PHONOCARDIOGRAPHY

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General Considerations

Human hearing has certain characteristics which must be undeistood before the principles of phonocardiography can be grasped. The audiogram (Fig. 1) shows the relative insensitivity of the ear to low tones, and its much greater sensitivity to higher tones. To be heard, a third heart sound, for example, at a frequency of 16 cycles per second, has to be ten thousand million times more intense than a faint murmur at 2,000 cycles. A second property of human hearing is its remarkable sensitivity to frequencies about 2,000 cycles per second, when the faintest sound which can be heard is one ten-millionth of the intensity of the loudest noise which can be heard without causing pain. This great range of sound intensities which the ear can appreciate, at 2,000 cycles per second, is achieved at the expense of judgment of grades of intensity, for a tenfold increase in intensity of sound may only double its 'loudness' to the ear (Weber-Fechner law) if the sound is of high intensity. At low sound intensities the ear is more sensitive to such changes.

The actual intensity of low frequency (low pitched) heart sounds is far greater than that of the higher frequency murmurs, yet to the ear,

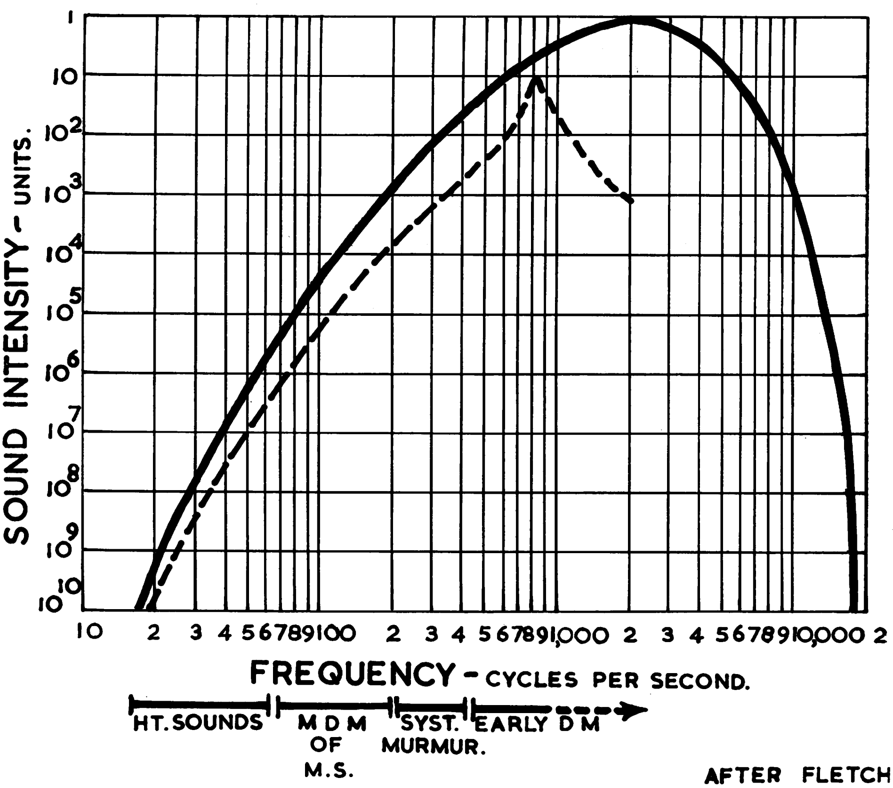

FIG. 1.—Curve showing threshold of audibility at different frequencies. This gives, in arbitrary units, the intensity of a sound required to stimulate the ear at any frequency. One unit is chosen as the lowest intensity which can be heard at 2,oco cycles per second, this being the frequency at which the ear is most sensitive. The dotted line is the HF curve of Fig. 2, and represents the response of the phonocardiograph in the high frequency filter position. The approximate frequencies of heart sounds, mid-diastolic murmur (MDM) of mitral stenosis, systolic murmurs, and aortic early diastolic murmurs are shown, but there is much variability and overlapping of one with another.

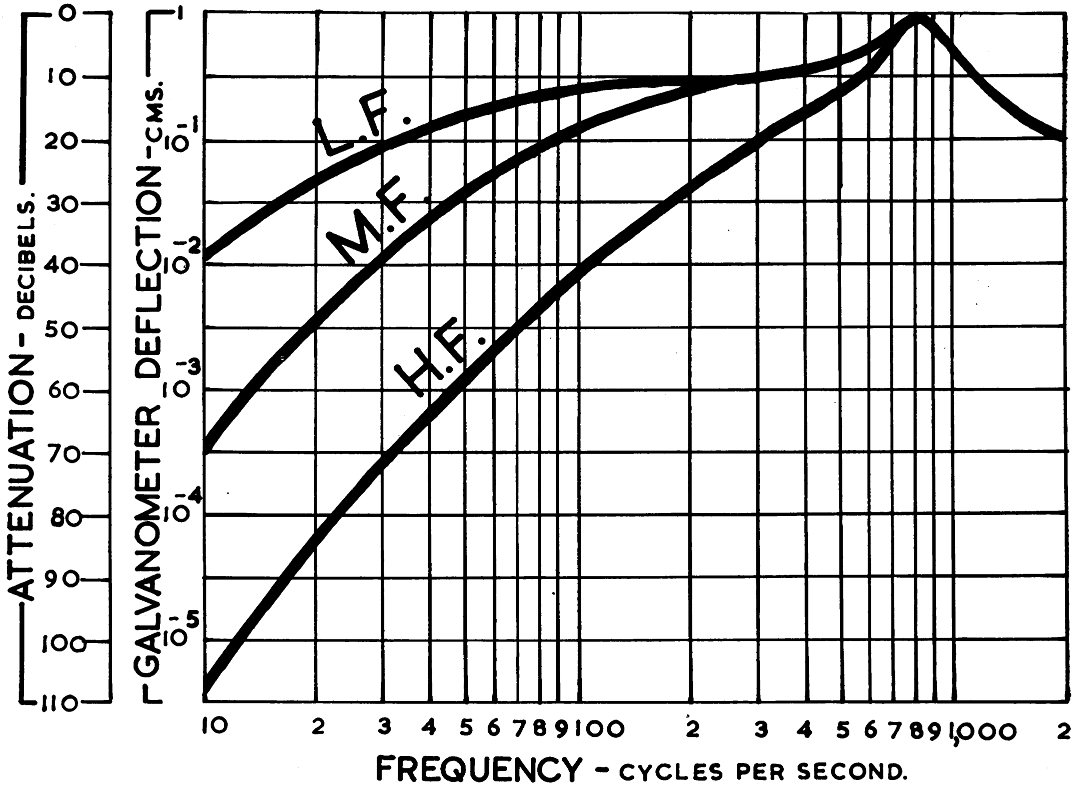

FIG. 2.—Response curve of the phonocardiograph, excluding microphone, taken through the three filters which have been found most satisfactory for clinical diagnosis. (A constant input was supplied at all frequencies.)

