Proposals for Ballistocardiographic Nomenclature and Conventions: Revised and Extended Report of Committee on Ballistocardiographic Terminology

By William R. Scarborough, M.D., and Samuel A. Talbot, Ph.D.

The committee's first report, published in Circulation for June 1953, recommended a terminology and certain conventions for recording ballistocardiograms of the type then in use. However, it soon became apparent that the committee's work was far from complete. Increasing knowledge of ballistic theory soon began to throw light on the relations of records secured by various instruments to one another, and a rapid advance in instrumentation began to provide records related to, but often not identical with, those which had been provided with a standard terminology by the committee in its first report. Accordingly, the committee has continued its labors to provide the rapidly advancing field with a uniform terminology.

While they were thus engaged, attention was called to the fact that the designation of spatial axes previously recommended for vector ballistocardiograms differed from that which had been recommended for electrocardiograms by another committee of the American Heart Association. The advantages of a common system for designating spatial axes were obvious to all. Accordingly, as the electrocardiographic usage had priority and as little had been published in the field of ballistocardiographic vectors the committee voted to withdraw their original recommendation and substitute one conforming to that in use by electrocardiographers. In the present communication this new convention is also set forth.

All members of the committee have shared in the deliberations and taken part in the decisions which form the basis of this report; but so much of the larger proportion of the actual work fell on Dr. Scarborough and Dr. Talbot that it was agreed without dissenting vote that only their names should appear as authors. This report has the endorsement of the committee as a whole, and the terminology it suggests is recommended as the official terminology of the American Heart Association.

John R. Braunstein Maurice B. Rappaport
William Dock William R. Scarborough
W. F. Hamilton John E. Smith
John L. Nickerson Samuel A. Talbot
Isaac Starr, Chairman

I. Introduction.
II. Conventions Applying to all Ballistocardiographic Systems.
A. Standard Spatial Axes and Conventions of Polarity.
B. Conventions for Presentation or Reproduction of Ballistocardiograms.
2. Vector Records.
C. General Definitions and Terminology.

* From the Department of Medicine, Johns Hopkins Medical School and Hospital, Baltimore, Maryland, and from the Howard Hughes Medical Institute.

This is a report of the Committee on Ballistocardiographic Terminology created by the American Heart Association and reflects that Committee's findings in the matter under study.

III. Recommendations Regarding Normal Records from Different Types of Ballistocardiographic Systems; Longitudinal (head-foot) Ballistocardiograms.
A. High Frequency Ballistocardiographic Systems (Starr): HF-BCG.
1. General Characteristics.
2. Nomenclature for Ballistocardiograms.
3. Calibration.
4. Suggestions Concerning Technical Data to be Included in Publications.
B. Low Frequency Ballistocardiographic Systems (Nickerson): LF-BCG.
1. General Characteristics.
2. Nomenclature for Ballistocardiograms.
3. Calibration.
4. Suggestions Concerning Technical Data to be Included in Publications.
C. Ultra-low Frequency or Aperiodic Ballisto-
cardiographic Systems (Gordon; Hender-
son; von Wittern; Talbot; Burger; Rappa-
port): UF-BCG.
1. General Characteristics.
2. Nomenclature for Ballistocardiograms
   (Displacement, Velocity, and Acceleration.)
3. Calibration.
4. Suggestions Concerning Technical Data
to be Included in Publications.
D. Direct Body Ballistocardiographic Sys-
tems (Dock; Smith; Arber; Walker): DB-
BCG.
1. General Characteristics.
2. Nomenclature for Ballistocardiograms
   (Displacement, Velocity, and Acceleration.)
3. Calibration.
4. Suggestions Concerning Technical Data
to be Included in Publications.
E. Unclassified Types of Ballistocardiographic
   Systems.
IV. Summary.
V. Bibliography.
VI. Technical Appendix.*
A. Transducers (Motion-sensing Devices).
B. Electric Integration and Differentiation.
C. Filters and Filtering in Ballistocardiography.
D. Calibration Methods.
E. Specification of Dynamic Behavior of Elec-
   tro-mechanical Systems in Ballistocardiog-
  raphy.
F. The Intrinsic Relationship between Dis-
   placement, Velocity, and Acceleration Ball-
   istocardiograms.
G. Glossary of Technical Terms Used in Bal-
   listocardiography.

This appendix has not been included in the pres-
ent article, but it has been reproduced by the Ameri-
can Heart Association and copies may be secured by
writing to Dr. William R. Scarborough, Department
of Medicine (Physiological Division), The Johns
Hopkins Hospital, Baltimore 5, Maryland, or to the
Medical Director of the American Heart Association.

