Hemodynamic-Phonocardiographic Correlations of the Fourth Heart Sound in Aortic Stenosis

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In a recent study on the hemodynamic function of the left atrium, an analysis was carried out of the atrial contraction (a) waves in left atrial and left ventricular pressure pulses of patients with a variety of cardiovascular abnormalities and it was noted that atrial contraction waves were particularly prominent in patients with obstruction to left ventricular outflow. This observation directed our attention to the auscultatory and phonocardiographic findings in these patients. In particular, it seemed of interest to determine whether the increased force of atrial contraction in patients with aortic stenosis is reflected in the presence of an atrial or fourth heart sound, and conversely whether the presence or absence of an atrial sound in patients with aortic stenosis could be correlated hemodynamically with the height of the “a” wave in the left atrial pressure pulse and with the severity of obstruction to left ventricular emptying.

Methods

A total of 46 patients with aortic stenosis was included in this study. Valvular obstruction was present in 43 patients while the remaining three patients had congenital subaortic stenosis of the discrete fibrous type. Twenty-four of the patients with valvular stenosis were considered to have the acquired form of the disease, whereas it was thought to be congenital in the other 19. The 46 patients ranged in age from 13 to 62, with an average age of 32 years. In view of the frequency of the occurrence of a fourth heart sound in normal children, in patients with prolongation of the P-R interval of the electrocardiogram, and in patients with idiopathic hypertrophic subaortic stenosis, regardless of the severity of obstruction, patients falling into these three categories were specifically excluded from this analysis. Other than possessing left atrial and ventricular pressure pulses and phonocardiograms that were of adequate quality for analysis, the 46 patients were not selected but represented consecutive patients with aortic stenosis studied in this clinic. Patients with aortic regurgitation in association with aortic stenosis were excluded from this study.

Left atrial and left ventricular pressures were recorded by the transseptal technic. In the three patients with subvalvular stenosis the obstruction was localized by retrograde left ventricular catheterization. The lesion was defined by selective left ventricular angiocardiography in 26 patients, and the diagnosis was confirmed at open operation in 24 of the 46 patients and at postmortem examination in two of them.

The phonocardiographic tracings were recorded with a Sanborn Twin-Beam apparatus, with use of a Sanborn 62-500 amplifier at a paper speed of 75 mm. per second. The fourth heart sound was identified as a distinct, low-pitched vibration which was preceded and followed by a steady baseline, and which followed the onset of the P wave by at least 0.07 second and preceded the R wave.

Results

A fourth heart sound was recorded in 30 of the 46 patients with aortic stenosis. This sound followed the onset of the P wave by 0.07 to 0.20 second (average, 0.078 second). Typical tracings are reproduced in figure 1.

Fourth heart sounds were heard predominantly in patients with prominent “a” waves in the left atrial pressure pulse, and were usually absent in patients with less prominent “a” wave peaks. Thus a fourth heart sound was recorded in all 27 patients in whom the “a” wave peak exceeded 13 mm. Hg and in only three of the 19 patients in whom the “a” wave peak did not exceed this value (fig. 2). Two of these three patients were boys 14 and 15 years of age, respectively, with congenital aortic stenosis; the third was a 53-year-old man with calcific, acquired, aortic stenosis. In two of these three patients the “a” wave peak equaled 12 mm. Hg.
The presence of the fourth heart sound correlated equally well with the level of the left ventricular end-diastolic pressure. It could be recorded in all 28 patients with a left ventricular end-diastolic pressure of 12 mm. Hg or greater, but in only two patients with left ventricular end-diastolic pressures of less than 12 mm. Hg; the latter were the two boys with congenital aortic stenosis mentioned above (fig. 3).

Twenty-eight of the 29 patients with left ventricular systolic pressures of 160 mm. Hg or greater had fourth heart sounds, whereas only two of the 17 patients with pressures less than 160 mm. Hg (the same two exceptions) exhibited fourth sounds (fig. 4). When the peak systolic pressure gradient between the left ventricle and brachial artery was correlated with the presence or absence of the fourth heart sound, it was observed that the sound was present in all 29 patients with gradients of 75 mm. Hg or more. On the other hand, only one of the 17 patients with a gradient less than 75 mm. Hg exhibited a fourth heart sound (fig. 5). The latter was the 53-year-old man with calcific aortic stenosis and a peak systolic gradient of 35 mm. Hg, mentioned above, who may have had associated coronary artery disease, which accounted for this sound.

Discussion

Charcey in 1838 was the first to describe the sound now designated as the fourth heart sound and suggested the possibility that it
was related to atrial contraction.\textsuperscript{10} This hypothesis was strengthened by Clark,\textsuperscript{11} who in 1858 reported that in a criminal a single heart sound was audible 90 minutes following execution. On opening the chest, "the ventricles were seen to be inert, but the right auricle was contracting regularly at 80 per minute," and was evidently responsible for the sound.

An atrial sound is frequently heard in normal children and in patients of all ages with delays in atrioventricular conduction. In the latter circumstance the abnormal temporal relationship between atrial and ventricular systole probably makes a sound audible that would otherwise have been obscured by the first heart sound. It is generally accepted that the fourth heart sound is frequently heard in patients in whom the peak systolic pressure developed by the ventricle is elevated, e.g., in patients with systemic or pulmonary hypertension,\textsuperscript{5, 6, 12-15} coarctation of the aorta,\textsuperscript{16} pulmonic stenosis, and aortic stenosis.\textsuperscript{6, 14-17} However, it may also be heard

\textit{Figure 1B}

\textit{Representative phonocardiogram in a patient with acquired aortic stenosis. Symbols same as in figure 1A.}
FOURTH HEART SOUND IN AORTIC STENOSIS

Figure 2
Relationship between left atrial "a" wave peak pressure and the presence or absence of a fourth heart sound. Circles represent data from patients with valvular stenosis; squares, data from patients with discrete subvalvular stenosis.