HF = High Frequency
MF = Medium Frequency
LF = Low Frequency

owing to its relative insensitivity at low frequencies, the murmur may appear almost as loud or louder. The stethoscope adds to this attenuation of the lower frequencies, especially if fitted with a diaphragm type of chest piece, though less with a bell. In an exact graphic registration of sounds and murmurs as they exist as the chest wall the sounds are seen to be far larger than the murmurs; thus if one record is to show both sounds and murmurs, the record will have to be many feet in width if the murmur is to be visible. It follows that one graphic record cannot possibly show both sounds and murmurs to their best advantage and it is necessary to take several records with varying degrees of attenuation of the low-frequency sounds. The amplification can then be increased and the less intense high-frequency murmurs shown without the more intense lower frequencies damaging the recording instrument or requiring a film of impracticable width. The most logical method of recording graphically this great range of pitch and loudness is to split the frequency range into many channels and take a record with suitable amplification for each. This was done by Mannheimer (1940), but it is too complicated for routine use. An alternative method is to produce a gradually increasing attenuation as the frequency is lowered, so that the loud low-pitched sounds and the faint high-frequency murmurs can be seen in the same record. In this manner Rappaport and Sprague (1941, 1942) chose three different filters. Their *linear* record, or apex cardiogram, was almost an exact graphic registration of all sounds and murmurs as they exist at the chest wall with little filtration, so that the graph consisted of large low-frequency waves bearing little relation to anything heard. In their second or *stethoscopic* curve, the low frequencies were moderately cut to resemble the effect of taking the records through a stethoscope. In their third or *logarithmic* curve the low frequencies were cut more severely to resemble the effect of the stethoscope and the human ear combined, so that this last curve was the only one

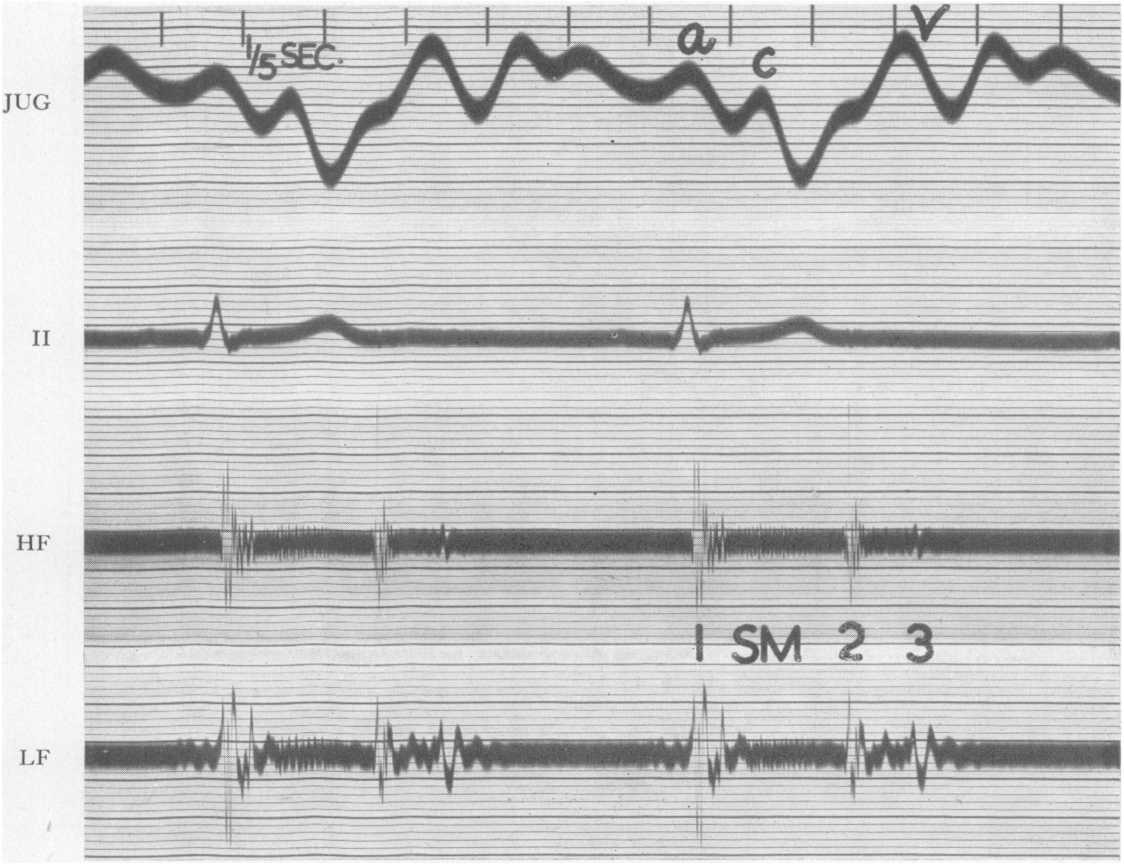

FIG. 3.—The phonocardiogram of a healthy young adult. Synchronous jugular tracing (JUG), electrocardiogram lead II, high-frequency (HF) phonocardiogram and low-frequency (LF) phoncardiogram recorded from the apex through one microphone. The small auricular and moderately large third sounds can be seen in the LF record. There is a slight systolic murmur ending before the second sound. The medium-frequency record is not shown but was intermediate between the low- and high-frequency recordings. The time interval in this and subsequent records is ⅕ second.

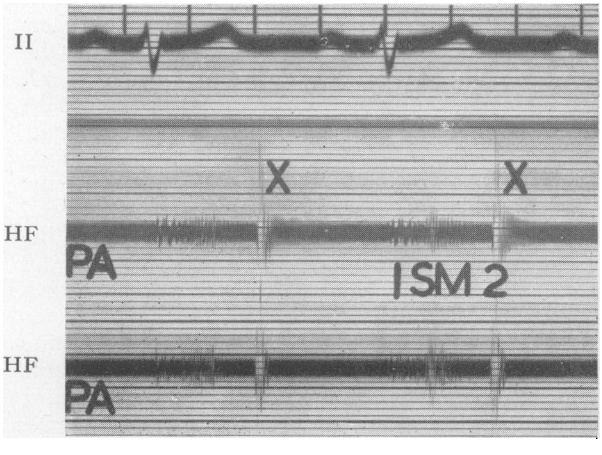

FIG. 4.—Synchronous high-frequency (HF) recordings from the pulmonary area (PA). The natural frequency of the galvanometer used for the middle tracing was too low; it was shocked into oscillation by a high-frequency component of the second sound causing the artefact (X) which was not present in the lower tracing taken with a satisfactory galvanometer.

which could be compared with clinical auscultation.

The curves of the three filtration channels, with varying low-frequency attenuation, which we have found most valuable in clinical diagnosis are shown in Fig. 2, while records made with them in a normal subject are shown in Fig. 3. The *low-frequency* (LF) record shows the low-frequency sounds such as the auricular and third heart sounds, and is valuable in recording triple heart rhythm. These sounds can be shown very well graphically when they are faint to the ear or even inaudible from its attenuation of the lower frequencies. In the *medium-frequency* (MF) record the lower frequencies are moderately cut so that the amplification can be increased and murmurs of medium frequency shown. The mid-diastolic murmur of mitral stenosis can be shown more clearly in this record even when not well heard. In the *high-frequency* (HF) record there is greater cutting of the lower frequencies, and systolic and early diastolic murmurs are shown best. The ear is extremely sensitive to these high-frequency murmurs and with present microphone-amplifier technique it may be difficult or even impossible to record clearly a very faint, high-pitched early diastolic murmur. The high-frequency record which we have found of most use is very similar to the logarithmic record of Rappaport and Sprague, and it is an approximate graphic representation of sounds and murmurs as heard by auscultation. The resemblance between the high-frequency curve and that of the human audiogram is shown in Fig. 1.

