The Phonocardiographic Differentiation of Pulmonic and Aortic Insufficiency

By Robert H. Schwab, M.D., and John H. Killough, Ph.D., M.D.

Patients presenting with high-pitched diastolic decrescendo murmurs along the left sternal border may have insufficiency of either the aortic or pulmonary semilunar valve. If the peripheral pulses are those of aortic insufficiency in type, the source of the diastolic murmur is located easily. However, in the absence of both the peripheral physical signs of aortic insufficiency and the electrocardiographic evidence of left ventricular hypertrophy, the insufficient semilunar valve is less easily identified.

Congenital aortic insufficiency, a rare anomaly, may not be associated with either a low diastolic pressure, bounding pulse, or electrocardiographic evidence of left ventricular hypertrophy. Similarly, patients with isolated pulmonic insufficiency, also a rare anomaly, may not present with electrocardiographic evidence of right ventricular hypertrophy. In each of these conditions, the clinical identification of the involved valve may be difficult. Patients with mitral stenosis frequently have a basal diastolic decrescendo murmur and, when there is laboratory and clinical evidence of pulmonary hypertension, the murmur generally is considered to be a Graham Steell murmur of functional pulmonic insufficiency. However, recent studies by Brest et al. and Runco et al. have demonstrated by retrograde aortography and cardiac catheterization that in the majority of these patients with mitral stenosis and pulmonary hypertension the diastolic decrescendo murmur is due to a moderate degree of aortic incompetence.

Theoretically, through the technic of phonocardiography, it should be possible to distinguish the diastolic decrescendo murmur of aortic insufficiency from that of pulmonic insufficiency by observing the relation of the diastolic murmur to the aortic and pulmonic components of the second heart sound. In normal individuals, the pulmonic component of the second sound follows the aortic component by 0.03 to 0.06 second in inspiration and 0.02 to 0.04 second in expiration. If the diastolic murmur begins immediately with the aortic component of the second sound, insufficiency of the aortic valve would be expected to be responsible for the murmur. However, if the aortic component of the second sound is followed by a silent interval of 0.02 to 0.06 second and then the pulmonic component occurs and is followed by a diastolic murmur, the source of the murmur should be insufficiency of the pulmonic valve (fig. 1).

Until recently technical difficulties have prevented the practical application of these considerations. The diastolic murmurs of semilunar valve insufficiency have been extremely difficult to record phonocardiographically although audible with the stethoscope. Low-frequency components of the heart sounds blurred the interval between the two components of the second sound, thus preventing the accurate observation of the relationship of the murmur to the components of the second sound. Employing phonocardiographic apparatus equipped with high-frequency filters, even faint diastolic decrescendo murmurs may now be recorded. The low-frequency vibrations, which previously obscured the interlude between the aortic and pulmonic components of the second heart sound, usually can be elim-
PULMONIC AND AORTIC INSUFFICIENCY

Figure 1

The diastolic murmur of aortic insufficiency (upper) begins with the aortic component of the second heart sound and is decrescendo in configuration when the high-frequency filter is used. The murmur of pulmonic insufficiency (lower) begins (a) either with the pulmonic component of the second sound or (b) shortly after the pulmonic component. The high-frequency filter reveals its configuration to be crescendo-decrescendo. D.M., diastolic murmur; S1, first heart sound; A2, aortic component of second heart sound; P2, pulmonic component of second heart sound.

method

A Sanborn Twin-Beam Unit operated at a paper speed of 75 millimeters per second was used as the recording device. The logarithmic filter was replaced with a 350-1700B Sanborn high-frequency filter amplifier unit. A 400-unit frequency-response filter was utilized with a 350-1700-C10 Contact microphone. A no. 374 Sanborn pulse-wave attachment was utilized to record an indirect carotid pulse simultaneously with the phonocardiogram.

The aortic component of the second sound precedes the dicrotic notch of the carotid pulse by 0.03 second due to an inherent delay in the pulse-pressure recording apparatus. To evaluate the validity of this phonocardiographic technic, patients were deliberately selected in whom the diagnosis was either already established or in whom it was anticipated that there would be no difficulty in determining the exact anatomic diagnosis.

Case Reports

Case 1

Patient W. M. was a 47-year-old Negro man with a systemic blood pressure of 140/50 mm. Hg. The peripheral pulses were the bounding type characteristic of aortic insufficiency. The electrocardiogram displayed left ventricular hypertrophy and strain. A loud grade-IV/VI high-pitched, diastolic decrescendo murmur was auscultated along the left parasternal border.

