A Method of Securing the Direct Body Ballistocardiogram by Means of a Microscope, Giving a Record Readily Calibrated

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We describe a simple method of recording the direct body ballistocardiogram by means of a microscope and a powerful light source. The beam passes through a slit attached to the body, and the image of this moving slit is magnified by the microscope and focused on moving photographic paper. When a static force is applied to the body, the base line of the record is permanently displaced and so the amplitude of the ballistocardiogram can be calibrated. By superimposing a ballistocardiogram obtained by means of the electrocardiogram on the same film, accurate comparisons of the two records and a calibration of the electrical instrument can be obtained.

BALLISTOCARDIOGRAPHS of the portable or direct body type were first designed by Dock and Taubman. Several types of these instruments now exist; they all record the motion of a bar placed on the shins of a subject lying on a rigid surface, by one of the several kinds of simple electrical pick-up units, and all use a standard form of electrocardiograph for recording the record. In these instruments the saving of expense over the table type of apparatus has been very great and, available commercially in several types, they are now widely used. Unhappily, unlike the table types of ballistocardiographs, a calibration of the static type cannot be applied to records secured from these portable instruments, for when a constantly acting deflecting force is applied to the body, because of the nature of the electrical circuits, the base line of the record returns to the original base line immediately. To meet this situation, attempts have been made to calibrate by means of a blow of short duration, but this method has been found unsatisfactory. Exact duplication of results is difficult, probably for several reasons. The spike produced on the record from a blow does not arise from the base line but is superimposed on that part of the subject's ballistocardiogram that is taking place at that instant, and the correction for this is not readily applied. Also some subjects cannot avoid tensing muscles in anticipation of the blow and this affects the tracing recorded. So the majority of doctors employing portable ballistocardiographs have proceeded with their clinical work without attempting to calibrate their records at all. Needless to say, the shift of the record caused by the introduction of the 1 mv. does not standardize ballistocardiograms recording through electrocardiographic equipment, although it is necessary to standardize the amplification introduced by the electrical apparatus itself.

Ballistocardiograms can become abnormal in three ways: because they are abnormally large; because they are abnormally small; or because the contour of the record is abnormal. Without a method of calibrating for sensitivity the operator is limited to detecting gross abnormalities of the last type. This is an important field, but certainly the utility of the simple portable ballistocardiographs would be greatly enhanced by devising a type of apparatus which could be easily calibrated, and which would thus permit a quantitative approach to many fundamental problems which cannot be attacked effectively from a purely descriptive viewpoint.

In this communication we will describe a

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type of portable apparatus so simple that it can be constructed of parts already available in all hospitals and to many doctors, and so at little or no expense. And, as our preliminary report indicates, it can be readily calibrated for sensitivity by the same static method now in use for the table types. No attempt will be made at this time to present abnormal records, or to discuss the more complex theoretic problems; we shall content ourselves with a detailed description of the method, its calibration and other advantages. Publication is made at this stage of the work because the opportunity for further collaboration has been denied us.

**APPARATUS**

We first set up the method with a light beam system and photokymograph which had been gathered together for another investigation, but we soon found that equally good records could be secured by using equipment available in most hospitals and to many doctors, so only the latter will be described. One needs:

1. A compound microscope of any standard type. It is convenient to have one with a hinge above the stand, which permits the barrel to be placed in the horizontal position. The lower power, a lens of 10 mm., was used with oculars of 10, 15 or 25 power, the choice depending on the distance from ocular to camera.

2. A light source with a powerful bulb. We have been using a 200 watt General Electric precision lamp for optical devices in a Bausch and Lomb lamp housing type 31-33-75. This housing was supplied with a diaphragm and a lens.

3. A standard electrocardiograph with a photographic recording camera. We have secured good records with both Cambridge and Sanborn types. When using a Sanborn electrocardiograph the wooden case had to be removed to admit the beam and to mount the mirror, but when using the Cambridge instrument this was not necessary.

4. A mirror for deflecting the beam into the camera. We used a front surface mirror made on a piece of plate glass by the Evaporated Metal Film Co. of Ithaca, New York, but a back surface mirror could be used with but little loss. This mirror was mounted on a brass support attached to the frame of the electrocardiograph so that the beam was turned into the camera without parallax to the beam of the electrocardiograph.

