The Ballistocardiogram in the Presence of Pulmonary Disease

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The purpose of this study was to determine the value of ballistocardiography in differentiating cardiac from pulmonary pathology in patients with pulmonary tuberculosis. Clinically, the picture is at times not well delineated. Dyspnea and pain occur in both pulmonary and cardiac disease, and the electrocardiogram in many cases of pulmonary disease presents non-specific abnormalities, mostly due to mediastinal shift and rotation. Fluoroscopic or roentgenographic examination is frequently not conclusive due to the indiscernibility of the cardiac contour in the haze of pleuro-pulmonary distortion. It was, therefore, hopefully attempted to look for new avenues of approach to the problem of differential diagnosis.

Procedure

The ballistocardiograms of 100 consecutive patients were analyzed primarily as to form and amplitude of the systolic and diastolic complexes. The apparatus used was the Glennite Ballistocardiograph made by the John Peck Laboratories of New York. Some tracings were obtained under basal conditions. Most tracings, however, were secured about two or three hours after breakfast or after lunch. Only tracings of patients who appeared nonchalant and relaxed were used in this study. All patients had pulmonary tuberculosis in various stages of activity—unilateral or bilateral. Some had unilateral pneumothorax at the time the tracings were obtained. All were ambulatory and none had associated difficulties. None were tachypnoeic or dyspneic. Those who seemed not to be able to obey commands of holding breath, etc. were not included in the study. None had evidence of cardio-vascular disease. Simultaneous complete electrocardiograms were obtained in all cases. The age groups were as follows: 63 cases were between the ages of 16 and 40; 20 were in the fifth decade; 17 were 50 years old or older.

Results

In the analysis of our series a patient was considered to have a normal tracing if the normalcy appeared in any phase of respiration—and leniency was generally applied to the interpretation of the normal, based on preliminary experience and anticipation of “more than usual” respiratory variations.

Of the 68 below the age of 50 and without therapeutic pneumothorax, 29 had normal electrocardiograms and normal ballistocardiograms; 24

From the Cardiac Service of Sea-View Hospital, Staten Island, N. Y.
had normal electrocardiograms and abnormal ballistocardiograms; eight had abnormal electrocardiograms and normal ballistocardiograms. The abnormalities in the electrocardiograms were those seen in mediastinal shift and were not interpreted as indicative of myocardial damage; seven presented abnormal electrocardiograms and abnormal ballistocardiograms. The total number of abnormal ballistocardiograms in this group was 31.

There were 15 below the age of 50 with therapeutic pneumothorax. Of this group seven had normal electrocardiograms and normal ballistocardiograms; five had normal electrocardiograms and abnormal ballistocardiograms; one had an abnormal electrocardiogram and a normal ballistocardiogram; in three both the electrocardiogram and the ballistocardiogram were abnormal. Thus, in the combined group of 83 patients below the age of 50—39 (50 per cent) had abnormal ballistocardiograms.

In 15 of the 20 individuals in the fifth decade, the electrocardiogram was normal and the ballistocardiogram was abnormal. In two cases both the electrocardiogram and the ballistocardiogram were abnormal. In two instances the electrocardiogram and the ballistocardiogram were normal and in one case the electrocardiogram was abnormal and the ballistocardiogram was normal. Thus, in the fifth decade group of 20 patients, only three had normal ballistocardiograms.

Of the 17 in the older age group (50 plus) none had an abnormal electrocardiogram. Only three had a normal ballistocardiogram. Two of the abnormal tracings were considered to belong to class two (Brown et al). The rest belonged to group three and four. (Brown et al).

The heart rate in the majority of the entire group of 100 cases studied varied between 80 and 100 per minute. Twenty had a heart rate of 80 or lower. Nine of this group had abnormal tracings and 11 had normal ballistocardiograms.

*The Trace*

The following observations were made in the ballistocardiograms of the series studied. In the few cases with tachycardia only L and M waves could be distinguished in the diastolic phase. In many cases in the same strip marked fluctuations in the depth of the I wave and amplitude of IJ and JK were frequently encountered. I was frequently shallow in inspiration and occasionally in expiration. JK was frequently seen to be unusually small in inspiration and occasionally notched. K was seen to be frequently deep in both the inspiratory and expiratory phase. The IJ/JK ratio was frequently smaller in inspiration than in expiration. By the same token the total systolic amplitude was frequently smaller in inspiration than in expiration. The diastolic waves were marked by inconstancy in form and amplitude. H and L were frequently markedly exaggerated and variable in the same strip. H was occasionally notched in expiration or inspiration.