Phonocardiographic measurements of the loudness of sounds and murmurs have been made (Mannheimer, 1940; Carlgren, 1946) and require a method of calibrating the sensitivity of the apparatus to allow for changes in sensitivity of the amplifier and microphone. Variations in conduction of sounds and murmurs in different patients, and in application of the microphone, make these methods impracticable at the moment for routine phonocardiography; comparison of the loudness of sounds and murmurs in different areas in one patient can be made if the method of attachment of the microphone is the same.

The next problem in phonocardiography is to secure a record free from extraneous vibrations or, more simply, to obtain a clear base line. These unwanted vibrations may come from outside noises, and a quiet room is necessary for clear records. Soundproofing is not needed with present methods, but may become so in the future with more sensitive apparatus. Great care is required in placing the microphone accurately on the chest to ensure a perfect fit; this prevents external noise from intruding and the heart sounds from escaping, and artefacts are less likely to occur. The greatest single factor in achieving a clear base line is perfect relaxation of the patient. The noise appears to come from muscles which are not relaxed, and it is essential that the patient should be warm, comfortable and fully informed of the simple nature of the procedure. The recording is usually made with respiration halted in expiration to avoid disturbance by breath sounds and this must be rehearsed beforehand. A listening post should be fitted to the amplifier to detect undesirable noise from a badly-held breath, from borborygmi or noise from without.

Apparatus

Much of the original work on the heart sounds was done by direct methods of recording (Wiggers, 1918; Orias and Menendez, 1939), but these methods are difficult to use, variable in performance and insensitive when compared with the modern combination of crystal microphone, valve amplifier and oscillograph.

Einthoven (1907) took records with a tambour on the chest leading by air conduction to a carbon microphone actuating a string galvanometer. This method was used by Sir Thomas Lewis (1920) and again in recent years by William Evans (1947). Attenuation of the low-frequency sounds in order to amplify the fainter murmurs was achieved by certain characteristics of the apparatus (e.g. air conduction in a narrow tube attenuates the low-frequency sounds) and by a side tube which allowed the low-frequency oscillations of the chest wall to escape though it also permitted noise from the room to enter. Such apparatus was relatively insensitive, but its great disadvantage was the use of acoustic methods of filtration, the variability of which was beyond the control of the worker. Nevertheless, acoustic methods of filtration, combined with electrical methods are still used by Rappaport and Sprague (1942) and Sprague and Wells (1949), who attach different stethoscope chest pieces to their microphone for murmurs of different frequency.

The introduction of the crystal microphone marked a great advance in phonocardiography because it was sensitive, sufficiently constant in its characteristics, free from inherent noise and light enough to be fixed directly to the chest. It is now in almost universal use. The crystal, which consists of Rochelle salt, has the property of converting sounds or pressure waves into electrical currents and responds fairly uniformly over the range of frequencies required for phonocardiography. It may be fixed directly on the chest wall but is then relatively insensitive and liable to be damaged. We prefer the crystal to be actuated by a diaphragm for it is thereby usually more sensitive.

The microphone should be attached lightly but firmly to the chest wall by means of suction or rubber adhesive, or by a rubber strap alone or in addition; if tightly applied, however, this lessens the sensitivity of the microphone. A standard technique must be adopted in fixing the microphone to the chest wall, for variation will cause changes in frequency response. A firm strap will increase the sensitivity of the microphone to low-frequency sounds but will diminish it to high-frequency murmurs. The microphone leads to a valve amplifier which must be specially designed and constructed so as to be free from internally generated noise. The valves must be specially selected, but even the best are not entirely silent and may constitute a limiting factor by disturbing the base line when great amplification is needed for faint, high-frequency murmurs such as the diastolic murmur of aortic incompetence. The first valve is the most important in this respect and great attention must be paid to this part of the amplifier. The increase of microphone sensitivity offers the most immediate hope of an improvement in this direction. External electrical interference cannot cause trouble provided the microphone and amplifier and all connections are carefully screened and earthed. Constant vigilance is required to see that the amplifier remains free from noise, which can develop from a small fault such as a battery which is defective. The amplifier can easily be tested for noise by changing the microphone for a condenser of the same capacity; a record is then taken with full amplification and there should be no disturbance of the base line.

Attenuation of the loud low frequencies in order to record murmurs requires filters in the amplifier, and these consist of condensers and resistances or condensers and chokes. By simply varying the value of these components, any degree of low frequency cut can be obtained. Although as easy, we have not found any practical advantage in cutting the higher frequencies when making a low-frequency record; the high-frequency murmurs or unwanted vibrations are of such low intensity compared with the great intensity of the heart sounds that they cannot be seen on these records. The cutting of higher frequencies in medium- or high-frequency recordings may also mask murmurs.

The amplifier leads to a galvanometer which must be sensitive and respond to frequencies up to 1,000 cycles, perhaps higher in the future. The galvanometer should have no natural frequency within or near this range since this will cause artefacts of the type shown in Fig. 4. The natural frequency of the galvanometer used for the middle tracing was too low and it was shocked into oscillation by a high-frequency component of the second sound. There was no such artefact following the second sound in the lowest record taken synchronously through the same microphone, because this galvanometer had no such defect. There are three main varieties of galvanometers in use. The mirror galvanometer is most generally used and is capable of giving very good results if it is carefully damped to avoid artefacts arising from stimulation of its natural frequency. The cathode ray tube is theoretically the best galvanometer since its frequency response is almost unlimited, but photographic technique with this instrument requires to be improved. We have had our best results with the tight string of an Einthoven galvanometer. It has an excellent frequency response to 800 cycles and moderately good to nearly 2,000 cycles; there is little variation over this range with different strings. Its disadvantage lies with its fragility particularly if used in a double fibre case. The frequency response curves in Fig. 2 were taken with the string galvanometer but were almost the same with a mirror galvanometer. Thus the type of galvanometer need not influence our low-, medium- and high-frequency response curves since the effect of the filters is so great compared with variations in the galvanometer. This, too, applies to microphones of the crystal variety.

The recording is made on photographic film or paper. Film has the advantage of a greater density range and is best for showing the fine detail of high-frequency murmurs. The speed at which the recording material travels should be variable since high speeds help accurate analysis or timing of a sound or murmur, while low speeds give repetition of the sounds and murmurs over a small area so that vibrations which are not repeated, usually artefacts, can be easily seen. We use a speed about 50 mm. per second for routine work. Direct writing instruments of the usual variety are of no use for sound recording because they respond poorly to the higher frequencies.

The reference tracing. This may be an electrocardiogram, a jugular tracing, an apex cardiogram or another phonocardiogram of a different frequency or in a different area. The electrocardiogram is the easiest to use and gives valuable information on the timing of the first heart sound and of auricular systole, but gives no accurate timing for the second sound or for diastole. The jugular tracing gives information on the timing of events in the right side of the heart, particularly of the second and third heart sounds; it may be difficult to obtain a clear record and the low frequency nature of the curve makes exact timing difficult. We have not found much help from adding the apex cardiogram to our low-frequency phonocardiogram. Of great use in practice is a

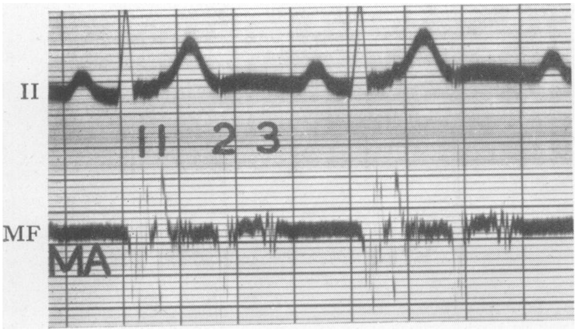

FIG. 5.—Healthy boy, aged 14 years. Splitting of the ventricular component of the first heart sound. The third sound is clearly shown.