I. INTRODUCTION

THE Committee on Ballistocardiographic
Nomenclature was originally appointed to
study the question of terminology and conve-
victions used in ballistocardiography and to make recommendations aimed at
greater uniformity and consistency in the
usage of terms in publications on this subject.
The rapid growth of the field and the intro-
duction of a variety of new and different ballistocar-
diographic methods began to produce
such confusing differences in terminology and
frames of reference that it seemed desirable to
attempt to formulate a body of general terms
and definitions relating to ballistocardiography.
The Committee's brief first report,1 published
in June 1953, dealt with certain conventions
to be used in recording and reproducing
ballistocardiograms and included recommenda-
tions for a terminology for the standard dis-
placement records from the ballistocardiog-
graphic instruments in use at that time. The
development of newer instruments and tech-
nics yielding different types of ballistocardi-
ograms, required that the original recommenda-
tions be revised and extended. The current
proposals are more comprehensive and detailed
than those in the First Report and are in-
tended to supplant them.

This report was designed to provide a prac-
tical and meaningful system of termi-
ology, broad enough to apply to the various
types of records from all of the different
ballistocardiographic instruments now in use.
The proposals therefore apply not only to the
displacement records from high frequency
(Starr) and low frequency (Nickerson) beds
but also to the displacement, velocity, and
acceleration records from the direct body (Dock)
and ultra-low frequency ballistocardiographic
systems.* The 4 general types of ballisto-
cardiographic systems are treated separately,
inas much as records of the same aspect of
motion (displacement, for example) from
different ballistocardiographic systems may be
quite different in pattern (fig. 4) and physical
content. In each case there is a brief outline of
the physical characteristics of the method,
a description of the recommended terminology
and suggestions regarding the kind of technical

* This Technical Appendix has been prepared by Drs. Scarborough and Talbot in order to provide
those interested in the field with important information
related to the general theory and design of
ballistocardiographs and to the characteristics of
electric equipment available for their construc-
tion. Its table of contents is given above.

* For economy of space, the names of the four
systems may be abbreviated as follows: "HF-BCG" for "high frequency (Starr) ballistocardiograph";
"LF-BCG" for "low frequency (Nickerson) ballisto-
cardiograph"; "DB-BCG" for "direct body (Dock)
ballistocardiograph"; "UF-BCG" for "ultra-low
frequency ballistocardiograph."
data which should be included in publications. Ballistocardiographic methodology is an exceedingly complex and, at present, poorly understood field. For this reason the authors made no attempt to describe the mechanical performance of the various methods in use\textsuperscript{6-19} nor did they attempt to standardize techniques for recording ballistocardiograms.

In proposing the nomenclature contained herein every effort was made to base the terminology and conventions on sound physical principles without, insofar as possible, interfering with customs already established. Although the several types of ballistocardiographic systems were treated separately, the same parent nomenclature was used for all systems. The most widely used terminology, that devised by Starr\textsuperscript{9} (the ballistocardiographic waves being given the capital letters G through O), forms the basis of wave identification in the records from all the different types of instruments.

Recent biophysical studies\textsuperscript{5-8} have revived interest in ballistocardiographic instruments similar in principle to those originally described by Gordon\textsuperscript{3} in 1877 and by Henderson\textsuperscript{4} in 1905. These instruments which either have an extremely low natural frequency or no natural frequency (aperiodic) are referred to as "ultra-low frequency ballistocardiographs," a term coined by Rappaport.\textsuperscript{1} The application of these instruments has thus far been so limited that no record terminology has been fixed by use. The \textit{acceleration} records from these systems are sufficiently similar in appearance and physical content to the standard Starr high frequency ballistocardiograms (fig. 5) that it seemed reasonable, as Deuchar\textsuperscript{10} suggested, to extend the older terminology to these new records as well. A different notation has been described in an excellent monograph in Dutch by Elsbach,\textsuperscript{10} who was associated with Burger and Snellen; their terminology was given very careful study before a decision was made to recommend the notation contained in these proposals.

The Terminology Committee considered the advisability of assigning names to the waves of ballistocardiograms abnormal in form but concluded that the present practice of using suitable descriptive terms is the simplest and most useful one. Consequently, a terminology is given only for normal records or those in which waves can be identified with reasonable certainty.

The Committee also agreed that there is not yet sufficient information relating to types of ballistocardiograms other than the usual longitudinal (head-foot) record to justify a nomenclature for them. In the interest of uniformity of recording and presentation, however, standard spatial axes and conventions of polarity were recommended. (These are somewhat different from those described in the First Report.)

During the preparation of this report, the authors realized that certain technical information might be useful to those in the field in clarifying some of the problems of ballistocardiographic methodology. Inasmuch as this information had no place in the Terminology Proposals, a Technical Appendix was prepared; its composition is shown in the foregoing outline. The length of the Appendix and its technical nature made it unsuitable for publication along with the Proposals. However, it has been printed and may be obtained from the authors on request.

The terminology and conventions proposed in this report should, in no sense, be considered final and irrevocable. Further advances in our understanding of ballistocardiographic methods and the information they supply will almost certainly require modifications and additions in the future.