On a number of occasions the "resting" tracings were bizarre and assumed a normal configuration in either the inspiratory or expiratory phase.

It was occasionally observed that a tracing was good one day and not definitive the next day, for no apparent reason. Differences in amplitude
and form were obtained in tracings taken in the morning and afternoon of the same day. Some tracings were better immediately after a meal than on an empty stomach. Two tracings presented low amplitude complexes. One for no obvious clinical justification assumed a normal pattern at a later date. She was 36 years old with an abnormal electrocardiogram, interpreted as due to mediastinal displacement and rotation. The other was a 24-year-old female with a low voltage electrocardiogram in the standard leads. The ballistocardiogram in this case presented a systolic amplitude of 4 mm. in the resting and inspiration tracing. In expiration the amplitude was only 3 mm. I and K were shallow. I was particularly shallow in inspiration. In seven cases traces were obtained prior to and following establishment of pneumothorax. It appeared that in this small series the H and L which were exaggerated in the pre-pneumothorax...
FIGURE 2: Note variations in all respiratory phases. Abnormal electrocardiogram.
Figure 3A: Ballistocardiogram obtained before breakfast, grossly abnormal—Figure 3B: Ballistocardiogram obtained shortly after lunch. Note definitiveness in the expiration phase with changes in amplitude of the systolic complex, slurring and notching of IJ and JK.

Figure 4A: Tracing obtained at 9 A.M. Normal—Figure 4B: Tracing of same patient at 2 P.M. Note abnormalities with normal respiration (resting), shallow I in the inspiration phase and stability of pattern in the expiration phase.
tracings diminished in amplitude following institution of pneumothorax. In two the pre-pneumothorax tracings were classified as belonging to group two (Brown et al). Following pneumothorax the tracings were normal—both in the expiration phase only.

**Positional**

In 31 cases ballistocardiograms were obtained in the prone, right and left lateral positions. It was reasoned that perhaps in some positions and not in others will the respiratory rhythm be more regular and the mechanical interference with respiration will be lessened, and perhaps a change will take place in the intrathoracic dynamics and thus modify the cardiac outflow. It was realized that the lateral position introduces the factor of change in surface contacts. Care was exercised to have the patient in the best possible resting condition and the apparatus was carefully positioned so as to avoid technical errors. Since most of the patients had bilateral pulmonary disease of varying degree, no position could be assumed to be the optimum position. Further studies are now being con-

*Figure 5A:* Tracing obtained at 9 A.M., after breakfast.*—*Figure 5B:* Tracing of same patient obtained at 2 P.M., about 2 hours after lunch. Note change in amplitude. Note shallow I and deep K in the inspiration phase. (Middle tracing).
ducted with a more select group of patients in order, perhaps, to gain a more correct impression of the influence of pulmonary function on the ballistocardiogram.

The following observations on the effect of position on the ballistocardiogram were made in the 31 cases studied.

The amplitude of the systolic complex was diminished in the lateral positions, at times markedly so, with an occasional exception when the amplitude was of the same magnitude or better. J frequently became smaller in the lateral positions, and occasionally notched. H frequently became larger, L frequently became larger and occasionally notched. IJ was frequently shorter and variable in the lateral positions. K became deeper.

Occasionally an abnormal tracing appeared approaching normal when the patient was lying on the side of more extensive pulmonary involvement. But generally, when a tracing was abnormal in the prone position, it was also abnormal in the right and left lateral positions.

One abnormal tracing (class 3, Brown et al) in the prone position became normal in the right lateral position in the inspiratory and expiratory phases, but not in the resting phase. In one abnormal ballistocardiogram the right lateral resting tracing was normal, in another one it became normal in the right lateral position on inspiration only.