5. A light beam slit. This we made ourselves from a strip of brass plate perforated by a long slit. The upper part of this slit was used to bolt the plate at right angles to the end of the shin bar. The lower part of the slit was narrowed by two razor blades cemented to the brass edge and adjusted to give a slit of satisfactory width through which the beam was passed. In place of the slit it has recently been found convenient to use a glass slide ruled with parallel black lines 60 to the inch and sold under the name of Ronchi rulings by the Edmund Scientific Corp. of Barrington, N. J. The multiple lines can be focused satisfactorily, the image appearing as alternating light bands and dark shadows with a similar ballistocardiogram on every edge. Before one record goes off the film another appears from the opposite side, so it is never necessary to center the slit.

![Diagram of the setup for obtaining a ballistocardiogram](http://circ.ahajournals.org/Download)
6. A well made pulley, which could be clamped to an upright iron rod at any desired height, the rod being clamped in turn to the

table edge; a strap to go around the ankles; a cord; a set of weights and a pan to hold them. These were required for the calibration.

7. A bar to be placed across the shins of the subject.

To set up the apparatus as shown in figure 1, after the microscope's condenser had been removed, the various parts were adjusted until

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**Fig. 2.** Tracing secured by the microscope ballistocardiograph, compared with the electrocardiogram, heart sounds, and with records from several types of electrical ballistocardiographs. "T" indicates a test for alignment; at "W" the calibrating weight of 330 Gm. was applied or lifted off. "R" indicates the position of the electrocardiograph R wave. Time is indicated by the vertical lines; the smallest interval is 0.04 second.

I. The tracing of the microscope method is on each edge of the heavy black line. The moving white line is the ballistocardiogram taken by the Sanborn photoelectric instrument. The horizontal white line is an artifact which appears when one form of Sanborn electrocardiograph is used as recording apparatus. Note the base line shift in the microscope record, and its absence in the electrical record when the calibrating weight is applied and removed in this and the later records.

II. The tracing of the microscope method with a simultaneous record of heart sounds, both taken by a Sanborn electrocardiograph equipped for sound recording. "I8" and "2S" are placed under the corresponding sounds of the last systole shown.

III. (A) The tracing of the microscope method with the electrocardiogram. (B) The tracing of the microscope method superimposed on the ballistocardiogram taken from an electromagnetic ballistocardiograph of the type introduced by Dock. The electrocardiogram has been thrown into the latter record causing the "pip" seen over the letter "R." (C) The tracing of the microscope method with an electrocardiogram both taken through a Cambridge electrocardiograph.

IV. Comparison of microscope record with a velocity tracing obtained by a coil and magnet method (white line), R, T and W as above; at E expiration begins, at I inspiration begins.
being in adjustment, the lamp, microscope and electrocardiograph were tightly clamped to a wooden board so that they could be moved as a unit without disturbing the adjustment.

Securing the Record

The subject lay on a strong laboratory bench and the apparatus was placed on a table beside. A roller was placed under his heels. The shin bar was placed across his shins at a distance from the heels varying from 15 to 35 cm., and the slit was adjusted to lie just beyond the stage of the microscope. The image of the moving edge was focused on the camera aperture; being by coarse and fine adjustments of the microscope and the record was taken.

Reading the Record

Typical records are shown in figure 2. Identical ballistocardiograms are written by both sides of the slit and either can be used. Because the respiratory weaving sometimes throws the beam off the film, we found it advantageous to use a wide slit. When the edges were kept several centimeters apart on the record the danger of both going off the film was greatly reduced. Eventually the substitution of the Ronchi rulings eliminated this problem.

The individual waves can be readily recognized and, if this proves difficult, a simultaneous electrocardiogram can be taken to aid in their identification; for the recording of the ballistocardiogram through the electrocardiograph's camera in no way interferes with the taking of an electrocardiogram in the usual manner through the same instrument.

Calibration

The pulley was firmly attached to the upright iron rod clamped to the footward edge of the table. The calibrating weight was suspended by a string which, after traveling over this pulley, was tied to a strap placed firmly around the ankles of the subject. The height of the pulley was adjusted so that the course of the string from pulley to subject was horizontal and parallel with the long axis of the body. To calibrate the record the weight was either lifted off and reapplied, or applied and then lifted off, while the record was running.