II. Conventions Applying to All Ballistocardiographic Systems

A. Standard Spatial Axes and Conventions of Polarity (figs. 1 and 2).

1. For Ballistocardiographs Recording Translations:
   a. Transverse (side to side) axis \((x)\): rightward positive, leftward negative.
   b. Longitudinal (head-foot) axis \((y)\): headward or cephalad positive, footward or caudad negative.
   c. Dorsoventral (anteroposterior) axis \((z)\): dorsal positive, ventral negative.

2. For Ballistocardiographs Recording Rotations:
FIG. 1. Ballistocardiographic spatial axes and conventions for polarity. In the 3 axes the arrows point in the positive direction. (See text.)

FIG. 2. The body in 2- and 3-dimensional projections to illustrate reference planes.

FIG. 3. Conventions for presentation or reproduction of vector ballistocardiographic records. The conventions for the frontal, sagittal, and transverse planes are shown. (See text.) (These figures are reproduced through the courtesy of Dr. John R. Braunstein who prepared them.)

a. About the transverse axis (x): Clockwise (viewed from the subject's left side) positive, counterclockwise negative.
b. About the longitudinal axis (y): Clockwise (viewed from the subject's feet) positive, counterclockwise negative.
c. About the dorsoventral axis (z): Clockwise (viewed from the subject's front) positive, counterclockwise negative.

B. Conventions for Presentation or Reproduction of Ballistocardiograms.

1. Scalar Ballistocardiographic Records:
a. In all scalar records time should move from left to right.
b. Positive polarity should be inscribed or reproduced upward; negative polarity downward.
c. Some event in the cardiac cycle (electrocardiogram, pulse, or heart sounds) should be recorded simultaneously to permit identification and timing of waves.

2. Vector Ballistocardiographic Records: (fig. 3)
   It may be noted that in each plane positive deflections will be upward and to the observer's left as he stands before the scope face.
a. Frontal plane (x, y):
   Longitudinal axis (y) is displayed vertically with positive polarity upward.
Transverse axis (x) is displayed horizontally with positive polarity to observer’s left.
b. Sagittal plane (y, z):
   Longitudinal axis (y) is displayed vertically with positive polarity upward.
   Dorsoventral axis (z) is displayed horizontally with positive polarity to observer’s left.
c. Transverse plane (x, z):
   Dorsoventral axis (z) is displayed vertically with positive polarity upward.
   Transverse axis (x) is displayed horizontally with positive polarity to observer’s left.

C. General Definitions and Terminology.

1. The Baseline:
   For most kinds of ballistocardiograms the baseline may be defined as the “neutral” line of the record indicating the position of the body when it is motionless. A reasonably flat baseline is often seen in late diastole when the body’s oscillations are minimal or have ceased. If a flat baseline is not visible it may be approximated by placing a horizontal line midway between the opposing tips of the small waves in late diastole. In records secured by electric amplification the baseline can be obtained by rapidly reducing the sensitivity until amplitudes become negligible, provided this has no effect on centering.

   In displacement records from ultra-low frequency ballistocardiographs, the selection of a baseline is an arbitrary matter. There is usually no flat baseline because at normal pulse rates the motion of the body and support never ceases, one cardiac cycle merging into the next. In practice, an arbitrary horizontal baseline may be placed by drawing a straight line through the displacement GH segment (GH) in successive beats. In velocity and acceleration records from the ultra-low frequency systems flat baselines may be present in diastole. If not, they may be placed in the same manner as that employed for the displacement records, using the GH segment in each case. (See also Technical Appendix, Section F.)

2. Parts of Waves:
   The point of a wave, directed upward or downward, may be called the tip, for example, “the K wave tip.”
   The part of the record joining the tip of one wave with the tip of the next wave is to be called a segment, for example, “the IJ segment.”

III. RECOMMENDATIONS REGARDING NORMAL RECORDS FROM DIFFERENT TYPES OF BALLISTOCARDIOGRAPHIC SYSTEMS:—LONGITUDINAL (HEAD-FOOT) BALLISTOCARDIOGRAMS

A. High Frequency Ballistocardiograms (Starr-type®): HF-BCG.

1. General Characteristics:
   a. A table, “bed,” or platform provides support for the body. A footboard is generally used to improve the coupling between the two.
   b. Stiffness of springs coupling platform to ground is 10–100 times greater than the stiffness of the body’s dorsal springs.* (1,000–30,000 lbs./in. compared with 200–300 lbs./in.)
   c. No external damping (except that introduced by the body).†
   d. Platform weights range from 20 to 100 lbs. (from 1 to \( \frac{1}{10} \) of adult body weights).
   e. Loaded with 150 lbs. dead weight, platform natural frequencies range from 8–14 c/s, depending on the stiffness of the platform spring.‡
   f. Loaded with a human subject the fundamental frequency of bed-body combination ranges from 3–9 c/s, depending on coupling between patient

---

* The stiffness or spring constant, k, of a flexible member represents the force required to produce a unit deflection.
† Damping is the progressive reduction in amplitude of vibration of an elastic body due to viscous frictional forces tending to oppose its motion.
‡ Natural frequency is the rate, in cycles per second, at which a (lightly damped) elastic body vibrates back and forth when it is set into motion and allowed to oscillate freely.
and platform; usually it averages about 5 c/s.