Comment

The phonocardiogram (fig. 2a) revealed a diastolic decrescendo murmur that began immediately with the aortic component of the second sound as identified by the carotid pulse. The murmur passed through the pulmonic component of the second sound and partially obscured it. The phonocardiographic pattern is that of aortic insufficiency, and this diagnosis was confirmed at surgery. There was no evidence of mitral stenosis or pulmonic insufficiency. The diseased aortic valve was replaced with a Starr-Edwards prosthesis and after surgery the diastolic decrescendo murmur was no longer audible (fig. 2b).

Case 2

This 12-year-old Negro boy, patient D. M., presented with a systemic blood pressure of 100/60 mm. Hg. Examination of the precordium revealed a vigorous left parasternal systolic heave suggestive of right ventricular hypertrophy. A loud, grade-V/VI, harsh ejection murmur was heard best in the second left intercostal space along the parasternal border. A loud grade-IV/ VI blowing diastolic high-pitched "decrescendo" murmur was auscultated along the left parasternal border. The electrocardiogram demonstrated right ventricular hypertrophy and strain. Right heart catheterization indicated a bidirectional shunt at the ventricular level. The right ventricular pressure was 103/4 mm. Hg and the pulmonary artery pressure was 43/12 mm. Hg. A venous angiocardiogram demonstrated a narrowed pulmonic valve with marked poststenotic dilatation of the pulmonary artery. Faint opacification of the aorta occurred prematurely. The diagnosis was pulmonic stenosis with a ventricular septal defect (tetralogy of Fallot).

Comment

Pulmonic insufficiency has been observed in patients with tetralogy of Fallot who have had
Figure 2A

Case 1, patient W. M. diagnosis, aortic insufficiency. The preoperative phonocardiogram with the high-frequency filter was recorded at a "loud" intensity at the aortic area (upper tracing) and at a "medium" intensity at the apex area (lower tracing). The aortic and pulmonic components of the second heart sound are split by 0.05 second. The diastolic murmur is seen starting with the aortic component and passing through the pulmonic component of the second heart sound. E.S.M., ejection systolic murmur; D.M., diastolic murmur; S₁, first sound; A₂, aortic component of the second heart sound; P₂, pulmonic component of the second heart sound.
marked narrowing of the valve ring and atresia of the valve leaflets.\textsuperscript{10, 11} However, aortic insufficiency may occur with a ventricular septal defect due to prolapse of the septal leaflet of the aortic valve.\textsuperscript{12} Thus the origin of the diastolic murmur was left in doubt.

The phonocardiogram (fig. 3) revealed a late peaking, kite-shaped, ejection murmur that encompassed a portion of the aortic component of the second heart sound. A diastolic crescendo-decrescendo murmur was recorded occurring 0.10 second after the beginning of the aortic component of the second sound. Although the pulmonic component of the second sound was not recordable, pulmonic closure would be expected to occur between 0.08 and 0.12 second after the aortic second sound in a patient with this degree of pulmonic stenosis.\textsuperscript{4, 15, 14} On the basis of the phonocardiographic evidence, the source of the diastolic murmur was considered to be pulmonic insufficiency. At cardiac surgery, there was no evidence of aortic insufficiency. The pulmonic valve was found to be markedly narrowed secondary to atresia of the valve ring. The pulmonary valve leaflets were markedly hypoplastic and were considered by the operative surgeon to be structurally inadequate for competency. On the basis of the surgical findings, the phonocardiographic diagnosis of pulmonic insufficiency seems adequately confirmed.

**Case 3**

Mrs. C. H., a 37-year-old Negro woman, was admitted for re-evaluation because of the recurrent symptoms and signs of congestive heart failure. The patient had undergone open-heart surgery 1 year previously for mitral insufficiency due to ruptured chordae tendineae. The system-
high-frequency filter
murmur
cendo-decrescendo
aortic
second (fig. of the second
markedly (literated
murmur "decrescendo"
sound
between
blood pressure was approximately 130/70
mm. Hg. Examination of the heart revealed atrial fibrillation and a vigorous left parasternal heave. The second sound was extremely loud in the pulmonic area. A grade-V/VI pansystolic murmur was auscultated at the apex. The murmur radiated posteriorly to the angle of the left scapula and to the left axilla. A grade-III/VI diastolic “decrescendo” murmur was auscultated in the second and third interspaces along the left sternal border. The electrocardiogram revealed atrial fibrillation and right ventricular hypertrophy. A markedly dilated pulmonary artery was visualized on the angiocardiogram.