Calculating the calibration from the record was not as easy as in records secured by table ballistocardiographs because respiratory arching is always present unless the breath is held, and in some subjects it is of considerable magnitude; therefore, during breathing the base line is never straight. But in quiet breathing it is not hard to estimate the deflection with an accuracy sufficient for most types of clinical work and, if necessary, accuracy can be further improved by calibrating while the patient stops breathing. But in either event, no calibration should be accepted unless the base line returns to its original position after the distorting change of force has been removed. This precaution provides a safeguard from errors due to slipping of the subject along the table, failure to hold the breath steady and the like.

Figure 3 shows repeated calibration with different weights on one of our subjects which is typical of many such estimations made while the subject was breathing normally. Obviously, when heavier weights are employed

![Graph showing the calibration of the microscope ballistocardiogram.](http://circ.ahajournals.org/content.figures/circ.0000000000000581)

**FIG. 3.** Calibrations of the microscope ballistocardiogram, displacement of the record base line caused by the application of graded forces to a single subject.
the deflection is larger and the effect of the error of reading the base line on the estimate is correspondingly diminished. But weights causing deflections larger than the ballistocardiogram could be properly used to calibrate the latter only if the calibration were linear. The data in figure 3 support the belief that the body's spring has a linear calibration over the range in which we are interested, although our accuracy and the number of cases studied is probably not yet great enough to rule out a small curvature. The scatter of the data in figure 3 permit a judgment of the accuracy we were able to secure in a blind test as the records were read without knowledge of how much weight had been applied. When the weight applied was 200 Gm. or under, the error of reading the base line usually prevents a satisfactory calibration. When weights of over 1 Kg. were applied large artefacts often appeared, sometimes obviously due to slipping of the subject on the table, but at other times perhaps due to changes in the characteristics of the body's spring. Weights of from 300 to 500 Gm. proved most satisfactory; it would appear that one point is all that need be established and that the line joining this point with the origin will define the relation of any ballistic amplitude to force with an accuracy sufficient for most clinical work.

**Discussion**

Good examples of the types of records secured are given in the figures. Unlike records obtained with the resisted table types of apparatus, respiratory weaving of the base line is a prominent feature of all records made during normal breathing. While this makes the base line harder to identify, it has certain advantages; the amplitude of the systolic complexes varies with their position in the respiratory cycle, as is well known. Any variation from the usual pattern could be detected in most ballistic records only by taking a simultaneous record of respiration. But in our record, the position of each systolic complex in the respiratory cycle can be seen at a glance.

While the general character of the cardiac waves resembles closely that recorded by resisted tables there are noteworthy differences. The waves tend to be a little broader in time, as are those recorded by the Nickerson type of table ballistocardiograph. This seems natural enough because of the restoring force of the body's spring, as the steel spring in Nickerson's instrument, is much weaker than the heavy spring used in the resisted table types. The magnification in the original table used by Starr and his associates, the instrument used for these comparisons, is about 500 times; the magnification of our direct photographic instrument need be only about 250 times to secure records of approximately similar size, so the actual body movement recorded is much larger in the conditions under which our instrument is used.

Our experience with the use of the microscope method to calibrate electrical methods will be briefly described. The slit of the microscope method was attached to the same shin bar which carried the light source or pick up unit of the electrical instrument. The ballistocardiograms of both instruments were recorded on the same film and, after alignment, one was adjusted until the records were identical in size. Then the calibration of the microscope method can be applied to the record of the electrical instrument. Thus a magnification of $177 \times$ by the microscope produced a record identical with that of our Sanborn photoelectric ballistocardiograph when the electrocardiograph was standardized so that 1 mv. displaced the base line 15 mm.; a magnification of $118 \times$ by microscope equalled a standardization of 1 mv. = 10 mm.

A magnification of $245 \times$ is about the upper limit of our present microscope ballistocardiograph. This gives a record much similar in size to that of the ballistic table used in this laboratory. Higher magnification would require more light than our present source provides and it becomes more difficult to maintain focus. A great many of our records were taken with a magnification of $177 \times$ and this was very satisfactory.

In a study of the relationship between corresponding wave areas of the two records, cardiac output was estimated by Tanner's formula by 12 times on 10 subjects; first from
records secured on the rigid table by the microscope method and then from records secured on subjects lying at rest on the resisted moving table. The cardiac output estimated from the former records was calculated to average 80 per cent of the value estimated from records secured on Starr's table. We conclude, therefore, that in the records of the direct photographic instrument the I and J waves are not only somewhat broader in time but also of less amplitude and of a little smaller area than similar waves recorded by resisted table instruments. Because the body's spring is weaker than the strong steel spring of the resisted table, the record of the microscope method is less highly differentiated, and for this same reason respiratory weaving of the base line appears in one and not in the other.