2. Nomenclature for Ballistocardiograms:
   a. Normal displacement records (fig. 4).
      (1) Recommended nomenclature:
         (a) Systolic waves.
            (i) The H wave is a headward deflection which begins its ascent at or
                near the peak of the electrocardiographic R wave. Its peak is at or
                near the beginning of ejection.
            (ii) The I wave is the footward deflection following the H wave in normal
                records; it occurs early in systole.
            (iii) The J wave is the largest headward wave in the normal record; it im-
                mediately follows the I wave, and occurs late in systole.
            (iv) The K wave is the footward wave following J; it occurs near the end of
                systole.
         (b) Diastolic waves.
            The two smaller headward waves which usually follow the K wave in normal records
            are to be called L and N, the footward wave between them is to be called M. The small
            waves, occurring later in some normal records may be given the letters in sequence.
            However, the large diastolic waves occurring in certain abnormal records are not to be
            given these letters as they are believed to be due to forces quite different from those
            which produce the smaller normal waves. Those ab-
            normal waves should not be given a letter, but should be

![Diagram of displacement records from different ballistocardiographic systems to show differences in timing of waves and relationship between waves and the carotid pulse, electrocardiogram, and phonocardiogram. Vertical lines are 0.2 sec. apart. Initial solid line marks the Q wave of the electrocardiogram. I. High frequency ballistocardiogram. II. Direct body ballistocardiogram. III. Low frequency ballistocardiogram. IV. Ultra-low frequency ballistocardiogram.](image-url)
described by their direction and position, for example, "A large headward wave occurring in late diastole."

e. Presystolic waves.

The G wave is the small footward wave which at times precedes the H wave.

A headward wave preceding G, not described by most authors, should be called F, if it is encountered, but any wave thus lettered should be clearly derived from presystolic forces such as atrial contraction and not be an after-vibration from forces liberated in the preceding systole.

These ballistocardiograms, unlike other types of displacement records, show no weaving or undulation of the baseline with respiration.

b. Velocity records: No recommendations.

c. Acceleration records: No recommendations.

3. Calibration; High Frequency Ballistocardiographs (HF-BCG):

a. Displacement calibration:

The ordinate of the displacement HF-BCG should be calibrated by adjusting the amplification so that a standard platform displacement produces a standard deflection of the baseline, e.g., $2 \times 10^{-4}$ cm. platform displacement/cm. deflection on record. The standard deflection is obtained by applying a corresponding deflection force (pulley and weight) to the platform (see Technical Appendix); this force should be stated.

b. Force calibration:

The classical method of calibration is to set the amplification to produce 1 cm. deflection in record/280 Gm. force applied to platform. Displacement calibration is preferred for reasons stated in the Technical Appendix.

c. Dynamic calibration: See Technical Appendix.

4. Suggestions Concerning Technical Data to be Included in Publications.

In order to compare records from different instruments of this type, it is recommended that certain physical constants be measured (if possible) and set forth in publications. These include:

a. Calibration (see above).

b. Weight of platform.

c. Spring constant, k, of platform; or weight and natural frequency of platform alone. ($k = F \times 0.1 \text{ wt.}$, where weight is in lbs., k in lbs./inch and f in cycles/sec.)

d. Characteristics of transducer, recorder, and associated electric equipment.

Other important data are: natural frequency, damping and weight of the platform—body combination. (See Technical Appendix.)

B. Low Frequency Ballistocardiographs (Nikerson-type$^{11}$): LF-BCG.

1. General Characteristics:

a. A table, "bed," or platform provides support for the body and a footboard is generally used to improve the body's coupling.

b. Springs coupling platform to ground are about $1/2$ as stiff as the body springs.

c. Platform weights are usually about the same as those with the high frequency beds.

d. Platform is critically damped with dead weight on platform equaling weight of subject.

e. Loaded with dead weight (equal to patient's weight) platform frequency is set at about 1.5 c/s.

2. Nomenclature for Records:

a. Normal displacement records (fig. 4).

1) Recommended nomenclature:

The wave form in these records
somewhat resembles that observed in high frequency ballistocardiograms. The waves in these records should be designated by the same letters (G, H, I, J, and K) as those in high frequency ballistocardiograms. They are in the same direction but considerably later in time. The J wave usually occurs in late systole, or early diastole and the K wave in mid-diastole. There are normally no other recognizable diastolic waves.

