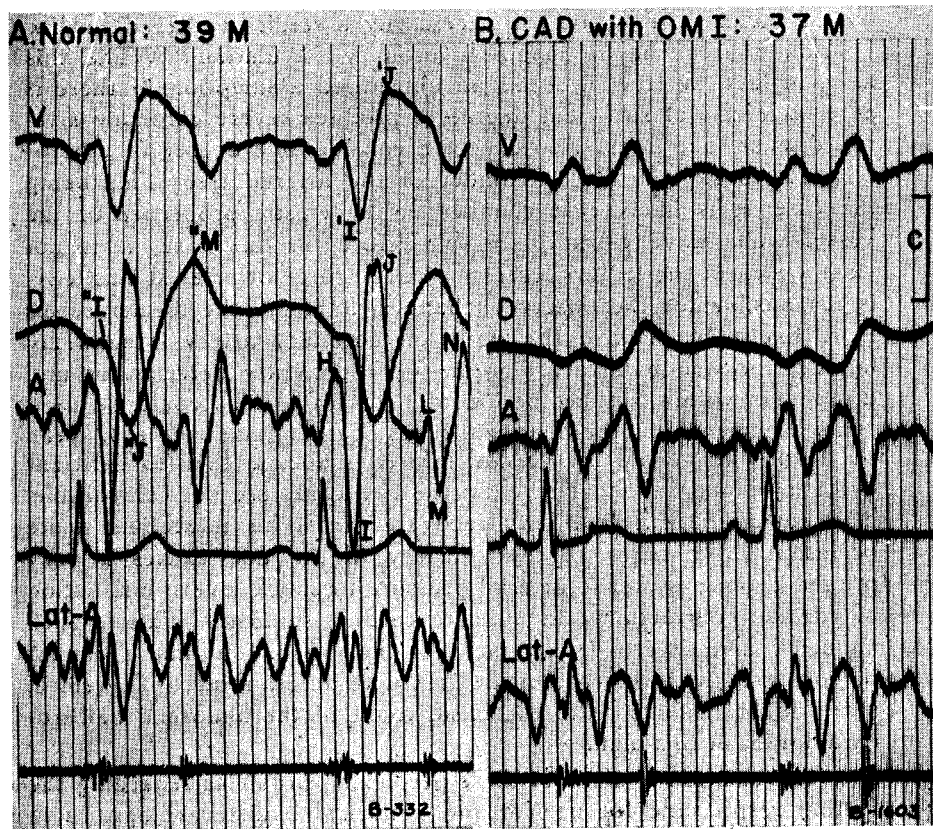


Fig. 11.

ULF ballistocardiograms (D, V and A) from a normal subject (A) and a patient (B) who sustained a myocardial infarction in the past. The men were comparable in age, weight and habitus. Calibration is the same for both. All three headfoot records in B are abnormal and are quite different from the normal records in A, both in amplitude and waveform. (Courtesy, Progress in Cardiovascular Diseases.)

Mention has already been made of the multiple variables which play a part in the genesis of the ballistocardiogram. One of the difficulties in the clinical interpretation of the ULF ballistocardiogram lies in determining which of the variables is responsible for observed alterations. In Fig. 11 are shown the ULF ballistocardiograms from