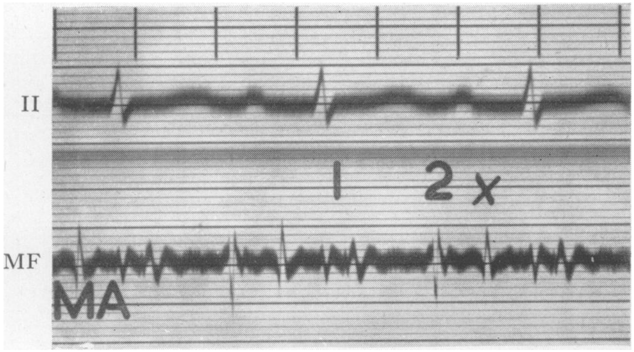

FIG. 6.—Healthy boy, aged 6 years. Innocent 'summation gallop' (X). Loud triple rhythm may sometimes be due to summation of the physiological thiid and auricular sounds from tachycardia.

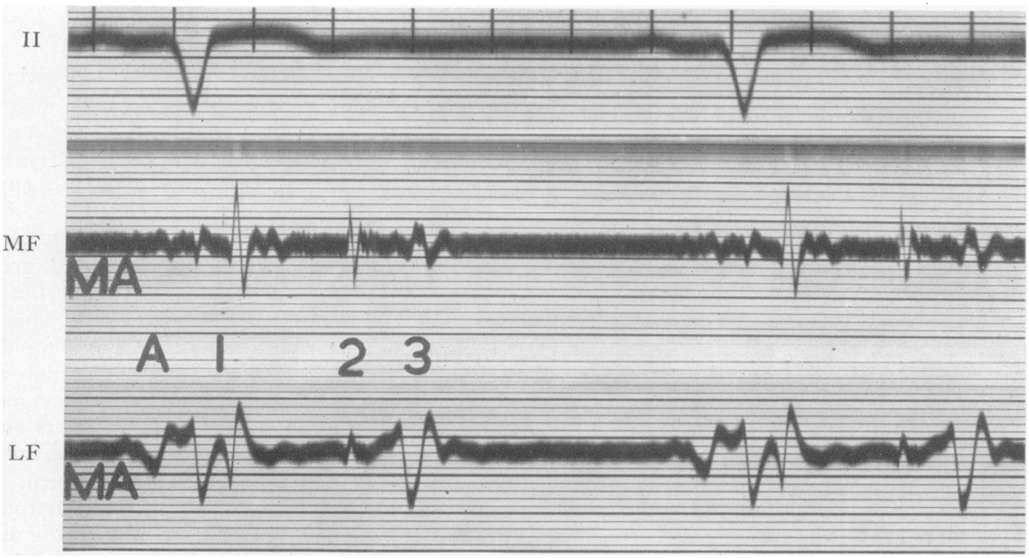

FIG. 7.—Cardiac infarction. Third heart sound following cardiac infarction in an elderly man, best shown in the low-frequency (LF) recording at the apex (MA).

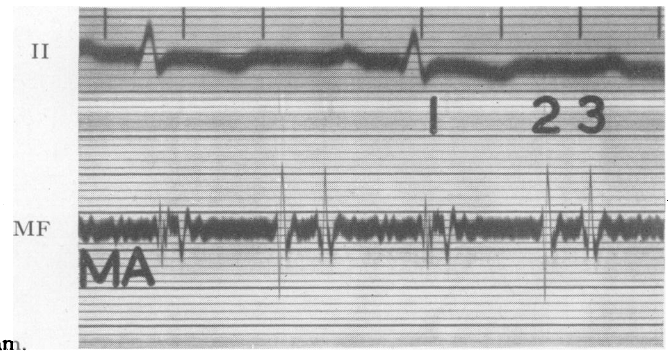

FIG. 8.—Constrictive pericarditis. Triple rhythm.

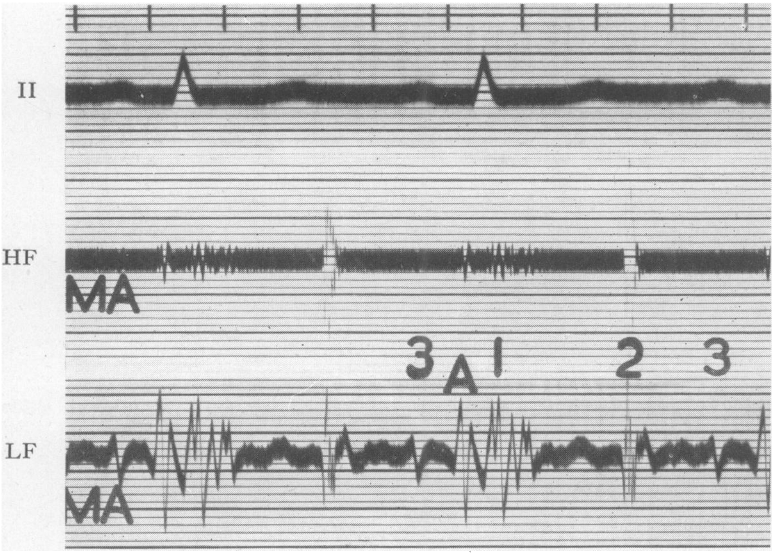

FIG. 9.—Hypertensive heart disease. Large auricular sound (A) in a patient with hypertension, moderate cardiac enlargement and no heart failure. It was heard as obvious splitting of the first sound. With tachycardia the splitting changed to triple rhythm, probably from summation of the third and auricular sounds.

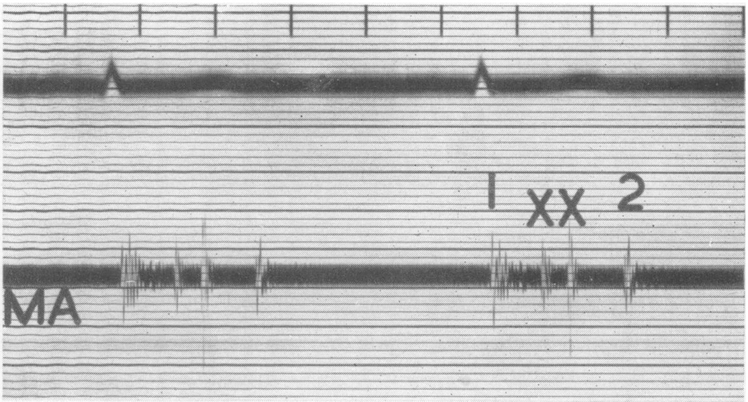

FIG. 10.—Healthy woman, aged 55 years. Innocent systolic triple rhythm. Two sounds (XX) were recorded at the apex (MA) in mid-systole.