It should be pointed out finally that contour of the waves in the direct photographic record is very similar to that secured on Starr's resisted table when the subject's heels are not in firm contact with the footplate.

The relation of our records to those secured from three types of portable electrical instruments can be summed up by the statement that they are practically identical. Examples of simultaneous recordings secured from several types of these instruments are given in figure 2. The manufacturers are to be congratulated, for had there been a discrepancy there is no doubt where the truth would lie; the microscope has the last word in the estimation of small movements. It is also to be noted that in the electrical instruments, when respiratory weaving has been taken out by electrical means, this has been accomplished without noteworthy damage to the recording of the cardiac complexes. But we are by no means confident that every one of the multiplicity of electrical devices now made and sold for recording the ballistocardiogram would pass the test so well, and we believe that the direct microscopic method will be useful in estimating the degree of distortion produced when new devices are introduced.

Despite this agreement in contour between records of the movement recorded through the microscope and those picked up and amplified electrically, when the calibrating weight is applied to the body the two records behave very differently. The base line of the microscope record is deflected at once, and it remains at its new level as long as the force is applied. In records from the electrical devices, however, if the weight is applied or lifted off suddenly a spike is seen, but if the distorting force is applied gradually the record is affected little if at all.

The microscope method can be used to calibrate the electrical methods indirectly. Thus in any subject, after ascertaining the amplitude of the record obtained through the microscope, in terms of force, by our method of calibration, one can adjust the amplitude of the electrical method to the same value. It is also planned to investigate how closely the strength of the body's spring can be related to body size and build; if this relation is found to be consistent, a table of the values found would help one predict the normal values in records difficult or impossible to calibrate accurately at every run.

Our experience in taking records from a bar laid across the shins both with and without being fastened to them has disclosed a difficulty which we believe has not been previously emphasized enough. The exact position of the bar on the shins may make considerable difference in the amplitude and form of the record. We have demonstrated in a number of our subjects that the amplitude of the tracing increases as the shin bar is moved from just above the ankles towards the knee; in some subjects the difference is large. Changes in the contour of the diastolic waves may also appear. We have not as yet investigated the cause of these differences, but we believe that, as direct body ballistocardiographs become more quantitative, knowledge of such inconsistencies will become increasingly important.

Finally it should be pointed out that by means of a pointer attached to the shin bar and brought into focus over the stage of any microscope, the ballistocardiogram can be directly viewed by any doctor. By our technic the record can be focused on any screen, wall or ceiling. Unfortunately, the movements are too quick for the eye to appreciate in detail; one cannot separate with confidence one wave.
from another of similar direction; and so one cannot distinguish the characteristics of single waves. But the over-all amplitude can be readily seen and, indeed, roughly measured by an ocular micrometer if viewed through the microscope, by a ruler if thrown against the wall. The respiratory variation is also seen clearly, and the extent of base line shift caused by the application of the calibrating weight is readily ascertained. A crude test of this kind leaves much to be desired, but it is within the reach of every doctor practicing medicine, and it might well provide better evidence of the forcefulness of cardiac action than does any part of the routine history or physical examination in use today.

**Summary**

1. A simple form of ballistocardiograph is described in which the movement of a bar across the shins is magnified by a microscope and recorded in the camera of a standard electrocardiograph.
2. This method gives an accurate record of displacement and it can be calibrated readily by applying a known force to the patient's body which causes a permanent displacement of the base line of the record.
3. Examples of tracings secured by the microscope method are shown. Simultaneous tracings secured by several types of electrical methods were almost identical, but electrical records cannot be so calibrated because the application of a static force to the subject does not cause a permanent displacement of the base line of the electrical records.

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**Sumario Español**

Describimos un método sencillo de registrar el balistocardiograma de cuerpo directo por medio de un microscopio y una fuente de luz fuerte. El rayo pasa atraves de una ranura pegada al cuerpo, y la imagen de esta ranura movible se magnifica por el microscopio y se enfoca en papel fotográfico en movimiento. Cuando una fuerza estática se aplica al cuerpo, la línea básica del trazado se desplaza permanentemente y de esta manera la amplitud del balistocardiograma se puede calibrar. Sobreponiendo el balistocardiograma obtenido por medio del electrocardiograma en la misma película, comparaciones exactas de los dos trazados y la calibración del instrumento eléctrico se pueden obtener.

**References**

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