Respiration causes rather large fluctuations of baseline in these records but this is abolished when respiration is suspended.

b. Velocity records: No recommendations.

c. Acceleration records: No recommendations.


a. Displacement calibration:

The scale of the ordinate should be adjusted, measured, and expressed in the same way as for the high frequency bed, e.g., .005 cm. platform displacement/cm. deflection on record.

b. Force calibration:

The classical calibration is to adjust the gain so that a known force (usually 35 or 40 Gm.) applied to the platform by means of a weight, produces a 1 cm. deflection on record. This is expressed: 40 Gm. force/cm. deflection on record. Calibration (a) is preferred because of dynamic disproportion between force and displacement, as in the case of the HF-BCG.

4. Suggestions Concerning Technical Data to be Included in Publications:

Same as for high frequency ballistocardiograph.

C. Ultra-low Frequency or Aperiodic Ballistocardiographs (Gordon; Henderson; von Wittern; Talbot; Burger; Rappaport): UF-BCG.

1. General Characteristics:

a. A platform or hammock, which is relatively stiff horizontally, supports the body. Additional coupling of body to platform is obtained with a footboard or other constraints.

b. Stiffness of spring coupling platform to ground is only 0.01-0.002 of the stiffness of the body's dorsal spring.

c. A small amount of external damping is generally used.

d. Weights of the supporting surface range from 3-20 pounds (1/6 to 1/60 of body weight). This is suspended so as to minimize vertical or flexural vibrations.

e. Platform frequencies (unloaded or loaded with dead weight) range from 0 to about 0.5 c/s.

f. Loaded with human subject the fundamental frequency of bed-body combination ranges from 0-0.5 c/s.

2. Nomenclature for Records:

a. Normal acceleration records. (See figs. 5 and 6)

The normal ballistocardiograms of this type generally resemble the normal displacement records from high frequency and direct body ballistocardiographs. They differ from the latter types in that: (1) They have a less sinusoidal appearance; (2) the K wave is usually small or absent; (3) there may be extra waves or deflections; (4) corresponding wave tips are slightly early in time; and (5) they tend to show faster detail. Under ordinary circumstances respiration causes no baseline weave.

In these records the waves which are similar in direction and time to the G, H, I, J, L, M, and N waves in high frequency bed and direct body displacement ballistocardiograms should be designated by the same letters.
Therefore, H, J, L, and N are positive (headward) waves and G, I, and M are negative (footward) waves.

The details of wave form observed in normal records of this type are greater than that in high frequency records. Not infrequently there are slurs on the HI segment and on the LJ segment. There is considerable individual variation in pattern between the J and M wave tips. (See fig. 5 for differences in detail). There is usually a small headward wave which roughly corresponds to the high-frequency L wave; this should be termed the L wave. Other deflections commonly occurring between J and L may be designated in any manner that seems suitable. This variable portion of the record may be termed “the JL segment” or “the K region.”

The H, I, and J waves are in
systole, while the M and N waves are in early diastole; the L wave usually occurs at the time of the second heart sound. Small deflections later in diastole are sometimes present; no specific names are recommended for them.

b. Normal displacement records (fig. 6).

The normal ballistocardiogram of this type bears little resemblance to any other type of ballistocardiographic record although its nearest relative is the low frequency displacement ballistocardiogram (fig. 4). These records are characterized by simplicity of wave-form and absence of detail. There are only 2 major waves, a footward one with its tip in mid-systole and a larger headward wave with its tip in early diastole. After this there is a slight footward flexure, followed by a gradual, sometimes undulating, return.

Respiration causes weaving of the baseline* many times the amplitude of the ballistocardiographic complexes even when the instrument is highly damped. The baseline usually stabilizes if respiration is suspended and the patient lies motionless.

There is a corresponding wave or flexure in these records for each wave tip in the acceleration record; although opposite in direction to the latter they are to be designated by the same letters, G, H, I, J, L, M, and N. A double prime symbol placed before these letters† may be used to distinguish displacement waves (or flexures) from acceleration or velocity waves under any circumstances wherein a distinguishing symbol is needed to avoid confusion. "H", "J", "L", and "N are footward waves or flexures (concave upward) and "G", "I, and "M are headward waves or flexures (convex upward).

The headward "G wave if present is small. The footward "H wave is also small and is often represented only by a bend or flexure before the headward "I wave tip. The "I wave is clear-cut but small and is followed by the deep footward "J, the tip of which is the lowest point of the record. The headward "M wave is the tallest of the waves of the displacement ballistocardiogram. Preceding the summit of the "M wave a distinct shoulder or slur is usually present; this coincides in time with the beginning and tip of the acceleration L wave and may be termed the "L flexure.