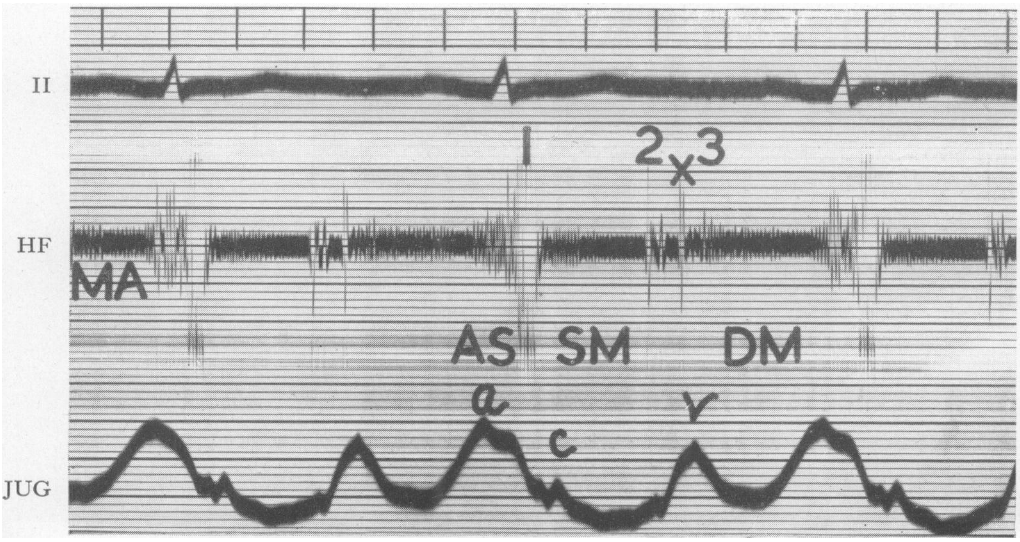

FIG. 11.—Mitral stenosis. Recording from the apex (MA). The pre-systolic or auricular systolic murmur (AS) leads up to a large first sound. After the second sound the 'opening snap' (X) occurs nearly at the peak of the V wave of the jugular tracing, followed by a small third sound and the mid-diastolic murmur. The small deflection between the second sound and the 'opening snap' is probably the second component of a split second sound.

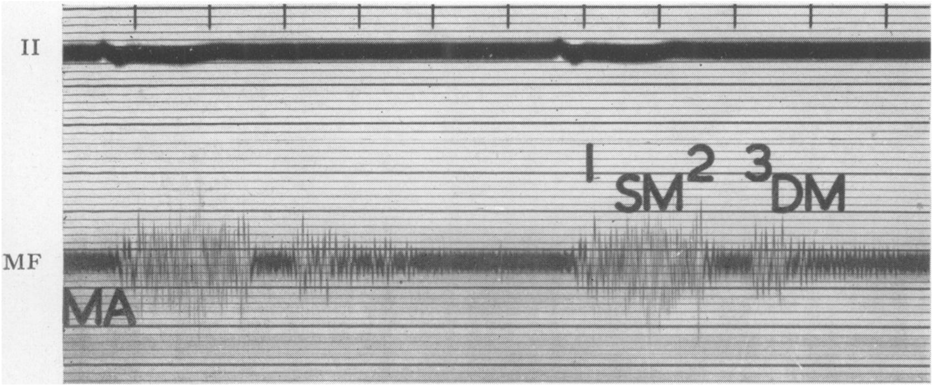

FIG. 12.—Mitral stenosis. The systolic murmur fills systole. A small third sound is followed by a mid-diastolic murmur.

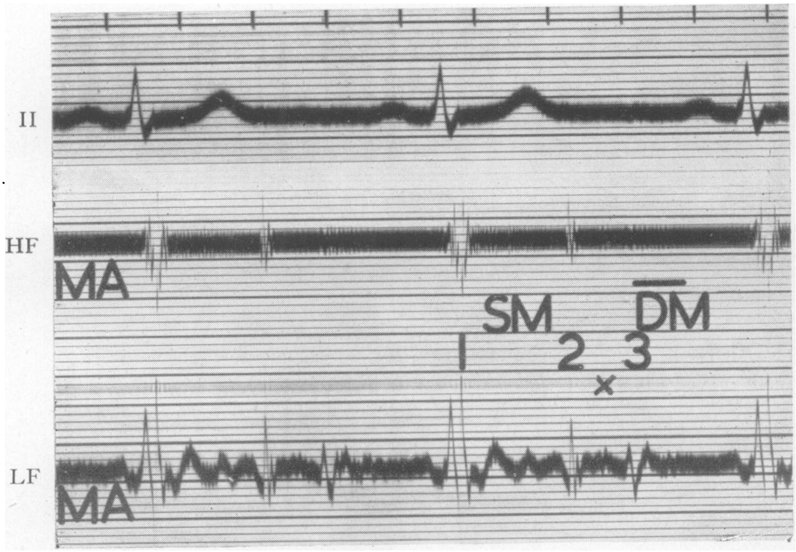

FIG. 13.—Doubtful mitral stenosis clinically and radiologically. A faint mid-diastolic murmur (DM) can be seen (HF record) following the third sound (LF record). The ' opening snap ' (X) can just be recognized.

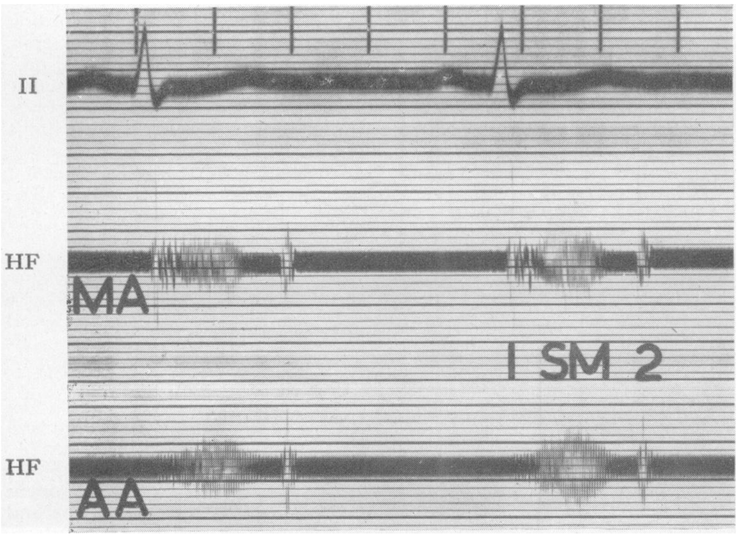

FIG. 14.—Aortic stenosis. The systolic murmur is characteristic in shape both in the mitral (MA) and aortic (AA) areas. The murmur is maximal in mid-systole and ends before the second sound.

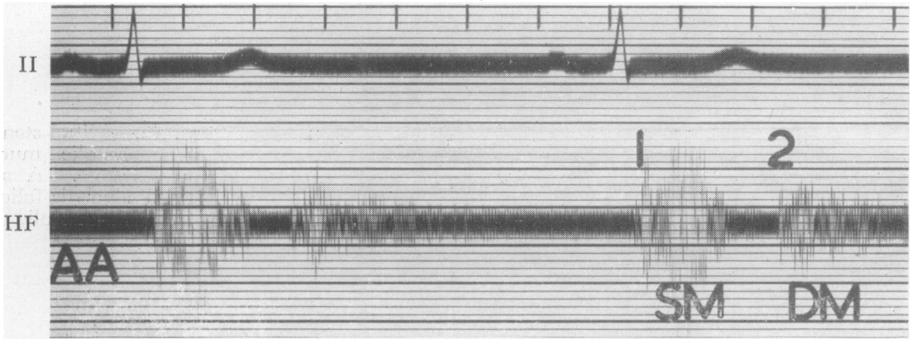

FIG. 15.—Syphilitic aortic valvular disease. Systolic and early diastolic murmurs.