Figure 3
Relationship between left ventricular end-diastolic pressure (LVED) and the presence or absence of a fourth heart sound. Symbols same as in figure 2.

in patients with ischemic heart disease, and in patients with various forms of cardiomyopathy, as well as in occasional adults without other evidence of organic heart disease.

In the past, the atrial heart sound or pre-systolic gallop has been considered of little diagnostic or prognostic value\(^{18,19}\) in distinction to the protodiastolic gallop. Ongley and his associates\(^ {20}\) however, recently suggested that elevated atrial pressure and atrial hypertrophy may be responsible for this sound. These authors also mentioned that aortic stenosis may result in left atrial hypertrophy and therefore in a fourth heart sound. Weitzman\(^ {15}\) however, reported the presence of a fourth sound in only four of a total of 46 patients with aortic valve disease. He concluded that the sound was evidence of ven-
The vibrations of the fourth heart sound may be divided into two components. The earlier, low-frequency, inaudible vibrations are synchronous with and presumably result from left atrial contraction. The later, higher frequency, somewhat louder, and therefore audible vibrations occur during the phase of ventricular filling which results from atrial contraction, and probably originate from the ventricle.

The present study was carried out on a series of 46 patients with aortic stenosis in whom the severity of obstruction varied considerably. A fourth heart sound was recorded with regularity in the patients with moderate or severe obstruction (left ventricular-brachial artery systolic gradients exceeding 75

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**Figure 4**

Relationship between left ventricular (LV) systolic pressure and the presence or absence of a fourth heart sound. Symbols same as in figure 2.

**Figure 5**

Relationship between peak systolic left ventricular-brachial artery (LV-BA) pressure gradient and the presence or absence of a fourth heart sound. Symbols same as in figure 2.
FOURTH HEART SOUND IN AORTIC STENOSIS

mm. Hg or left ventricular systolic pressures above 160 mm. Hg). It was present in only an occasional patient with hemodynamic evidence of relatively mild obstruction (figs. 4 and 5). The patients with moderate or severe degrees of obstruction to left ventricular outflow tend to have elevation of their left ventricular end-diastolic pressures as well. It is likely that the thickened left ventricular wall, with the resultant decrease in the compliance of the ventricle during diastole, is at least in part responsible for this elevation of the end-diastolic pressure. The correlation between the fourth heart sound and the level of the left ventricular end-diastolic pressure (fig. 3) is thus of interest, since it may reflect a change in the mechanical characteristics of the left ventricular wall, which makes it more likely to emit a sound during filling from the atrium. As already noted, however, atrial sounds may also frequently be present in patients with thickening of the ventricular wall unassociated with obstruction to ventricular outflow. It therefore seems likely that the presence of the fourth heart sound reflects the combination of vigorous atrial contraction and a thickened left ventricular wall. The occurrence of a fourth heart sound in aortic stenosis reflects the severity of the process only insofar as atrial systole is more forceful and ventricular hypertrophy more marked in patients with severe obstruction.

It has recently been demonstrated that the left atrium serves an important hemodynamic function in patients with elevated left ventricular end-diastolic pressures and sinus rhythm. In such patients atrial contraction is vigorous and prolonged, and, as a result, the left ventricular end-diastolic pressure is elevated, while mean left atrial pressure is maintained at a significantly lower level. The clinically beneficial effects of atrial systole in such patients have been discussed previously. The vigorous atrial contraction in patients with severe aortic stenosis is reflected in the tall "a" wave peaks in their left atrial pressure pulses. In these patients, in whom there is hemodynamic evidence of forceful atrial contraction, a fourth heart sound is usually present, and the apex cardiogram usually exhibits a prominent outward pulsation during atrial systole, presumably from the large volume of blood delivered into the left ventricle by atrial systole (fig. 1). These findings correlate well with the observations of Sarnoff and his collaborators, who have recently provided important hemodynamic evidence for the important role played by the atrium in ventricular filling.

Summary

The hemodynamic findings obtained at left heart catheterization in 46 patients with aortic stenosis of varying severity were correlated with the presence of a fourth heart sound determined phonocardiographically. From this correlation it may be concluded that, when a fourth heart sound is detectable in an adult patient with aortic stenosis, it usually indicates that the obstruction is severe (gradient exceeding 70 mm. Hg, left ventricular systolic pressure above 160 mm. Hg), that the left ventricular end-diastolic pressure is elevated (12 mm. Hg or above), and that the "a" wave in the left atrial pressure pulse is tall (14 mm. Hg or higher). The sound probably results from a forceful atrial contraction that forces a large volume of blood into a ventricle, the walls of which have been rendered less compliant than normal by the presence of left ventricular hypertrophy. The presence of this sound is easily detectable at the bedside by auscultation, and its presence may be confirmed by phonocardiography. The potential clinical usefulness of this physical finding, the presence of which is capable of separating patients with moderate or severe obstruction from those with mild obstruction, is self-evident.

References


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Religio Medici

To wiser desires it is satisfaction enough to deserve, though not enjoy, the favours of Fortune: let Providence provide for Fools. 'Tis not partiality, but equity in GOD, Who deals with us but as our natural Parents: those that are able of Body and Mind He leaves to their deserts; to those of weaker merits He imparts a larger portion, and pieces out the defect of one by the excess of the other. Thus have we no just quarrel with Nature for leaving us naked; or to envy the Horns, Hoofs, Skins and Furs of other Creatures, being provided with Reason, that can supply them all.—Sir Thomas Browne. Religio Medici. Edited by W. A. Greenhill, M.D. London, MacMillan and Co., Ltd., 1950, p. 32.
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