On the Unitary Nature of Cardiac Vibrations*

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SUMMARY

Present day sensors are able to pick up both the low frequency pulsations (apex cardiogram or pressure tracing) and the high frequency vibrations (phonocardiogram).

Studies were made by external tracings in 10 normal subjects and by both external and left ventricular catheterization tracings in 5 normal, anesthetized dogs.

Either filtration or differentiation of the apex cardiogram results in a high frequency tracing, identical to a simultaneously recorded phonocardiogram.

Either filtration or differentiation of the left ventricular pressure tracing results in a high frequency tracing, identical to a simultaneously recorded phonocardiogram.

This demonstrates that high frequency vibrations of sonic frequency are produced within the heart by rapidly changing intracardiac pressures. These vibrations are then transmitted from the internal cardiac structures to the chest surface with minor apparent alteration.

The low frequency (infrasonic) vibrations recorded on the chest wall apparently result from volume changes, movements of the heart, and rapid pressure changes.

Additional Indexing Words:
Heart Heart sounds First heart sound Apex cardiogram Vibrocardiography Phonocardiography

THIS study was conducted in order to evaluate the relationship of the various types of cardiac vibrations from the lowest (appreciated by palpation) to the highest (appreciated by auscultation). We also compared the intracardiac (left ventricular) vibrations with those recorded over the chest wall.

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Material and Methods

This study was made in 10 healthy subjects. They were all aged between 18 and 25 years with the exception of one 12-year-old boy. In addition, left heart catheterization studies were made in a series of 5 dogs weighing between 15 and 20 Kg, anesthetized with subcutaneous morphine sulfate (10 mg/Kg) followed by i.v. pentobarbital (10 mg/Kg).

The graphic studies were made by the use of a multi-channel Hewlett-Packard photographic recorder with paper speed of either 100 or 200 mm/sec.

In man, the study was conducted by applying a contact microphone (H.P. No. 2105A) at the apex with the subject in the supine position. This microphone was connected to a phonocardiograph amplifier (H.P. No. 8813A) with an additional connection for recording the apex cardiogram.* The phono amplifier was supplied with high pass filters having a nominal frequency of 25, 50, 100, 200, 400, 800 Hz. Only the first 3 filters were used for the present study. The slope of the filters could be set at 12 db/octave or 24 db/octave, and both were alternatively used. In the illustrations, 25/12 indicates a nominal frequency of 25 Hz with a slope of 12 dB/octave.

The apex cardiogram was recorded by connecting the special outlet of the phono amplifier to an ECG amplifier (H.P. No. 8811A).

The derivatives of these vibrations were recorded by making use of a series of 6 derivative computers (H.P. No. 8814A), the first of them giving us the first derivative (dp/dt); the second, the second derivative (d²p/dt²); etc. These derivative computers were applied to either the apex cardiogram or the left ventricular pressure tracing.

The electrocardiogram was always simultaneously recorded through a 8811A amplifier.

In the dog, left ventricular catheterization was performed in a retrograde fashion by introducing a Statham SF1 catheter-tip pressure transducer into the central portion of the left ventricle. This catheter was connected with a Hewlett-Packard No. 8805B pressure amplifier. The latter could then be connected to either a derivative computer (see above) or a Krohn-Hite No. 3342R band pass filter.

Results

When simultaneous tracings with various filters are recorded from the same microphone, placed over the apex, one can observe that the slow deflections of the apex cardiogram are gradually attenuated by the filters. When the slowest deflections disappear, the low frequency third and fourth sounds become apparent, as well as the first and second sounds, and then the first and second heart sound assume the greatest prominence (Fig. 1).

The first derivative of the apex cardiogram gives a tracing that is already

* Time constant of the response in the apex cardiogram mode to a unit change in force applied to the transducer has been measured to be about 2 sec.
Fig. 1. Tracings recorded from a single contact microphone placed at the apex of a normal 18-year-old female.

From below—apex cardiogram (ACG)
- phono at 25/12
- phono at 50/24
- phono at 100/24

ECG

Speed 100 mm/sec.—Time lines 40 msec.
Note that the phonocardiogram is obtained from the same microphone as the apex cardiogram by adequate filtration. The waves of the cardiogram are then transformed into the first, second, and third heart sound.

similar to the phonocardiograms recorded with minimal filtration for the low frequencies. When the 2nd and 3rd derivatives are recorded, the tracing assumes more and more the aspect of a phonocardiogram recorded in the medium and high frequency bands, respectively (Fig. 2).

By recording the tracing of left ventricular pressure and modifying it through either differentiation or filtration, fascinating results are obtained: the second derivative of LV pressure still shows some low frequency vibrations
Fig. 2. Tracings recorded with a single contact microphone placed at the apex in an 18-year-old normal male.

From below—apex cardiogram (ACG)
- first derivative of ACG (dp/dt)
- second derivative of the ACG (d²p/dt²)
- third derivative of the ACG (d³p/dt³)

Speed 200 mm/sec.—Time lines 40 msec.