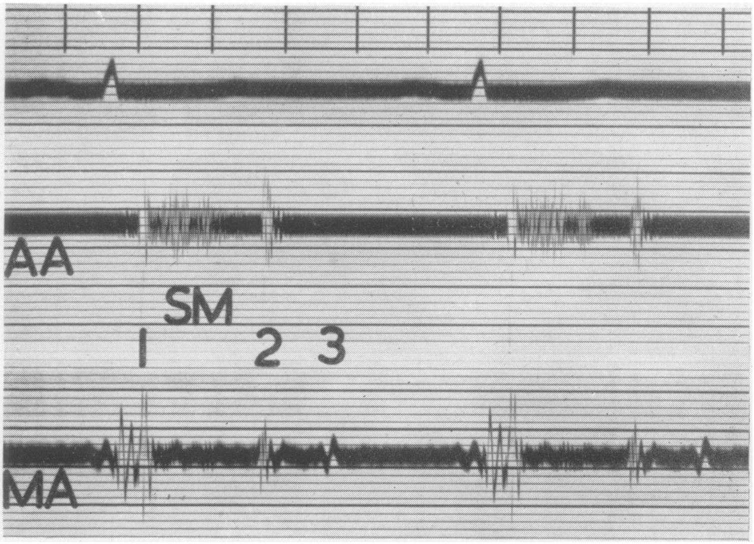

FIG. 16.—Coarctation of the aorta. Systolic murmur in the aortic area (AA).

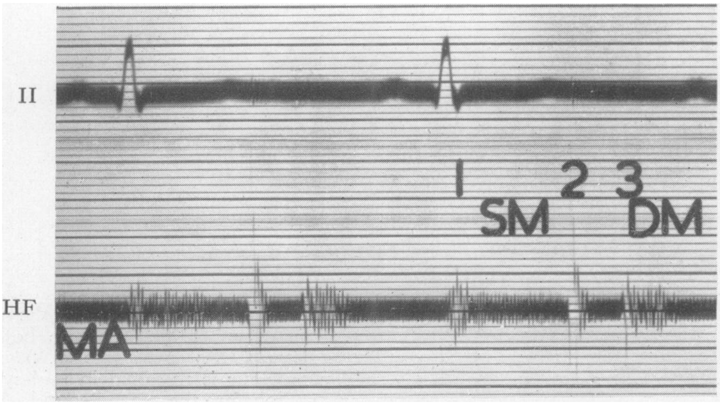

FIG. 17.—Coarctation of the aorta. Apical mid-diastolic murmur.

second phonocardiogram synchronous with the first, taken in a different area; the apical record will give information about mitral and aortic valve murmurs, the aortic second sound and the auricular and third heart sounds, while a record in the pulmonary area or at the lower left sternal edge will show more clearly the pulmonary second sound, the so-called opening snap of the mitral valve, and early diastolic murmurs. Synchronous low- and high-frequency phonocardiograms from the same area are of help in showing the sounds in relation to the murmurs. A sound with high-frequency components may be ' dissected ' in the high-frequency record to simulate a murmur, but a synchronous low-frequency record will prevent this misinterpretation.

The Normal Phonocardiogram

A normal phonocardiogram is shown in Fig. 3. The auricular sound is recorded in the low-frequency record and may be of sufficient intensity to be heard as a dull thud immediately preceding the first sound. It may produce the impression of splitting of the first heart sound which is a common finding in health, although this is usually due to splitting of the ventricular part of the first sound (Fig. 5). A faint systolic murmur may be recorded in the high-frequency record showing as fine vibrations in mid-systole. The second sound is best shown in the high-frequency record, which often shows splitting in the pulmonary area particularly if recorded during inspiration. A third sound occurring about 0.15 seconds after the second sound, on the descending limb of the V wave of the jugular tracing, can often be recorded in the low-frequency tracing. The third sound may not be heard, even though recorded, because the ear is less sensitive to its low pitch. It is more intense in younger subjects and may be heard best, as a dull thud, with the bell type of stethoscope lightly applied to the apex, with the subject lying on the left side. It has not been heard in a healthy person over the age of 40 years (Evans, 1948).

Heart Sounds

Triple heart rhythm. This may be differentiated on auscultation, though sometimes with difficulty, from splitting of the heart sounds which may occur in health or in bundle branch block. In splitting, the two components are close together, usually of the same high pitch, and best recorded in the high-frequency phonocardiogram; the exception to this is splitting of the first heart sound in health from a faintly audible low-pitched auricular sound. In triple rhythm the extra sound is separated farther from the first and second sounds and is of different quality. It is often low pitched and best recorded in the low-frequency phonocardiogram. The extra sound in triple rhythm is usually in diastole. It may be due to exaggeration of the third or of the auricular sound. In tachycardia the physiological third and auricular sounds, each by itself faint or inaudible, may coincide to produce a ' summation gallop ' (Fig. 6) which may be of no significance (Margolies and Wolferth, 1932). Nevertheless it is often associated with heart disease (Duchosal, 1935) and its significance must be based on the clinical findings. A third heart sound is often heard in healthy young people, but it is abnormal to hear it, though not to record it, in the middle aged or elderly. It may occur in cardiac infarction (Evans, 1949), as in the patient whose phonocardiogram is shown in Fig. 7, where a dull thud could be heard in mid-diastole which was shown in this record to be a third heart sound of much greater amplitude than is ever found in healthy adults. A third sound is usually found at the apex in mitral stenosis in addition to the so-called ' opening snap ' of the mitral valve which is best heard at the left sternal edge. An extra sound in diastole is often heard in constrictive pericarditis (Fig. 8). The auricular sound may be exaggerated in hypertensive heart disease, not necessarily with failure (Fig. 9). It is heard as splitting of the first sound, the first component of the split being low pitched. There is difficulty in differentiating it from physiological splitting. For the large auricular sound to become audible as an obvious gallop rhythm it is probably necessary for tachycardia to cause summation of the third and auricular sounds.

Systolic triple rhythm is only important because it is often mistaken for the more important type. It has no significance (Johnston, 1938; Wolferth and Margolies, 1940; Evans, 1943) and it can usually be recognized clinically, but with tachycardia a phonocardiogram may be necessary (Fig. 10).

Heart Murmurs

Mitral Stenosis. Doubtful cases of mitral valve disease form the biggest group referred for phonocardiography. A presystolic murmur may be suspected, or the third sound perhaps seems too long. There may only be a loud apical systolic murmur. The radiological findings may be within normal limits. The phonocardiogram may show that the auscultatory findings are merely due to an unusually clear auricular sound or, more often, the ventricular component of the first heart sound shows splitting. The third sound may be short and not followed by a murmur. In mitral stenosis there may be an auricular systolic (presystolic) murmur (Fig. 11). The first sound may be large with many high-frequency components. If there is a systolic murmur it usually fills systole between the first and second sounds (Fig. 12). About 0.10 seconds after the second sound, at the peak of the jugular C wave, there is an extra sound (Fig. 11), the so-called 'opening snap' of the mitral valve (Margolies and Wolferth, 1932). This sound is high pitched and may be loud at the lower left sternal edge or pulmonary area. It has similar quality though later than the second component of a split second sound, and is earlier than the third sound (Lian, 1933). It has been considered to be of value in the diagnosis of mitral stenosis but has been recorded as a small deflection in the absence of mitral valvular disease (Luisada, 1948). At the third heart sound the mid-diastolic murmur begins (Fig. 12) and is usually shown best in the medium-frequency phonocardiogram. We believe that this is the best auscultatory sign of mitral stenosis (Evans, 1949). It has never yet been absent from the sound tracing of any case of mitral stenosis recorded in this clinic. The faintest mid-diastolic murmur that we have yet recorded is shown in Fig. 13, the opening snap can just be recognized.

