Auscultation of the heart is an art in which the conclusions of the observer depend upon acuity of hearing, sense of timing, and appreciation of tonal quality of complex transient noises. These noises are often near the lower limit of audibility in respect to intensity and also frequency. Indeed, the experienced listener utilizes the tactile sensation of the ear drum, below the auditory level, in interpreting such signs as third heart sounds and gallop rhythms.

It is desirable to capture and record graphically data on rapidly recurring transient sounds in order to submit them to analysis free from the subjective distortion of hearing. In this connection it should be remembered that the trained ear has the advantage of great sensitivity to the higher pitches of the sounds useful in diagnosis and also it can automatically reject artefacts such as amplifier hums, muscle sounds, and other noises not produced by the heart which might appear as valid vibrations in a phonocardiogram. The warning must be issued, therefore, that phonocardiography is only an additional aid in a small group of cases in which the ear has some limitations, and then only when there is an appreciation of the inherent technical pitfalls in the method.

Phonocardiography has been retarded for several reasons. The major technical advance had to await the development of electronic amplification in which the amplifier output was free from ground noise; in other words, a record had to be produced in which the baseline could be depended upon not to contain oscillations produced in the instrument. A crude recording which I made 25 years ago (fig. 1) illustrates the 60 cycle alternating current in the baseline which vitiates any interpretation of murmurs. A second example (fig. 2) shows modern electronic recording in which one can identify the components of the normal first, second, and third heart sounds.

Richard Cabot was interested in this field over 25 years ago, and his clinical descriptions in hospital records of what he heard in the heart were illustrated with drawings of his auscultatory findings. Figure 3 shows his impression of the sounds he heard in a phonograph record, which he made in 1926, of a patient with mitral stenosis. A note from him of this period shows the problems of a heart sound recorder: "In the record of this last patient and of the previous one there is some extraneous noise, due to a snowstorm which was raging outside the room where we worked."

Another factor affecting the development of

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Fig. 1. Phonocardiogram recorded with original Einthoven string galvanometer at Massachusetts General Hospital. First and second sounds can be distinguished, but alternating current artefact in the baseline makes it impossible to record murmurs satisfactorily.

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FIG. 3. Sketches and handwriting of Dr. Richard Cabot illustrating the first stage of mitral stenosis. The drawing on the left shows a presystolic murmur, loud first sound, a decrescendo systolic murmur, second sound with either an opening snap of the mitral valve or third sound followed by a short murmur. On the right are the same features except for the absence of the presystolic phase of the diastolic murmur. The mark following the comma between the two sketches is the word "or."

phonocardiography has been failure to recognize the necessity for recording heart sounds with more than one type of microphone and with two different types of stethoscope chest pieces, the open bell and the diaphragm. The clinical importance of the use of these two chest pieces was noted in 1926.1

One might imagine that it would be desirable to photograph the jumble of frequencies comprising a heart sound cycle with a microphone which would respond to all frequencies in a linear fashion. This is not practical since the linear displacement of the galvanometer beam produced by the apex beat would be several meters on the same scale of amplification which would move the beam only 1 mm. in recording a soft aortic diastolic murmur. Therefore, the linear microphone is used only to record such gross mechanical movements as those of the chest wall or of the neck veins or of peripheral arteries as reference tracings.2

The second type of microphone, the stethoscopic, is so controlled, electronically, that it records those vibrations delivered to the ear by an average stethoscope. Such a record presents the pattern of sound which does not emphasize the higher frequencies to which the ear is peculiarly alert and allows analysis of the lower frequencies which may not always be audible.

The logarithmic, or high frequency, microphone records graphically the sounds and murmurs in a manner comparable to the way in which the brain interprets them since, like the human ear, its distortion is of the type which emphasizes the high frequency, low energy vibrations at the expense of the low frequency, high energy components (fig. 4).

In addition to these three microphones, it is possible to alter the chestpiece as the physician
CLINICAL VALUE OF PHONOCARDIOGRAPHY

does in clinical auscultation, namely, by changing to open bells of different diameters and diaphragms (Bowles type) of differing thicknesses. Open bells transmit all frequencies with large bells emphasizing lower tones, while diaphragms damp out mechanically these lower tones, permitting the higher notes to appear unmasked by them. A diaphragm about twice the usual thickness of 0.015 inch (0.035 inch), will often brilliantly reveal a high pitched murmur. Its use permits high electrical amplification without causing the heart sounds to become loud and booming and thus masking the murmur as in the fatiguing effect on the ear when over-all amplification is increased.

One other feature of phonocardiography must be accepted, and that is the necessity for recording simultaneous reference tracings of cardiac and vascular sounds with which to relate the sounds of the heart. For the timing of systolic activity the electrocardiogram is satisfactory, but for diastolic events the cervical phlebogram and the apex cardiogram are valuable.

To one who is interested in the intricacies of phonocardiography, the recording of all sorts of heart sounds and murmurs is useful in the collection of a permanent portrait gallery of what has been a series of ephemeral auditory impressions. The actual contribution of these portraits toward the understanding of what is going on in the heart is another question. It is to this area that I wish to confine the illustrations of the clinical value of the method.

