Higher Frequency Phenomena in the Normal Ballistocardiogram

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Physiologic higher frequency phenomena may be demonstrated in ballistocardiograms from normal subjects. These phenomena consist of notches or multiple oscillations on the H-I and K-L segments of the tracings. They may be demonstrated by recording the unfiltered output of an electromagnetic direct-body ballistocardiograph. They become more prominent as the transducer is applied closer to the source of cardiovascular forces, or by passing the output of the transducer through a band pass filter. The time relationship of these oscillations to simultaneously recorded heart sounds suggests their association with the ballistics of the closing heart valves.

Standard ballistocardiographic transducers, including high and low frequency units, are designed to record body motion up to approximately 15 cycles per second. Higher frequency oscillations are generally masked in the ballistocardiogram because they are smaller in amplitude and more damped in their transmission to the surface of the body.

Yet, closing heart valves interrupt the major flow of blood through the cardiovascular system, and thus recoil from their action should have some representation in body ballistics. Since the lower end of the frequency range of valve motion is just above that recorded in the standard ballistocardiogram, only slight adjustment in recording techniques should be necessary to bring out valve closure oscillations.

Physiologic higher frequency phenomena, manifested as notches on the H-I and K-L segments, first became evident to us in ballistocardiograms recording lateral motion of the chest. We have noted variation in position of each notch on the basic waves and variation in configuration of the notches from subject to subject and with respiration. The notches appear either as single or multiple oscillations. The H-I segment notch may appear anywhere from the peak of the H wave to the peak of the I wave. The K-L segment notch may appear anywhere on the K-L segment and occasionally after the peak of the L wave (actually on the L-M segment). Regardless of their position in the ballistocardiogram, however, the notches are consistently related in time to the heart sound waves.

Three methods have been selected to record higher frequency phenomena. The first method utilizes a standard transducer whose response rises linearly with frequency. The second method employs the placement of the transducer closer to the source of cardiovascular forces. The third method uses the band pass filter and its ability to select various frequency ranges for examination.

The standard Dock electromagnetic transducer, without its low pass filter, can be used to demonstrate the first method because its response then rises linearly with frequency. When this transducer is applied to the legs of normal subjects, some tracings are produced which show H-I and K-L segment notches considerably smaller, but otherwise similar to those in lateral tracings (fig. 1).

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The effect of filtering the transducer response is also demonstrated in figure 1. As the capaci-
stance of the circuit is increased and thus the frequency response of the transducer is decreased, the notches disappear.

In these tracings it is evident, however, that the absence of a filter permits the appearance of extraneous vibrations which obscure the higher frequency notches. This interference

Fig. 1. Higher frequency ballistic notches recorded from the legs. Simultaneous tracings of (1) electrocardiogram, lead I; (2) heart sounds from the apex; (3) serial ballistocardiograms, which show damping out of the notches as the capacitance is increased. (A) Without a filter—arrows indicate the H-I and K-L limb notches; (B) with a capacitance of 5 microfarads; (C) 20 microfarads; (D) 50 microfarads. Figures 1, 3, and 4 have been recorded from the same subject.

Fig. 2. (A) Diagram of the spring platform transducer. (1) Moving table top; (2) 2 by 2 inch opening for head placement; (3) compliant springs; (4) magnet; (5) coil. (B) Diagram of the electromagnetic pick-up. (1) Magnet; (2) coil; (3) variable capacitance switch.

sets a practical limitation on the first method as applied to the legs.

Since higher frequency vibrations of the body are more attenuated than the low frequency vibrations (H-I-J-K complex), as the distance from the source is increased, the second method is employed. A modified transducer is applied to the head, a position closer to the origin of cardiovascular forces. This transducer consists of a moving platform upon which rests the occipital region of the head (fig. 2). The moving platform is supported by three flat compliant springs which stand erect and are anchored to a stationary base. An electromagnetic pick-up has been attached to the moving platform. Records obtained from this transducer, without a filter, show H-I and L-M segment notches somewhat more consistently than heretofore described (fig. 3). When present, they are more prominent than those in the leg tracings. The introduction of a filter into the circuit diminishes the amplitude of the notches (fig. 3).

Fig. 3. Ballistic notches recorded from the head. Simultaneous tracings of (1) electrocardiogram, lead I; (2) heart sounds from the apex; (3) serial ballistocardiograms which show damping of the notches as the capacitance is increased. (A) Without a filter. Arrows indicate H-I and K-L limb multiple notches; (B) With a capacitance of 5 microfarads; (C) 20 microfarads; (D) 50 microfarads.

