Origin of Heart Sounds as Elucidated by Analysis of the Sequence of Cardiodynamic Events

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The genesis of the first heart sound has been the subject of considerable speculation because of its simultaneity both with mitral valve closure and with the onset of left ventricular contraction. In the presence of mitral stenosis, however, it has been pointed out that the presence of a pressure gradient between the left atrium and left ventricle at the end of diastole results in temporal dissociation of the onset of left ventricular contraction and mitral valve closure. The latter event cannot take place until the left ventricular pressure reaches the level of the elevated left atrial pressure. The time interval between the onset of left ventricular contraction and mitral valve closure ranged from 0.01 to 0.04 seconds in 7 patients with mitral stenosis. This finding was of interest in light of the phonocardiographic observations on patients with mitral stenosis which demonstrated that the first heart sound was delayed by similar intervals when it was related to the electrocardiogram.

Further, it was found that the duration of diastole was inversely related to the end-diastolic left atrioventricular pressure gradient, but was directly related to the rate of pressure rise during the subsequent ventricular contraction. Similarly, the time interval between the onset of ventricular depolarization and the first heart sound in patients with mitral stenosis has been noted to be inversely related to the duration of the preceding diastole. While such observations suggested that the first heart sound results from mitral valve closure, not from ventricular contraction, conclusive evidence for this would require the simultaneous recording of heart sounds with left atrial and left ventricular pressure pulses.

Left heart pressures were recorded by means of transbronchial left heart catheterization. The phonocardiograms were recorded simultaneously utilizing a logarithmic filter and a cathode-ray photographic recorder at a paper speed of 25 or 75 mm. per second, generally the latter. Fourteen patients without mitral stenosis, who did not have an end-diastolic atrioventricular pressure gradient, and 11 patients with mitral stenosis who had such a gradient were studied.

Figure 1 shows results which are representative of those obtained in all patients without mitral stenosis. The first heart sound began simultaneously with both the onset of left ventricular contraction, as indicated by the beginning of the left ventricular pressure ascent, and with mitral valve closure, as indicated by the peak of the c wave of the left atrial pressure tracing. In contrast, in all patients with mitral stenosis the first vibrations of the first heart sound were not coincident with the onset of left ventricular contraction; they occurred when the left ventricular pressure reached the level of the elevated left atrial pressure, at which time the mitral valve closed and the left atrial c wave was inscribed (fig. 2 and 3). These observations indicate that the opening vibrations of the first heart sound result from closure of the mitral valve, rather than from left ventricular contraction.

However, as has been noted above, in the absence of mitral or tricuspid stenosis, atrioventricular valve closure occurs coincidentally with the onset of ventricular contraction. Splitting of the first heart sound would then be related to the slight asynchrony in the onset of ventricular contraction which normally occurs. Figure 4 represents the average of the results obtained in 13 individuals without cardiac disease and indicates that the onset of left ventricular contraction precedes the onset of right ventricular contrac-

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Fig. 1 Top. Simultaneous phonocardiogram and left heart pressure pulses in a patient with aortic stenosis but without mitral stenosis. S₁ and S₂ represent the two heart sounds. L.A. = left atrium. L.V. = left ventricle. Ao. = central aorta.

Fig. 2 Middle. Simultaneous phonocardiogram and left ventricular (left) and left atrial (right) pressures. Symbols same as figure 1.

Fig. 3 Bottom. Simultaneous phonocardiogram and left ventricular (left) and left atrial (right) pressures. Symbols same as figure 1.
tion by a brief interval. It is also of interest that while the left ventricle begins to contract before the right ventricle, its ejection commences later. On the other hand, left ventricular ejection normally ends before right ventricular ejection (fig. 4) and the normal splitting of the second heart sound therefore consists of the aortic component followed by the pulmonic component.

It has been observed that there is no consistent delay in the onset of left ventricular contraction, but there is prolongation of left ventricular ejection in patients with the electrocardiographic configuration of complete left bundle-branch block. This correlates with the phonocardiographic observation of a single first heart sound, but a paradoxically split second heart sound, with a delayed aortic component, in many of these patients.

The duration of ventricular ejection is also prolonged by an augmentation of stroke volume or a marked increase in the pressure against which the ventricle ejects. These observations afford an explanation for the abnormally widened splitting of the second heart sound in patients with atrial septal defect or pulmonic stenosis in whom the pulmonic component is delayed, and in patients with patent ductus arteriosus or aortic stenosis in whom the aortic component is delayed.

**SUMMARY**

Evidence for the valvular origin of the first heart sound was obtained by simultaneous phonocardiograms and pressure pulses from the left atrium and left ventricle in patients with mitral stenosis. It was consistently observed that the first heart sound begins at the time of mitral valve closure, significantly after the onset of left ventricular contraction. Hemodynamic observations which explain the splitting of heart sounds in the normal and in diseased states were briefly reviewed.

**SUMMARIO IN INTERLINGUA**

Le prova del origine valvular del prime sono cardio esseva obtenite per medio de phonocardiogrammas registrate simultaneamente con determinaciones del pulsos de presion ab le atrio sinistre e le ventriculo sinistre in patientes co stenosin mitral. Esseva observate uniformemente que le prime sono cardio comenceva al tempore del clausion del valvula mitral, significativamente plus tarde que le declaration del contraction sinistro-ventricular. Es presentate un breve revista de observationes hemodynamic que expica le fission de sons cardio in status normal e pathologic.

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