Correlation of Heart Sounds and Murmurs with Pressure During Left Heart Catheterization

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The development of a method\textsuperscript{1, 2} to obtain triple equisensitive pressure pulses in the left atrium, left ventricle and aorta in the heart exposed at operation, and to display them together, with the same baseline, made it possible to visualize the mechanical events of the cardiac cycle and to measure their phases with great accuracy. It was apparent that the method lent itself naturally to a study of the genesis of heart sounds and murmurs, provided it was possible to record the sounds simultaneously and with sufficient fidelity.

Methods

An oscillographic recorder was designed* utilizing a single-gun electron tube, in which the beam is split into 8 parts by an electron switch operating at the rate of 26,000 per second. This unit contains an electrocardiography channel, two phonocardiography channels, three pressure channels and finally two “pressure difference channels” by means of which continuous pressure differences between 2 adjacent channels may be obtained by electronic subtraction of the outputs of the 2 pressure transducers involved.

With this recorder, it is possible to obtain 8 parameters simultaneously without significant parallax error. The only timing error lies in the transmission delay of the pressure events through the plastic tubing-stopeck-pressure transducer system, which we have found on a previous occasion\textsuperscript{3} and have recently verified to be no greater than 0.005 or 0.006 seconds. When our records are taken at a paper speed of 50 mm. per second this delay may be ignored but at the fast speed of 150 mm. per second it must be taken into account.

Triple equisensitive pressure pulses have been obtained in the human heart during left heart catheterization by the transbronchial route.\textsuperscript{4} Whenever possible fine polyethylene catheters have been left in place in the left atrium and left ventricle, and the bronchoscope removed. Central aortic pulses have been obtained simultaneously by catheterization with a fine vinyl plastic catheter through the right brachial artery. Placement of the latter close to the aortic valve has often proven difficult, however, the fidelity of the system may easily be verified, as any error in placement of the catheter tip becomes apparent in the tracing as a slight phase difference in the pressure pulses. Damping and other artifacts are similarly exposed.

Whenever possible right heart catheterization has been performed simultaneously and phonocardiograms recorded together with pressure events on the right side of the heart as well. Heart sound records from the chest wall have been obtained by means of the Sanborn dynamic or the Peiker crystal microphones, with the aid of passband filters. Conditions during the left heart catheterizations have not been ideal from the standpoint of heart sound recording. This accounts for some of the deficiencies apparent in our phonocardiograms.

Our series, which amounts to 50 cases at this time (February 1957), consists of adult patients with acquired mitral or aortic valve lesions who are candidates for cardiac surgery.

Results

Results, which are here reported in preliminary form, may perhaps be best illustrated by reference to a group of representative tracings.

Figures 1 and 2 were taken several seconds apart from the same patient, the first at a paper speed of 50 mm. per second and the second at 150 mm. per second. In figure 1 note that the second beat is a ventricular premature contraction. Although it is not possible to localize the ectopic focus from lead II of the electrocardiogram, the time interval from Q2 to left ventricular systole is about the same in the premature beat as in the nor-
mally conducted beats, suggesting that the ectopic focus is in the left ventricle. The premature contraction is barely sufficient to open the aortic valve.

Note that the first heart sound is of shorter duration and lesser intensity in the premature beat, which may be explained by the small quantity of blood ejected.

In the first beat, the second heart sound coincides exactly with the dicrotic notch of the aortic pressure pulse and the closure of the aortic valve. This is also true of the premature beat. (The phase of reduced ejection of the left ventricle in the premature beat is slightly distorted.) A sound of high intensity which occurs at the pulmonic area shortly after the peak of ventricular systole in the third beat, does not coincide with any of the pressure events on the left side of the heart. That this is an artifact is attested to by its absence in the remainder of the record.

In figure 2 taken at fast speed, the correlation of the heart sounds with the events of the cycle on the left side of the heart is more readily apparent. This photograph also demonstrates, with greater clarity, the continuous pressure difference across the stenotic mitral valve (here labeled "L.A. to L.V. gradient"). It is basically M-shaped. Although the low pitched diastolic murmur of mitral stenosis is

Fig. 1 Top. Electric, mechanical and acoustic events in a patient with mitral stenosis, recorded during left heart catheterization. Paper speed equals 50 mm. per second; time lines 0.04 seconds.

Fig. 2 Bottom. The same patient as in figure 1, recorded a few seconds later. Paper speed equals 150 mm. per second; time lines 0.02 seconds.
not well depicted in this illustration, it is apparent (and it is also a well-known clinical observation) that the murmur is loudest in early and late diastole. This corresponds to the periods of maximum pressure difference and presumably maximum blood flow across the valve.

Figure 3, from a patient with aortic stenosis, shows several characteristic features. The ventricular pressure pulse has a peaked contour (similar to that found in the right ventricle in pulmonic valvular stenosis). The aortic pressure pulse has a slow upstroke, delayed peak and poorly defined dicrotic notch. The continuous pressure difference across the aortic valve ("ejection gradient") is shaped like an inverted V. In most beats in this case the maximum pressure difference precedes the peak of ventricular pressure.

The aortic systolic murmur begins a short time after the first sound; the latent period representing part of the time interval between the beginning of ventricular systole and the beginning of ejection (isometric contraction phase). The murmur demonstrates the characteristic diamond shape, which in each heart beat may be seen to correlate closely both in time and intensity with the continuous pressure difference across the valve. From beat to beat, the intensity of the murmur also varies directly with the height of the pressure difference.

The second sound, visible on the aortic phonocardiogram, apparently arises from the pulmonic valve, as it occurs much later than the closure of the aortic valve as determined by the cross-over point of ventricular and aortic pressures during diastole.

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