The tip of the headward "M wave usually occurs in early diastole and is synchronous with the footward acceleration M wave. Between this point and the beginning of the next cycle, there is a variable pattern. In general the early part of the downstroke is moderately steep and the later part shallow. The transition between the two is usually marked by a distinct negative (footward) bend which corresponds in time to the acceleration N wave tip and may be referred to as the "N flexure. After this there is usually a gradual footward descent.

c. Normal velocity records (fig. 6).

The normal ballistocardiogram of this type differs considerably from other types of ballistocardiograms. There are 3 major waves: the first is a small, rather narrow footward wave; the second is a large, broad headward wave which usually extends to or slightly beyond the end of systole; the third is a smaller, sharper, footward wave with its tip in early diastole.

---

* Refer to paragraph on baseline.

† Primes placed before the letters are meant to denote integrals; double primes are used for displacement (double integral of acceleration) and single primes for velocity (single integral of acceleration). This convention is not to be confused with the one used for designating waves in direct-body records for in the latter case the single and double primes are placed after the letters to indicate the 1st and 2nd derivatives of displacement which are velocity and acceleration, respectively.
Respiratory wave of the baseline again exceeds the amplitude of the (velocity) ballistocardiogram, with a lightly damped platform. It stabilizes when respiration is suspended.

The tips of the waves in these records are later than the wave tips similarly named in displacement and acceleration records. (See Appendix, section on relation of D, V, and A.) There is usually a small footward wave followed by a small headward wave and a larger footward wave in the same direction as the acceleration G, H, and I respectively, but delayed in time. These may be designated by the same letters adding, when needed, a single prime before the letters to indicate they are velocity waves; for example, “the ‘I wave.” The next succeeding wave, the ‘J, is the dominant headward wave. After ‘J a well marked rather rapid upward deflection is usually present; this may be termed the ‘L wave although it is slightly later in time than the acceleration L wave and the displacement ‘L flexure. The final major wave ‘M, is footward, and its tip follows the acceleration M and displacement ‘M waves.

The time relationships between displacement, acceleration, and velocity records may be checked by the following rule: The velocity tracing crosses the baseline at the tips of the "H, "I, "J, and "M displacement waves and at the tips of the H, I, J, and M acceleration waves.

   a. Acceleration records:
      (1) The record should be calibrated by adjusting the amplification so that a standard acceleration of platform or accelerometer produces a standard deflection of the baseline, for example: 2 cm./sec.²/cm. chart deflection.

      The frequency range over which this calibration applies should be stated. (See Technical Appendix for methods of producing standard accelerations and finding pass-band.)

      (2) Force sensitivity: The ordinates of the acceleration record should not be scaled in force units, as the relation of BCG force to platform acceleration is unclear.

   b. Velocity records:
      The velocity should be calibrated by amplifier adjustment so that a standard velocity of platform or transducer produces a standard deflection of the baseline, for example: 0.1 cm./sec. platform velocity/cm. chart deflection. The passband over which this applies should also be given, for example: “over the range 1–20 c/s.” (Methods of producing standard velocity and measuring the passband are given in the Appendix.)

   c. Displacement records:
      The displacement record should be calibrated by so adjusting the amplifier that a standard displacement of platform or transducer produces a standard chart deflection, for example: 0.05 mm. platform motion/cm. chart deflection over the range 1–20 c/s. (The Technical Appendix gives method of producing standard deflection and measuring passband with the transducers generally used with the UF-BCG.)

4. Suggestions Concerning Technical Data to be Included in Publications:
   In order that records from different instruments of this type may be compared, certain physical characteristics should be described. These include:
   (1) Type of support and nature of its coupling to “ground.”
   (2) Construction and weight of platform.
   (3) Natural frequency and damping of platform.
   (4) Methods used to increase coupling of body to platform (footboards, etc.).
D. Direct Body Ballistocardiographs. (Dock\textsuperscript{2}; Smith\textsuperscript{3}; Arbel\textsuperscript{4}; Walker\textsuperscript{5}): DB-BCG.

1. General Characteristics:
   a. Body is not supported on a spring-coupled platform. Patient usually reclines on a rigid flat surface but other surfaces are used.
   b. The motion of a single part of the body is recorded. Most commonly a crosspiece connecting the two shins is used; its motion is referred to the supporting surface. The top of the skull and other points on the body have also been used.
   c. Since there is no spring-coupled supporting platform, the mechanical characteristics are those of the human body. Of the 3 variables, body mass, spring constant, and damping, the latter 2 vary (or can be made to vary) depending on: (1) the kind of supporting surface used (hard surface, rubber, sand, putty, etc.), (2) how the body is supported (blocks or sandbags beneath the heels, pillows for the head, etc.), and (3) nature, location, and tightness of added couplings, if any (footboard or hip, shoulder, chest, and head supports).