Aortic Valve Disease. In aortic stenosis (Fig. 14) the systolic murmur is of characteristic shape both in the aortic and mitral areas (Leatham, 1949). It may start a little late, it rises to a crescendo in mid-systole and it ends or is much diminished by the second sound which may, or may not, be absent; there is often a diastolic murmur though there may be none. The systolic murmur differs in shape from the systolic murmur in mitral valve disease which fills systole (Fig. 12); this should help in the recognition of aortic stenosis where the systolic murmur is loud at the apex. A murmur of this shape from the aortic valve is not specific to stenosis for it may be found in syphilitic aortic incompetence (Fig. 15), and in coarctation of the aorta (Fig. 16), where a diastolic murmur may also be recorded (Fig. 17).

The diastolic murmur in aortic valve disease starts immediately after the second sound, and is of higher frequency than the diastolic murmur of mitral stenosis. It often rises to a crescendo shortly after the second sound (Wells, 1949) and then diminishes later in diastole. It may terminate in low frequency vibrations which increase in size before the next first sound, and an additional diagnosis of mitral stenosis was thus suggested in a patient with a ruptured aortic cusp whose phonocardiogram is shown in Fig. 18; at necropsy there was endocarditis on a bicuspid aortic valve with a ruptured cusp, but no mitral stenosis and the auscultatory and graphic findings may have been due to the Austin Flint phenomenon. Mitral stenosis in addition to aortic incompetence can usually be recognized by comparing apical sound tracings with those from the left sternal edge. The aortic diastolic murmur is of high frequency, maximal soon after the second sound at the left sternal edge, and it gradually fades away, while the apical record will show a murmur of low frequency starting at the third sound, or a presystolic (auricular systolic) murmur (Fig. 19).

Innocent Systolic Murmur. The murmur in late systole is usually innocent particularly if early systole is almost free from vibration as in Fig. 20. This healthy man, aged 61 years, had a murmur all his life; on cardioscopy his heart appeared small and normal. Other innocent systolic murmurs may be mainly in mid-systole ending before the second sound (Fig. 3). In anaemia the systolic murmur in the pulmonary area is of similar shape though more intense (Fig. 21).

Congenital Heart Disease. In pulmonary stenosis the systolic murmur extends to the second sound (Fig. 22) and differs in shape from the systolic murmur in aortic stenosis.

In patent ductus arteriosus the phonocardiogram shows a continuous murmur which is maximal in late systole and at the second sound; a typical example is shown in Fig. 23. In Fig. 24 the murmur is of similar shape but has ceased by mid-diastole; a small ductus was found at operation. The systolic and diastolic murmurs in a patient with atrial septal defect are shown in Fig. 25; they had been mistaken for the continuous murmur of patent ductus arteriosus, admittedly atypical, but the phonocardiogram excluded this diagnosis since the murmur was absent in late systole.

Conclusions

Good apparatus and extremely careful technique are required to obtain records of murmurs of adequate size with a clear base line and without artefacts.

The relative insensitivity of the human ear to low-pitched sounds and murmurs makes graphic recording of these lower frequencies of value; thus phonocardiography can be of help in the diagnosis of mitral stenosis and in distinguishing the various types of triple heart rhythm.

Human hearing is very sensitive to the higher frequencies, and murmurs such as the early diastolic murmur of aortic incompetence, can sometimes be heard by a practised observer better than they can be recorded with present-day microphone-amplifier technique.

Phonocardiography can be of diagnostic value in showing the relationship of sounds to murmurs. Thus it may be possible to distinguish the systolic murmur of aortic stenosis and of some innocent murmurs from that of mitral valve disease.

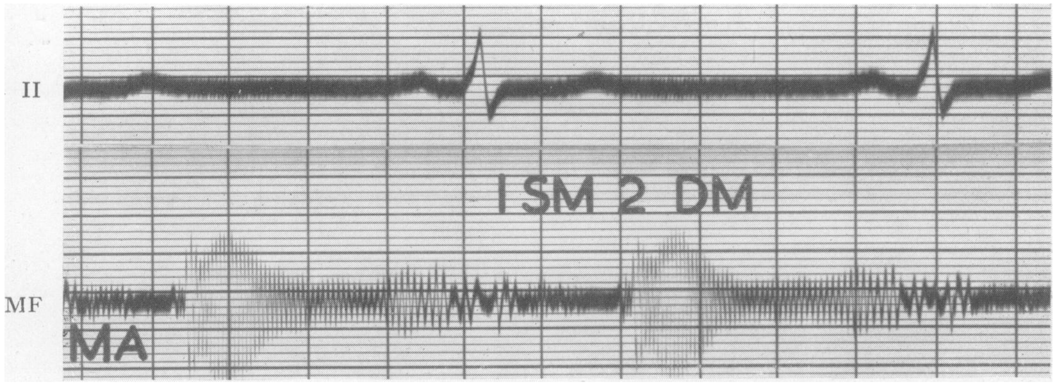

FIG. 18.—Ruptured aortic cusp. Apical recording. No additional mitral stenosis at autopsy.

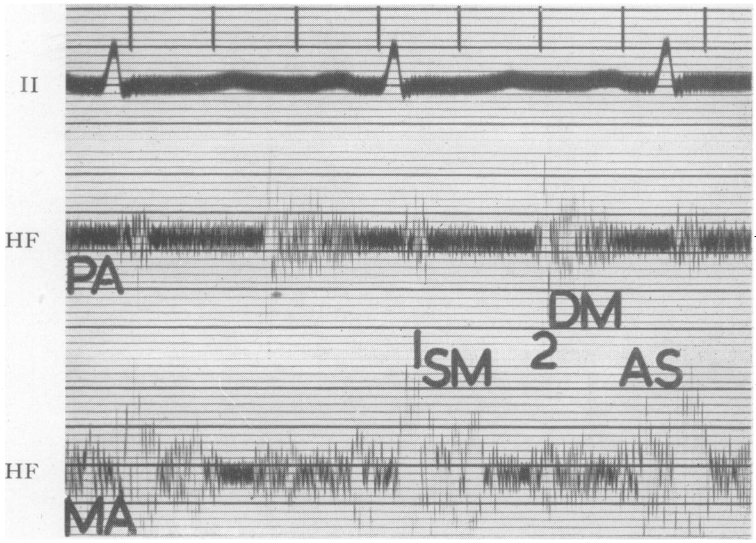

FIG. 19.—Mitral stenosis and aortic incompetence. The tracing from the pulmonary area (PA) shows the diastolic murmur of aortic incompetence maximal in early diastole. At the apex (MA) the diastolic murmur is maximal in auricular systole (AS), indicating additional mitral stenosis.

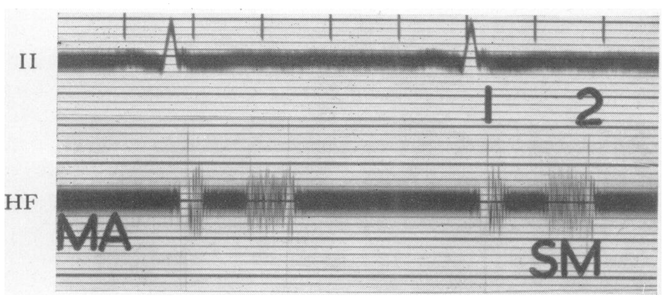

FIG. 20.—Innocent late systolic murmur.