two subjects similar in age, body size, and weight; the only difference between the two is that the records in «A» were from a normal individual while those in «B» were from a patient who had sustained a myocardial infarction at an earlier date. The calibration in the two sets of records is the same so that they are directly comparable in amplitude. The differences between these two sets of records are obvious, even to anyone not familiar with tracings of this kind. Knowing that this man had sustained a myocardial infarction in the past, can one assume that the abnormalities manifested by the ballistocardiogram are necessarily a result of altered cardiac ejection consequent to impaired coronary circulation? While this may, in fact, be true, it seems an unjustified assumption. If there is atherosclerosis of sufficient degree to produce severe coronary arterial disease, one might also expect a considerable degree of atherosclerosis throughout the remainder of the arterial tree. This being the case, it is likely that changes in the elastic properties of the vessel walls have taken place. Therefore, in this case, it is not clear which of the factors, cardiac ejection force or arterial elasticity, is responsible for the observed changes, although the former seems more likely. In dogs, if the main left coronary artery is suddenly ligated, the dog ballistocardiogram very promptly deteriorates and disappears within a short period of time (10). This could be used as an argument that the abnormal ballistocardiograms in the 37 year old man with an old myocardial infarct is due, in fact, to deficient coronary blood supply. However, the two cases are not comparable. The human patient had fully recovered from his infarction; acute occlusion of a major coronary artery in the dog causes a very prompt drop in systemic arterial pressure to shock levels, diminution of cardiac contraction and ultimate cardiac standstill. This is such an acute and severe derangement of the circulation that it cannot be compared with the case of the man with an old infarct. Therefore, some doubt remains as to the basic cause of the abnormal ballistocardiogram in this man.

The solution to some of these perplexing problems regarding the factors responsible for normal and abnormal ballistocardiograms in man has been sought by attempts to simulate the circulatory system in various ways. One method which has been used is that of hydraulic models. Professor Klensch's group has had considerable experience with them but they have been used by other groups, as well. These studies have unquestionably contributed important information to our basic knowledge. However, there are a number of difficulties, some quite large, in simulating the human circulatory system. One of the most difficult problems is to find a tubing-material with the proper elastic properties which may be used to make a model with proper junctions, branchings, and changes in taper. Such models are rather difficult to work with since it is necessary to change its characteristics at will; without instruments of proven precision for

and Michael Taylor. These have permitted correction for the « sleeve effect » at the vessel wall and for the effect of anomalous viscosity. Limited time does not permit a further digression into this new and fascinating work. However, it may be said that this

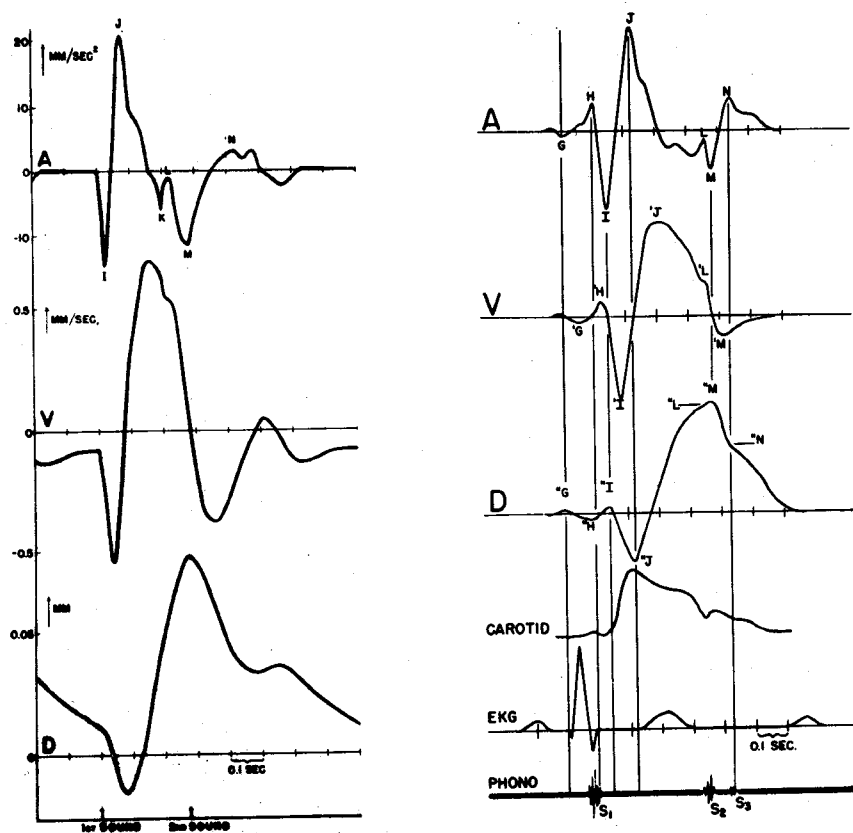


Fig. 13.