   For the average patient lying on a hard floor with blocks under the heels, and a small pillow to support the head, reasonable values for spring constant (k), body natural frequency (f\textsubscript{a}), and damping (\zeta), are \( k = \pm 240 \text{ lbs/in.} \); \( f_a = \pm 4 \text{ c/s} \); \( \zeta = \pm 15 \) (15 per cent of critical). Changes in these physical factors may cause changes in the dynamic performance of the body-ballistocardiographic system and therefore changes in the ballistocardiographic records. In practice, an attempt is made to keep as invariant as possible the conditions under which routine records are taken. Different operating conditions are currently in use and no standard method is proposed.
   d. The transducer used to sense the motion of the body constitutes a second spring-coupled mass which may or may not modify the recorded ballistocardiogram depending on the transducer's physical characteristics. With the shin crosspiece type of transducer, distortion of the record is reduced by (1) reducing weight of crosspiece, (2) increasing coupling between crosspiece and shins, and (3) reducing or removing coupling between crosspiece and body support.
   e. In general, frequency response characteristics of direct body ballistocardiographic systems (including body) are rather similar to those of the "high frequency" systems. (See Appendix.)

2. Nomenclature for Records:
   a. Normal displacement records (fig. 7).

   Most ballistocardiograms of this type show a rather close resemblance in waveform to the displacement records from the high frequency ballistocardiograph but are somewhat later in time (fig. 4). Unlike the latter, there is respiratory baseline weave which disappears during suspended respiration. Records taken from other parts of the body along the longitudinal axis resemble, in a general way, those from the shins but they may differ in various details.

   The waves in these records, similar in direction and time, should be designated by the same letters given the corresponding waves in the high frequency ballistocardiogram, that is, G, H, I, J, K, L, M, N, and O.
   b. Normal acceleration records (fig. 7).

   Ballistocardiograms of this type
roughly resemble displacement and velocity records, the latter more than the former. In the acceleration record the waves are sharper, there is more rapid detail (notching, slurring, etc.) and greater susceptibility to ambient vibration. Respiration does not cause baseline weave.

The waves of the normal acceleration ballistocardiogram are to be given the same letters as those waves in the displacement record which are synchronous in time but opposite in direction. The double prime symbol placed after the letters* denotes acceleration waves. $H''$, $J''$, and $L''$ are negative or downward and their tips coincide with those of the positive $H$, $J$, and $L$ waves in the displacement record. Similarly, $G''$, $I''$, $K''$, and $M''$ are positive or upward and their tips coincide with those of the negative $G$, $I$, $K$, and $M$ waves.

c. Normal velocity records (fig. 7).

Ballistocardiograms of this type bear a general resemblance to the related displacement ballistocardiograms. They differ in that there is usually no baseline weave with respiration, they contain faster detail, and the waves are earlier in time.

The waves of the normal velocity ballistocardiogram are to be assigned the same letters as those given to waves of similar appearance and polarity in displacement records although the velocity waves appear earlier in time. The velocity waves are to be distinguished by the single prime symbol placed after the letters. $H'$, $J'$, and $L'$ are positive (headward) waves and $I'$, $K'$, and $M'$ are negative (footward) waves.

Although tips of normal displacement and acceleration waves occur synchronously, this is not true for velocity waves. However, the correct time relationship of the normal velocity record with the other two can be checked by means of the following rule: Velocity is always zero (baseline crossing) at the tips of displacement and acceleration waves. Thus, each intersection of the velocity tracing with the baseline serves to