Note the gradual transformation of the apex cardiogram into a phonocardiogram by the use of the derivatives, a process that is similar to a filtering technique.

(Fig. 3B); the third derivative and the sixth derivative show only high frequency vibrations, which are practically identical to those recorded by the external phonocardiogram (Fig. 3C and 3D). A minor difference is due to the fact that, with this type of differentiation, the tracing is already in a higher frequency band than the phonocardiogram, and that phase shifts and minor time delays are introduced by the electronic networks.

A similar tracing is obtained by passing the output of the pressure amplifier through a high pass or band pass filter (Fig. 4): the resulting tracing
Fig. 3. Tracings recorded in an anesthetized dog.

A—From above—electrocardiogram, phonocardiogram at apex with medium filter, first derivative of left ventricular pressure (dp/dt) (I D), left ventricular pressure (recorded with SF 1, catheter tip pressure transducer).

B—Same—except that the derivative of pressure is the second derivative (d²p/dt²) (II D).

C—Same—except that the derivative of pressure is the third derivative (d³p/dt³) (III D).

D—Same—except that the derivative of pressure is the sixth derivative (d⁶p/dt⁶) (VI D).

Note that the third and sixth derivatives have lost the slow deflections and show vibrations similar to those of the heart sounds.
Fig. 4. Tracings recorded from the same dog as in Fig. 3.
Above—routine phonocardiogram at apex in the medium frequency range.
Below—left ventricular pressure tracing passed through a band pass filter
with a 48 dB/octave slope.
Speed 100 mm/sec.
Note similarity between the 2 tracings.

is identical to a phonocardiogram; the minimal delay in the timing of the
vibrations is due to the "electronic filtration".

DISCUSSION

The cardiologists of a century ago observed the vibrations caused by
the cardiac actions mainly through their hands (palpation) and their ears
(auscultation). Thus, they considered their perceptions as caused by two,
unrelated, different phenomena. When electronic equipment was developed,
the engineers tried to satisfy the desire of the clinicians, and developed in-
struments that could record either the extremely low frequency vibrations
or the auditory vibrations in the higher bands. At the First International
Congress of Cardiology (Paris, 1950) as well as in other subsequent meetings,
any instrument recording inaudible vibrations was considered unsuitable for
use by clinical cardiologists.

In the past, certain physiologists (Wiggers, Rushmer) discussed the cardiac vibrations and stated that they were all part of the same phenomenon but were not heeded by clinical workers. We repeatedly stated\textsuperscript{1-4} that the cardiac vibrations were all part of a single spectrum. Laurens\textsuperscript{5} as well as Agress et al\textsuperscript{6} suggested a common origin of precordial vibrations but their statements were soon forgotten.

While demonstration of this was more difficult when microphones for recording "sounds" were unable to also record "pulses", this is now easier because new microphones can record both. Obviously sounds will distinctly appear as soon as the low frequency pulsations are abolished by filtration or differentiation. Equally no exact study of the left ventricular pressure curve could be done until the sensors became able to record both low frequency (pressure changes) and high frequency (sonic) vibrations. Then filtration or differentiation would abolish the slower vibrations (pressure changes) and, through amplification, reveal the high frequency vibrations of sonic frequency. In order to confirm this concept, 2 main avenues were followed:

(1) Comparison of the external phonocardiogram with the apex cardiogram was made and demonstration was given that the former could be obtained from the latter through either filtration or differentiation.*

(2) Comparison of the external phonocardiogram with the intracardiac left ventricular pressure tracing was made and demonstration was given that a tracing similar to the former could be obtained from the latter through either filtration or differentiation.*

This demonstrates that high frequency vibrations of sonic frequency are produced within the heart by rapidly changing intracardiac pressures. These vibrations are then transmitted from the internal cardiac structures to the chest surface with minor apparent alterations.

The low frequency (infrasonic) vibrations recorded on the chest wall apparently result from volume changes, movements of the heart, and rapid pressure changes.

Since the heart sounds are recorded as an integral part of the apex cardiogram or the left ventricular pressure tracing, it is clear that all these phenomena are in reality a single event, which in the past has been artificially separated by means of various recording techniques and given different names. It should be realized that the first sound is simply the manifestation of the high fre-

* Functionally, the difference between a high pass filter and a differentiator is mostly a matter of amplification. However, in a differentiator, we record signals in the frequency range of the slope while, in a filter, we mainly record frequencies that are in the flat portion, above the range of the slope.
frequency components of the pressure-induced vibrations of the left ventricle (walls and blood). Our process of differentiation or filtration of intracardiac vibrations mimics the effects of transmission through tissues plus filtration, as used in the taking of a routine phonocardiogram.

Although this seems to be an obvious conclusion, restatement is necessary because many cardiologists have not yet tried to modify older concepts.

REFERENCES

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