The recent impressive development of cardiovascular surgery has made accurate diagnosis of congenital defects and acquired valvular lesions of more than academic interest. Cardiac catheterization and angiocardiography have fostered diagnostic humility in the clinician, as has the ability of the surgeon to describe the mechanical activity of the mitral valve which he is actually palpating at operation. However, the time has not come to discard the stethoscope nor to substitute for it the phonocardiograph.

Phonocardiography, however, has shown us, for example, that the normal first heart sound has four components in addition to the auricular sound, and that the second heart sound also has four components, and that the third heart sound is truly a manifestation of the rapid inflow stage of the ventricles. It has also been useful in the timing of sounds and murmurs as in loud auricular sounds (fig. 5a and 5b) confused with first and second sounds, in defining systolic clicks (fig. 6), and even in explaining blowing systolic-diastolic murmurs in children thought incorrectly to be due to patent ductus arteriosus (Fig. 7).

The confusing splitting of sounds is readily interpreted from phonocardiograms (fig. 8). By this method one may demonstrate the presence of murmurs which have been inaudible because of the masking effect of preceding loud sounds or murmurs (fig. 9), and the hiding of heart sounds in loud murmurs (fig. 10). Such has been the case in both the apical and basal areas.

In mitral stenosis it is possible to differentiate the opening snap (fourth component of the second sound) of the mitral valve from the third heart sound and to determine whether or not a short murmur is present after the
Fig. 5a. Logarithmic record at apex of a patient with congenital heart disease, cyanotic type. First sound was described as loud on auscultation; phonocardiogram reveals a faint first sound and a loud auricular sound, which bears constant relationship to the wide, tall, and notched P of the electrocardiogram.

b. Logarithmic record at the apex of a 20 year old white male diagnosed “myocarditis” following an upper respiratory infection. Four heart sounds are shown in the presence of left bundle branch block. The first sound is of normal intensity and is followed by a systolic murmur (SM). The second and third sounds are followed by a loud auricular sound (4).

Fig. 6. Systolic click at apex. Stethoscopic (upper), and linear (middle) phonocardiogram, recorded with lead II of the electrocardiogram. (Standardization tone of 80 decibels shown at the right.) A systolic click (c) and 3rd sound are demonstrated.

third sound (figs. 11, 12). Also it has defined true mitral stenosis, in which the presystolic murmur always starts before the Q wave of the electrocardiogram, from pseudo mitral stenosis due to modified first heart sounds; and it has shown the delay of the first heart sound, relative to the electrocardiogram, in this condition.

Phonocardiography has not been superior to auscultation in the diagnosis of mitral regurgi-
tation combined with mitral stenosis. At operation a regurgitant stream through the valve has been felt by the surgeon's finger in the left auricle when no systolic murmur has been audible or recordable.

Phonocardiography has shown, however, that the Austin Flint murmur may be indistinguishable from that of mitral stenosis when aortic regurgitation is present and the mitral valve normal at autopsy. The loud first sound at the apex, the sharp opening snap of the mitral valve, and the accentuated pulmonic second sound are the diagnostic points in organic mitral stenosis.

In rare cases tricuspid regurgitation may be shown by systolic vibrations in the jugular veins (fig. 13).

Fifty years ago the clinical observation was made that, in pulmonary stenosis, the first sound over the pulmonary artery was sharp

![Figure 8](image_url)  
**Fig. 8.** Logarithmic phonocardiogram recorded at the apex of a 54 year old white male with the clinical diagnosis of "idiopathic cardiac hypertrophy." Bundle branch block is present in the electrocardiogram. There are widely split first and second heart sounds and a third sound. There are also systolic and presystolic murmurs. The latter was thought to be due to the high energy of auricular contraction which was demonstrated by stethoscopic recording in the same area. The jugular pulse also shows a high "a" wave.

![Figure 9](image_url)  
**Fig. 9.** Inaudible basal diastolic murmur. Basal diastolic murmur was not detected on auscultation because of fatiguing effect on the ear produced by the combination of the preceding systolic murmur and the markedly accentuated second sound. The stethoscopic record (upper) shows that the diastolic murmur (DM) actually is of high energy, but its intensity in the sensitive area of the frequency spectrum of hearing is low, as shown by the logarithmic record (lower). These audible vibrations are of much less amplitude in spite of the higher amplification used in the lower tracing as indicated by the wider standardization band on the right of the record.
and high pitched and accompanied the onset of the systolic murmur. This was explained as due to the snapping upward of the fused pulmonic valve cusps at the onset of ventricular ejection. Recently this has been shown phonocardiographically to be associated with an accentuation of the third component of the first heart sound, which is the element contributed by the opening of the semilunar valves. It has been called the "slatting sail" effect and is perhaps to be expected in valvular rather than infundibular stenosis. A similar phenomenon may occur in pulmonary hypertension alone, and also over the aortic area in aortic lesions, and is explained as at times a vascular sound from the main pulmonic and aortic walls.