---

* Single and double primes after the letters are used to indicate the first and second derivatives of displacement which are velocity and acceleration, respectively.
mark the temporal positions of the
displacement and acceleration wave
tips.
a. Displacement calibration:
The record should be calibrated by
so adjusting the amplification that a
standard displacement of the shin
(or head) piece produces a standard
chart deflection, for example; 0.006
cm. displacement of shin piece/cm.
chart deflection, over the range 1–20
c/s. Appendix gives method of deter-
mining these with usual DB-BCG
transducers, and the correction for
resonant motion of the shin piece.
b. Velocity calibration:
Similarly, the gain adjustment
should be described, for example: 0.1
cm. per sec. velocity of shin piece/cm.
chart deflection, over the range 1–20
c/s. (See Technical Appendix for
methods.)
c. Acceleration calibration:
The acceleration record should be
scaled by similar adjustment, for
example: 2 cm./sec.² acceleration of
shin piece/cm. chart deflection, over
the range 1–30 c/s. (See Technical
Appendix for methods.) Note: Some
commercial assemblies preadjust the
ratios of gain for the 3 aspects of
motion, so that stated calibrations of
motion result for a prescribed sensi-
tivity of the amplifier, for example: 1
mV./cm. deflection of record. In this
case also the range should be stated
over which the calibration applies.
4. Suggestions Concerning Technical Data
to be Included in Publications:
In order that records from different
instruments of this type may be com-
pared, the method used should be de-
scribed as clearly and completely as
possible. This description should include
the following items:
a. Method of supporting body: type of
supporting surface, (hard, rigid sur-
face; sand, putty, etc.), shin blocks,
pillows, padding, constraints, etc.
b. Transducer, recorder, and associated
electric equipment. The type of
instrument (electromagnetic, photo-
electric, piezoelectric, etc.) used should
be indicated. If filters, integrators,
differentiators, and other electric
devices are used this should be stated.
They need not be described if the
complete over-all performance data
are given. (See Technical Appendix.)
For example, the following statement
would provide sufficient description of
the performance of the instrument.
“Displacement, velocity, and accelera-
tion records were obtained using an
electromagnetic pickup in associa-
tion with an integrator, a differen-
tiator, and high cut filters. In all 3
cases over-all performance indicated
that there was less than 15° phase
shift and less than 15 per cent ampli-
tude error from 1–20 c/s.”
If performance data are unknown,
then the actual values (resistance,
capacitance, etc.) of all the electric
components should be given and, if
it seems warranted, a circuit diagram
should be shown. Appropriate cali-
bration values also should be given.
c. Coupling of transducer to body:
If part of the transducer is applied
to body, its weight, the way in
which it is coupled to the body and, if
possible, the natural frequency of this
coupling should be indicated. Also,
if the body is coupled through the
transducer to the supporting surface,
the nature of this coupling (stiffness,
natural frequency, etc.) should be
indicated. (See Technical Appendix
for method of testing.) With most
electromagnetic and photoelectric
transducers there is no physical con-
nection between the part of the trans-
ducer on the body and the part on the
table; with other types there is
usually some coupling between the 2
parts.
IV. Summary

1. Revised and extended proposals for ballistocardiographic nomenclature and conventions are presented.

2. Proposed conventions applying to all ballistocardiographic systems include:
   a. Standard spatial axes and conventions of polarity.
   b. Conventions for presentation or reproduction of ballistocardiograms.
   c. General definitions and terminology.

3. Current ballistocardiographic instruments are classified in 4 separate types and treated individually. For each type the general characteristics of the method are given along with suggestions regarding calibration and other technical data to be included in publications.

4. A terminology for waves, based on Starr’s original system, has been devised for displacement records from the high frequency (Starr) and the low frequency (Nickerson) ballistocardiographs and for displacement, velocity, and acceleration records for direct body and ultra-low frequency ballistocardiograms.

5. These new proposals are endorsed by the Committee on Ballistocardiographic Terminology and are intended to supplant the earlier proposals set forth by this Committee.

SUMMARIO IN INTERLINGUA

1. Es presentate revidite e augmentate proponimentos pro le nomenclature e le conventions ballistocardiographic.

2. Le proponimentos de conventions applicable a omne systemas ballistocardiographic representa le sequente categorias:
   a. Standard axes spatial e conventions de polaritate.
   b. Conventions in le presentation e reproduction de ballistocardiogrammas.
   c. Definitions e terminologia general.

3. Le instrumentos ballistocardiographic que es currentemente in uso es dividite in quatro typos separate. Iste typos es tractate individualmente. Pro omne typo le caracteristicas general del metodo es presentate insimul con propositiones relative al calibration e altere datos technic que debe esser includite in publicationes.

4. Quanto al undas, un terminologia basate super le sistema original de Starr eseva elaborate pro registratione de displacement ab ballistocardiographos a alte frequentia (Starr) e basse frequentia (Nickerson) e pro registratione de displacement, velocitate, e acceleration ab ballistocardiographos directe e ab ballistocardiographos a ultrabasse frequentia.

5. Iste proponimentos ha le approbation del Committee pro le Terminologia Ballistocardiographic. Le intention del Committee es que illos suplante le proponimentos previemente formulate per illo.

V. Bibliography


b. —: Displacement, velocity and acceleration ballistocardiograms as registered with an undamped bed of ultra-low natural frequency.


10 Elsbach, H.: Klinische onderzoekingen met de laag-frequente ballistocardiograaf volgens Burger. (Clinical investigations with the low-frequency ballistocardiograph according to the method of Burger.) Monograph in Dutch with English Summary. Thesis from the Cardiological Dept. (Dr. H. A. Snellen) of the University of Leiden, 1954.


Proposals for Ballistocardiographic Nomenclature and Conventions: Revised and Extended: Report of Committee on Ballistocardiographic Terminology

WILLIAM R. SCARBOROUGH, SAMUEL A. TALBOT, JOHN R. BRAUNSTEIN, MAURICE B. RAPPAPORT, WILLIAM DOCK, WILLIAM R. SCARBOROUGH, W. F. HAMILTON, JOHN E. SMITH, JOHN L. NICKERSON, SAMUEL A. TALBOT and ISAAC STARR

Circulation. 1956;14:435-450
doi: 10.1161/01.CIR.14.3.435

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1956 American Heart Association, Inc. All rights reserved.
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/14/3/435

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/