Of the 17 normal tracings in the prone position (in this group of 31

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**Figure 6A**: Tracing of a patient secured on June 2, 1953. **Figure 6B**: Tracing of same patient on June 17, 1953. Note difference in amplitude. No demonstrable clinical or technical justification.
cases) only three tracings were normal in the lateral position—with variations, however, in the amplitude of the various systolic and diastolic components. Fourteen had abnormal ballistocardiograms (Brown—2 and 3) in the lateral positions. Since the abnormalities noted in this group were not only of amplitude but also of form and component relationship, the technical arrangement of the generating components cannot be held accountable. The fault must lie in the circulatory forces and their vectorial arrangement (Figs. 10 and 11).

Discussion

The statistical part of this report is probably not of much significance. The figures would likely differ considerably in the next consecutive 100 cases. Only considerations of a general nature are permissible. In our earliest experience with the ballistocardiogram at Sea-View Hospital it became rather obvious that the graph is not a diagnostic expression of circulatory disease proper. On the contrary we were tempted to assume that the ballistocardiogram is more a reflection of "pulmonary physiologic

**FIGURE 7**

*Figure 7:* Upper tracing—normal respiration. Middle tracing—inspiration phase. Note deep K (paradoxic). Lower tracing—expiration phase. Most definite and stable. Deep I (paradoxic).

**FIGURE 8**

*Figure 8:* Upper tracing—normal respiration. Middle tracing—inspiration phase. Lower tracing—expiration phase. Compare I in inspiration and expiration. Note notching of H (?) in inspiration and L (?) in expiration.
FIGURE 9: Case of herniation of right lung into left. Expiration tracing most definite and stable. I deeper than in the inspiration phase.

FIGURE 10: Case one of left pneumothorax. Figure 10A: Prone position.—Figure 10B: Left lateral position.—Figure 10C: Right lateral position. Upper tracing—normal respiration. Middle tracing—inspiration phase. Lower tracing—expiration. Best tracing obtained in the right lateral position. The inspiration tracing is the most definable and normal.
state” rather than of cardiac or vascular abnormality. That the ballistocardiogram is dependent on respiratory function is a known fact. It appears, however, that in the presence of pulmonary disease, this respiratory component is of major importance.

Is it because of the distorted pulmono-vascular anatomy or changes in the intrathoracic pressure due to respiratory arrhythmia that the auricular filling and the ventricular ejection become so chaotic so as to cause the marked structural changes in the tracing? Or are there other factors not readily explainable? Does the labile ballistocardiogram indicate an ever changing systemic circulatory state when pulmonary disease is present? Or does it represent variations in direction, quantity and force of the pulmonary circulation? To be more specific, is the short HI segment frequently observed in the inspiration tracing of our series due to para-

![Graph showing ballistocardiogram in pulmonary disease](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21259/)
doxical changes in the intrathoracic pressure—because of pleuro-pulmo-
mary or pleuro-diaphragmatic adhesions? Or are there other factors not
quite discernible at present to explain this phenomenon or the deep K
when not expected or the exaggerated diastolic complexes? We have not
observed in this analysis any constancy of sufficient degree in any of the
components of the ballistocardiogram to permit cause and effect specula-
tions. Only a few facts stand out prominently. Abnormal ballistocardi-
ograms occur in patients with pulmonary disease in the absence of heart
disease in all age groups. Age, however, seems to be a factor, in that the
frequency of abnormalities increases with years. While in the general
literature on the subject, one speaks of a ballistocardiogram below the age
of 50 and above the age of 50, in patients with pulmonary disease the
age of 40 seems to be a more distinct dividing line. Another observation
of significance seems to be the fact that a single tracing obtained in the
“usual” prone position may perhaps be sufficient in the patient without
pulmonary disease; in the presence of pulmonary disease a tracing should
not be considered abnormal unless obtained in various positions and vari-
ous phases of respiration, and repeated in the same manner on the same
or following day. Because of the extreme lability of the structure of
the complexes in the presence of pulmonary disease a more liberal ap-
proach to the interpretation of the amplitude and form of the individual
complexes is essential.