Noordergraaf's computed ULF Ballistocardiograms (left) compared with ULF Records from normal Subjects (rights). No calibration shown for records on right; for comparison of amplitude values see Fig. 7.

new analog is one of almost incredible sophistication by current standards but it will require further development to more closely simulate the human circulatory system. In order to improve it further, a considerable body of data, anatomic and physiologic, must be accumulated of a kind not now available. It is expected that this type of work will be quite productive in the future.

A few other research results must be touched on and these relate to correlations between the ballistocardiogram and various aspects of cardiovascular physiology. Dr Starr's early work dealing with the calculation of cardiac output with measurements made on the ballistocardiogram is well known (8). His more recent work has

shown rather better correlation between ballistocardiographic measurements and records of the force of cardiac ejection. Of the more recent investigators, Professor Klensch recognized that the ultralow frequency displacement record was the one most closely related to stroke volume and he remains the most experienced in this approach. (Of historical interest is the fact that this was Henderson's goal, more than 50 years ago.) The difficulties inherent in deriving a method for computing stroke volume from the displacement record are not to be minimized. These include the differential uptake by, and relative sizes of, the arterial tree above and below the heart level, the unknown values for elastic modulus of all vessels, and the lack of a method for determining cardiac ejection velocity. In spite of these and other difficulties, these investigations are of very real importance because there is no method available now for recording beat-to-beat stroke volume in large numbers of subjects without significant risk.

Another correlation on which there has been progress is that relating the ballistocardiogram to « cardiac force ». Reference has already been made to Starr's cadaver ejection work in which a high degree of correlation was found between « cardiac force » and the high-frequency ballistocardiogram, the latter being a close relative to the ultra-low frequency acceleration ballistocardiogram. Correlations of this sort have also been obtained by Darby and the South Carolina group in dogs and humans (18). Another type of investigation should be referred to because, as yet, nothing has been published about it (19). This was carried out through collaboration between Drs Samuel Fox, Donald Fry and their associates at the National Institutes of Health, and my colleagues and me now working in the medical research facilities of the Aviation Medical Service, Federal Aviation Agency. In this study Dr Fry's method (20) of measuring differential pressure in the ascending aorta was used and this measurement permitted the instantaneous computation of the velocity and acceleration of blood flow in the ascending aorta; the latter quantities were recorded simultaneously with an ultra-low frequency acceleration ballistocardiogram. Although the number of human subjects involved was small the number of experimental observations was considerably larger, inasmuch as various procedures were used to produce changes in stroke volume and blood flow. The results yielded a surprisingly high degree of correlation between the maximum acceleration of blood in the ascending aorta and the H-I segment of the acceleration ballistocardiogram. This work has been suspended through factors beyond our control but it is hoped that it can be pursued in the future because it is thought that this is an extremely fertile area for investigation. Ideally, we would like, in the living intact man, to be able to measure instantaneous pulsatile blood flow at many points in the circulatory system.

While a great deal of progress has been made in the last two years in the development of electronic flow meters, work with them has been, for the most part, limited to use in animals. There is as yet only Fry's method for use with intact humans. Further technical advances in the future may make it possible to more nearly approach the ideal requirements in the human.

One final short comment is in order pertaining to animal work. Physiologic studies in animals have been undertaken by several groups in an effort to provide a sound physiologic basis for ballistocardiography because it is possible in animals to make measurements of a sort not generally possible in humans. It is unfortunate, but true, that work in this important area has thusfar been so limited that no really sizable contribution has been made. My associates and I at the Johns Hopkins Hospital carried out work on animals for several years about which very little has been published. Early in this work we were forced to the conclusion that ballistocardiograms from dogs under general anaesthesia and on artificial respiration were inconsistent in wave-form and showed marked variations from time to time. This forced us to turn attention to the origin of the « abnormality » of the dog ballistocardiogram. The results of these studies, which have been reported (12), suggest that these alterations are a consequence of anaesthesia and artificial respiration, both of which appear to conspire to produce rather marked circulatory derangement. Candid appraisal of the contribution made by our group in animal investigation is, that if any contribution were made at all, it was most modest. However, three groups in Europe that have impressed us with the quality of their work; these include Professor Hoitink and Drs Knoop and Pretorius, in Amsterdam and Professor Klensch, in Bonn. The third is Dr Manuel Moreira at the University of Porto, Portugal; Dr Moreira's work is not known to many but an English translation of his original Portuguese monograph is now available.