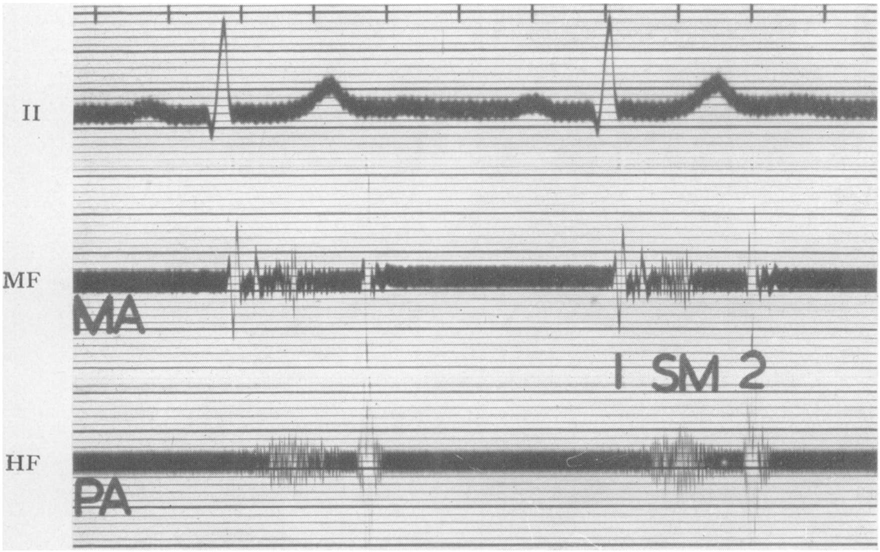

FIG. 21—Anaemia (Hb. 60 per cent.). Mid-systolic murmur in pulmonary area (PA).

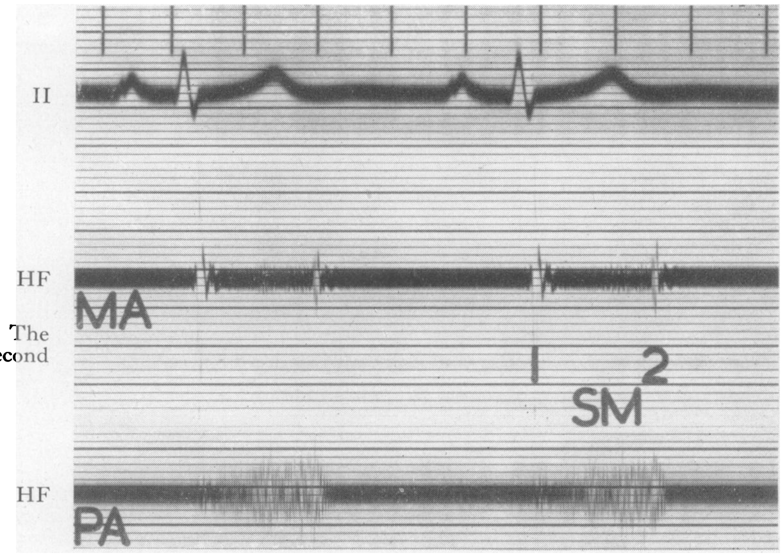

FIG. 22.—Pulmonary stenosis. The systolic murmur reaches the second sound.

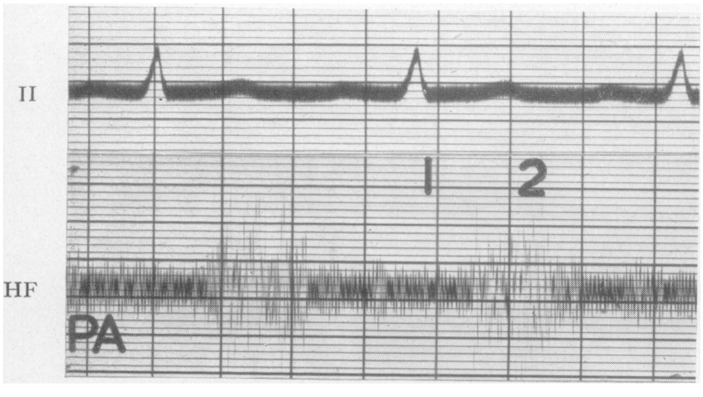

FIG. 23.—Patent ductus arteriosus. Typical continuous murmur maximal in late systole and early diastole.

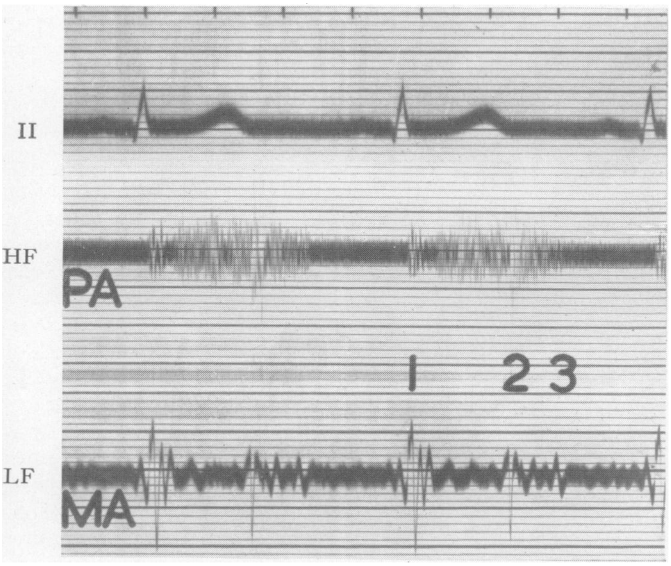

FIG. 24.—Small patent ductus arteriosus at opera-tion.

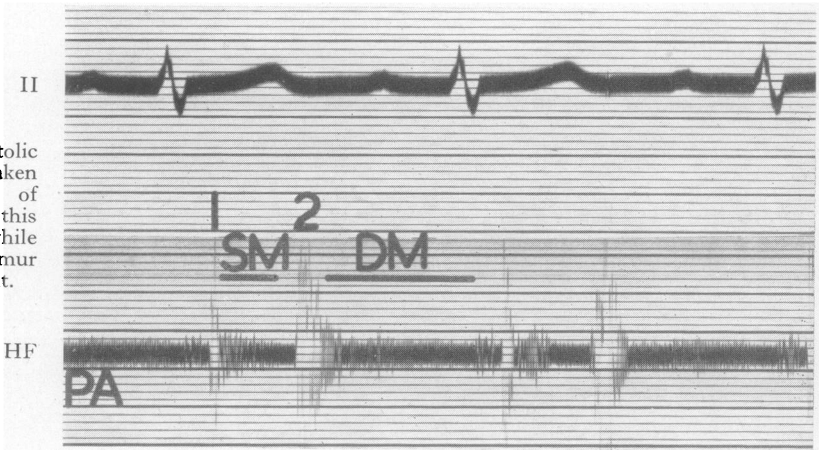

FIG. 25.—Atrial septal defect. Systolic and diastolic murmurs, mistaken for the continuous murmur of patent ductus arteriosus. In this record late systole is clear, while in patent ductus the murmur should be maximal at this point.

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