Leatham stated that "the combination of a loud pulmonary systolic murmur with a second sound which is single, even during inspiration, is almost diagnostic of pulmonary stenosis or atresia, provided the patient is young and therefore splitting would normally be expected." We have shown with the phonocardiograph, however, that a pulmonic systolic murmur associated with delay in conduction.

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**Fig. 10.** Stethoscopic record from the apex of a 73 year old man with the clinical diagnosis of "rheumatic heart disease with mitral stenosis and regurgitation." There is a loud first heart sound preceded by a coarse low frequency vibration of auricular origin and followed by an intense systolic murmur which extends to the end of systole and obscures the second sound. A murmur fills diastole (DM) in which appears a loud third heart sound. Clinically the second sound was obscured by the systolic murmur and the third heart sound was mistaken for it. The intensity of the systolic murmur is shown by its detection in the apex cardiogram (linear).

**Fig. 11.** Early mitral valve disease. The systolic murmur is present and the third sound followed by a short, mid-diastolic rumble with no presystolic phase.
in the right ventricle in pulmonic stenosis will extend into left ventricular diastole and a cardiac catheter in the right ventricle in such a case will record an intraventricular pressure curve maintaining its systolic peak after collapse of the left ventricular carotid pulse wave (fig. 14).

Aortic regurgitation as a complication in patients with mitral stenosis in whom valvulotomy is being considered is at times difficult to differentiate from regurgitation through the pulmonary valve (Graham Steell murmur). Phonocardiography has not been definitive in this differential diagnosis. The pulmonary component of the second sound ordinarily follows the aortic, especially during inspiration, but an aortic diastolic murmur may be delayed in reaching maximal intensity so that it may appear to arise after the pulmonic valve sound. The musical murmur of an everted aortic cusp shows a characteristic pattern (fig. 15).

Aortic stenosis is now operable. In most instances the diagnosis may be made on auscultation with the combination of the loud systolic murmur (at times with thrill) and absent, or much diminished, second sound at the aortic area. Sometimes, however, mitral regurgita-

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**Fig. 12.** Record from the apex of a 35 year old man with mitral stenosis two years after mitral valvuloplasty. No diastolic murmur was audible in the several months prior to operation, and he was severely incapacitated. The tracing shows the first, second, and third heart sounds. The opening snap (OS) appears in relation to the ascending limb of the "v" wave of the phlebogram (middle curve). The third sound is followed by a mid-diastolic murmur (DM) which disappears before the final presystolic phase (PSM) occurring with auricular systole.

**Fig. 13.** The systolic murmur apparent in the upper tracing is shown to be tricuspid in origin since it appears so clearly in the venous tracing from the jugular bulb.

**Fig. 14.** Tracing taken over the pulmonic area in a patient with pulmonic valve stenosis and right bundle branch block. The middle curve is the arterial pressure. The systolic murmur can be seen to extend beyond the first element of the second sound. This element coincides with aortic valve closure as shown by its relation to the dicrotic notch (D) of the arterial pulse. The second component of the second sound is due to delayed pulmonary valve closure related to slow ejection from the right ventricle. In this patient these phenomena were further correlated with catheter pressure readings from the right ventricle which confirmed this interpretation.
Fig. 15. Phonocardiogram taken at the aortic area of a 47 year old man with congestive failure secondary to an everted aortic cusp. Blood pressure 176/90-28. A low pitched, rough systolic murmur was heard in the aortic area and a grade 4 musical diastolic murmur in that area and in the third left intercostal space. The first sound is seen in the tracing to be very much diminished in this area; the systolic murmur (SM) is of low intensity. The second heart sound is somewhat delayed in its relationship to the end of the T wave of the electrocardiogram, and is followed by a loud crescendo-decrescendo diastolic murmur with a frequency averaging 112.5 cycles per second over a period of 0.4 second.

tion may resemble aortic stenosis since the systolic murmur of the latter condition may be well heard at the apex. Phonocardiography shows the murmur of aortic stenosis to be "diamond" shaped, starting somewhat after the first sound, reaching its maximum in mid systole and ending before the second sound. In mitral regurgitation the systolic murmur starts early and extends throughout systole up to the second sound. However, these typical patterns are not always to be relied upon in differential diagnosis.

Conclusions

Phonocardiography is a method of accessory value in a few cardiac conditions. It is technically a difficult procedure. It has been of greatest help in the timing of heart sounds having abnormal components or unusual accentuation of normal components—split sounds, third sounds, auricular sounds, and gallop rhythms.

In only rare instances are the data provided by phonocardiography of critical importance in diagnosis. Such instances include the recording of murmurs which are inaudible due to masking and fatigue effects on the ear from previous loud sounds; the demonstration of true presystolic murmurs of mitral stenosis; and the definition of characteristic patterns of pulmonic and aortic stenosis.

The discriminating use of phonocardiography will undoubtedly be increasingly helpful in the diagnosis of valvular and congenital heart disease.

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