To summarize these few comments concerning physiologic work in the animal, I would like to reiterate that I feel this work is quite important and it needs greater emphasis in the future.

Clinical Investigations :

Time and space do not permit more than a mere mention of clinical investigations in this field. In a review of ballistocardiography published 10 years ago (21), I expressed the opinion that ballistocardiography would probably prove most useful as a clinical tool for the diagnosis and prognosis of non-valvular heart disease. This opinion was based on the facts : 1) that patients with this kind of disease frequently demonstrated ballistocardiographic abnormalities while the results obtained with other methods were often normal or non-specific and 2) that in patients with congenital or valvular heart

disease the ballistocardiogram, through frequently abnormal, did not often reveal a sufficiently specific pattern to permit diagnosis whereas other available methods usually provided more specific information for diagnostic purposes.

This opinion, though essentially valid, tells only part of the true story and should be revised in the light of the last 10 years of experience. Elsbach (13) later decided that, since the significance of ballistic abnormality in older persons was uncertain, he would focus attention on individuals under the age of 40 and his results provided useful and stimulating information. We are in agreement that abnormal ballistocardiograms in persons less than 40 are quite significant; even in those in whom the ballistocardiographic «pattern» is not distinctive enough for diagnosis, it often supplies useful information regarding the functional state of the circulation.

I will now return to the patient with coarctation of the aorta. In cardiovascular conditions associated with such marked structural and functional abnormality, the diagnosis can usually be made by methods which are more reliable and specific although an occasional patient is seen in whom this diagnosis was not suspected until a ballistocardiogram, with its characteristic pattern, was obtained. In any case, even if other methods suggest this diagnosis, the ballistocardiogram should supply confirmatory evidence. In addition, this method may be useful in periodically checking the patients' circulatory function and in evaluating physiologic changes after resection of the lesion (*). In this era when right and left heart and aortic catheterization and puncture are common place, if periodic tests of cardiovascular function are needed, a method capable of supplying important information which involves no pain, discomfort, or hazard to life should be a source of considerable gratification to the patient.

There is an urgent need to carry out systematic and extensive investigations with the ULF ballistocardiograph on patients with all kinds of congenital and acquired disease states, especially in young individuals, under 40 years of age. It has been 8 years since Elsbach published his Dutch monograph and 6 years since its translation into English, yet no extension has been made of his studies and no investigation, comparable in scope to his, has been published. His work was quite productive in spite of the fact that it was somewhat limited by the lack of a suitable multi-channel recorder, by the fact that his transducers were not calibrated in absolute units and by the necessity of taking records only after

(*) It is of interest that, following resection, there is usually no sudden disappearance of the characteristic pattern. Often there is gradual change in wave-form over a period of several months before its complete disappearance. As with systemic blood pressure, this suggests a gradual re-adjustment of the circulation to its new conditions of operation.

the suspension of respiration. The current availability of more equipment of improved types and designs should now permit more extensive and definitive clinical investigations to be carried out. Even though records in axes other than the longitudinal are imperfect from the physical point of view, this does not mean that they may not provide important information in clinical studies. Thusfar such records have received almost no attention by investigators and this would seem virgin territory.

Summary and Conclusions :

I will conclude by saying that much has been accomplished by research efforts but more must be done in the biophysical, physiologic, and clinical area before the true potential of ballistocardiography can be measured. The enigma which must stimulate the imagination of any curious investigator is the reason for the changes which occur in the human ballistocardiogram with age; what causes the definite decrease in amplitude with increasing age and why the deterioration in waveform in individuals above the age of 40? If some of the foregoing questions could be answered, then a very large step will have been made in determining the true significance of the ballistocardiogram in the human.

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