In a general way the following remarks are perhaps justified: Abnor-
malities observed under certain circumstances of stress are not dissimilar
to the ones we observed in our series. This suggests the possibility that
changes induced by stress are at least in some measure dependent on
the integrity of the respiratory mechanism. As an alternative, one would
have to suspect that many changes in the ballistocardiogram are non-
predictable, non-specific and not diagnostic of distinct cardiac or vascular
entities and do not reflect in all instances the force of ventricular ejection.
“The varying amplitudes of deflections obtained with repetitive recordings
at the same amplification sensitivity also indicate that”—with the device
employed in our study, the tracing cannot . . . “be used to quantitate
initial cardiac force in a manner similar to the method used with a bal-
istocardiographic table.” We have not observed any of the components
of the ballistocardiogram to be the least variable and therefore more or
less dependable for calculation purposes.

The role of extracardiac factors in producing ballistocardiographic
abnormalities and particularly the role the pulmonary mechanism plays
in altering some of the components of the ballistocardiographic tracing
has been emphasized by other observers. Thus, even in the
presence of heart disease the H and L waves in the ballistocardiogram
of mitral stenosis are stated to be due to changes in the pulmonary cir-
culation. Our report further stresses the fact that abnormalities in the
I wave, shortening of I-J stroke with increase in the prominence of the
K wave, low amplitude and even generally indefinable patterns can occur
in the absence of heart disease.
The importance of the pulmonary functional integrity in the structure of the ballistocardiogram is further attested by the fact that in certain cases the application of an abdominal binder may improve the appearance of the tracing.13 Such improvement in the ballistocardiographic picture is surely due to the improvement of the respiratory function by the elevated diaphragm as observed clinically by the application of an abdominal binder or the institution of pneumoperitoneum.

Our study permits no speculation on the subject of genesis of the individual waves in the ballistocardiogram. There is perhaps an indication, however, that both the H and L waves are related to the pulmonary status of the patient. Following pneumothorax the amplitude of the H and L waves were diminished. It would seem that the patho-physiologic state present in the diseased lung or in cases of pulmonary hypertension or in cases of cardiac failure is in some manner responsible for the increased amplitude of the H and L waves in certain cases.

SUMMARY AND CONCLUSION

The ballistocardiograms of 100 consecutive cases of pulmonary tuberculosis in the absence of heart disease, were analyzed as to form and amplitude. The number of abnormal tracings in all age groups was higher than that observed in the general population. The abnormalities observed occurred in both the systolic and diastolic complexes of the tracing. Some of the abnormalities were paradoxical, simulating reflection of circulatory stress rather than expressing respiratory dependence.

It is suggested that in the presence of pulmonary disease, ballistocardiographic tracings should be secured in various positions and various respiratory phases, and that generally the interpretation of ballistocardiogram be more cautious and lenient.

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RESUMEN

El balistocardiograma en 100 casos consecutivos de tuberculosis pulmonar en ausencia de afección cardiaca, se analizó en su forma y amplitud. El número de trazos anormales en todas las edades fue más alto que el observado en la población general.

Las anormalidades observadas ocurrieron tanto en el complejo sistólico como en el diastólico de 1 trazo. Algunas de las anormalidades fueron paradójicas, simulando reflexión del esfuerzo circulatorio más bien que dependencia respiratoria.

Se sugiere que en presencia de tuberculosis pulmonar, deben obtenerse trazos balistocardiográficos en varias posiciones y en diversas fases respiratorias y que generalmente la interpretación de los balistocardiogramas ha de ser cautiva y no severa.

RESUME

Les auteurs ont analysé dans leur forme et dans leur amplitude les ballistocardiogrammes de cent cas de tuberculose pulmonaire chez lesquels
il n’y avait pas d’affection cardiaque associée. Le nombre des tracés normaux dans les groupes de tous âges fut plus élevé que celui qu’on observe généralement dans l’ensemble des individus non tuberculeux. Les anomalies qui furent notées atteignaient à la fois les complexes systoliques et diastoliques. Certaines d’entre elles donnaient paradoxalement l’impression d’une atteinte circulatoire beaucoup plus qu’une altération secondaire à une atteinte des voies respiratoires.

Les auteurs sont d’avis qu’au cours d’une affection pulmonaire, les tracés ballistocardiographiques doivent être pris en diverses positions et au cours de différentes phases respiratoires. Ils admettent que d’une façon générale, l’interprétation due ballistocardiogramme doit être prudente et réservée.

REFERENCES