As evidence that the notches are not a function of the springs, we have compared this electromagnetic transducer with two other head units: one, the same moving platform, without springs, mounted on ball-bearing runners, and the other, a coil mounted on the head directly over a magnet on a stationary stand. Tracings taken by each unit have identical low frequency (H-I-J-K) ballistic complexes. Furthermore, these complexes are identical to those in tracings taken from the Dock electromagnetic unit on the legs.

Closer approximation to the source of cardiovascular forces is accomplished by placing the electromagnetic spring platform transducer beneath the interscapular region. The
transducer is mounted in an opening in the top of a stationary table and is fixed so that the moving platform protrudes 1 cm. above the surface of the table. The low frequency complexes of these tracings are identical to those from the head and the legs.

With the transducer in this position and no filter attached, the H-I and L-M segment notches are demonstrable quite consistently and are more prominent than those in tracings from either the head or the legs (fig. 4). Even with a capacitance of 5 microfarads across the circuit, the notches are still consistent, and with a capacitance of 20 to 50 microfarads, they are evident in some tracings.

Therefore, these experiments show that higher frequency events in the form of 1:1.-1 and K-L (L-M) segment notches may be demonstrated in the normal ballistocardiogram by either or both of the first two methods.

The third method, the introduction of an electronic band pass filter* into the circuit, is used to select a suitable frequency range for study of the notches and to relate them more specifically to the closing of the heart valves. A series of experiments similar to those described above was repeated with this filter interposed between the pre-amplifier and the amplifier of the recording apparatus.*

Utilizing the Dock electromagnetic transducer on the legs, the frequency range of the band pass filter is gradually narrowed from 0.2-40 cycles per second to 16-40 cycles per second (fig. 5). The resultant tracings show a gradual damping-out of the lower frequencies and the gradual appearance of two groups of higher frequency oscillations which are related in time to the simultaneously recorded notches and heart sounds. At a frequency of approximately 20 cycles per second these oscillations are somewhat better differentiated.

The output of the electromagnetic head transducer is now passed through the band pass filter. In a frequency range of approximately 20 to 40 cycles per second the tracings show definite coupled groups of higher frequency oscillations (fig. 6A). In fact, the ballistocardiogram becomes a tracing of the lower frequencies of the heart sounds a valve closure ballistocardiogram.

In the interscapular region with the same transducer, the band pass filtered tracing shows even more clearly the valve closure oscillations (fig. 6B). Like the notches, these higher frequency oscillations become more


* Grass S-channel recorder.
prominent as the transducer approaches the cardiovascular forces.

We wish to point out that lateral tracings from the interscapular region show consistently the most prominent notches and band pass filtered oscillations. These tracings have other unusual characteristics that will be presented in a subsequent paper.

The presence of these oscillations when all other transducers (heart sound microphone, etc.) are disconnected proves that they are not picked up from other circuits.

The relationship between the notches and these higher frequency oscillations can be illustrated even more dramatically. A standard ballistocardiogram is obtained from the head electromagnetic transducer. Superimposed upon this tracing, which shows no notches, is the tracing obtained from the same transducer passed through the band pass filter at a frequency range of approximately 20 to 40 cycles per second (fig. 7). The product of this fusion is a tracing which shows a typical ballistocardiogram with superimposed typical multiple valve closure notches.

![Image of coupled groups of higher frequency oscillations in band pass filtered tracings from the head and interscapular region.]](image-url)

Fig. 7. Higher frequency oscillations superimposed upon a standard ballistocardiogram. Simultaneous tracings of (1) Electrocardiogram, lead I; (2) ballistocardiogram from the head transducer filtered through a capacitance of 50 microfarads; (3) ballistocardiogram from the same transducer passed through the band pass filter in a frequency range of 20 to 40 cycles per second, superimposed upon the standard ballistocardiogram recorded in number 2. The arrows point to the multiple H-I and K-L limb notches.

We believe, therefore, that these findings indicate conclusively that the recoil of the closing heart valves reaches the surface of the body in sufficient force to be represented in the ballistocardiogram, and can be recorded by a modified technic either as A-V (auricular-ventricular) and A-P (aortic and pulmonic) valve closure notches superimposed on a standard ballistic pattern, or as a higher frequency valve closure ballistocardiogram.

**SUMMARY**

1. Physiologic higher frequency phenomena have been demonstrated by modified technics in the standard ballistocardiogram.
2. They are represented as H-I and K-L segment notches or as coupled groups of higher frequency oscillations.

3. These higher frequency oscillations are considered to be the ballistic responses to the closing heart valves.

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