Comment
The phonocardiogram demonstrated the interval between the aortic and pulmonic components of the second heart sound to be 0.04 to 0.05 second (fig. 4). The “silent” interval between the aortic and pulmonic components of the second sound was more clearly demonstrated by the high-frequency filter system. A diastolic crescendo-decrescendo murmur starting 0.02 to 0.04 second after the pulmonic component of the second sound was recorded with both the logarithmic and high-frequency filters. The peak of the diastolic murmur occurred 0.10 to 0.12 second after the aortic component of the second sound. A soft third sound, 0.16 second after the aortic component, was recorded at the apex of the heart. The later occurrence of the third sound precluded the possibility that the peak of the basal diastolic murmur was, in fact, due to superimposition of a transmitted third sound onto the basal diastolic murmur. The late onset of the diastolic murmur after the pulmonic component of the second sound and the crescendo-decrescendo configuration of the murmur constitute the phonocardiographic criteria for the diagnosis of pulmonic insufficiency. The patient again underwent open-heart surgery with the aorta being perfused in a retrograde manner from the femoral artery. The surgeon found a markedly dilated pulmonary artery and again no evidence of aortic insufficiency. The patient died subsequent to surgery and at autopsy the aortic valve leaflets were grossly normal.

Case 2, patient D.M. Diagnosis, ventricular septal defect, pulmonic insufficiency, and pulmonic stenosis. The phonocardiogram is recorded with a high-frequency filter at the pulmonic area. The “silent” pulmonic closure should occur 0.8 to 0.12 second after aortic closure in patients with severe pulmonic stenosis. The diastolic murmur is seen following the silent period after the aortic component of the second sound, which is obscured in the pulmonic ejection murmur. E.S.M., ejection systolic murmur; D.M., diastolic murmur; S1, first sound; A2, aortic component of the second heart sound; P2, pulmonic component of the second heart sound.

Figure 3

Circulation, Volume XXXII, September 1965
examination of the aortic cusps revealed minimal fibrosis. The pulmonary artery was markedly dilated. The diagnosis of pulmonary insufficiency secondary to pulmonary hypertension was considered adequately confirmed on the basis of the right ventricular hypertrophy, the marked dilatation of the pulmonary artery, and the exclusion of aortic insufficiency at both operations and later at postmortem examination.

Case 4

Patient H. M., a 30-year-old white man, diagnosed as having osteogenesis imperfecta, presented with the peripheral findings of aortic insufficiency and a blood pressure of 155/50 mm Hg. A grade-III/VI very high pitched diastolic decrescendo murmur was auscultated along the left sternal border. The electrocardiogram revealed marked left ventricular hypertrophy and strain. The clinical diagnosis was aortic insufficiency.

Comment

A phonocardiogram, taken with the logarithmic filter system, revealed the aortic component of the second heart sound 0.03 second prior to the dicrotic notch of the carotid pulse and the pulmonary component 0.01 to 0.02 second after the dicrotic notch (fig. 5). However, despite repeated attempts, the diastolic decrescendo murmur could not be demonstrated with the logarithmic filter. After substituting the high-frequency filter for the logarithmic filter, the diastolic murmur was clearly demonstrated beginning 0.03 second prior to the dicrotic notch of the carotid

Figure 4

Case 3, patient C. H. Diagnosis, mitral insufficiency and pulmonic insufficiency. A phonocardiogram with use of the logarithmic filter recorded with a simultaneous carotid pulse at the pulmonic area demonstrates (1) a pansystolic murmur extending up to and partially enveloping the aortic component of the second heart sound and (2) a high-pitched diastolic murmur occurring 0.04 to 0.06 second after the pulmonic component of the second heart sound. D.M., diastolic murmur; P.S.M., pansystolic murmur; S., first sound; A., aortic component of the second heart sound; P., pulmonic component of the second heart sound; D.C., dicrotic notch.
Case 4, patient H. M. Diagnosis, aortic insufficiency. A phonocardiogram (upper tracing) taken at the fourth left sternal border with a logarithmic filter system demonstrates the aortic com-

Circulation, Volume XXXII, September 1963
pulse (fig. 5). On the basis of the phonocardiographic evidence the source of the murmur was attributed to insufficiency of the aortic valve. The blood pressure, peripheral pulses, and the electrocardiogram were considered adequate evidence to substantiate the diagnosis of aortic insufficiency.

The murmurs of aortic and pulmonic insufficiency in these four patients were not distinguishable by auscultation with a stethoscope. All observers auscultating at the bedside "heard" the murmur of pulmonic insufficiency as a high-pitched decrescendo murmur. However, the phonocardiogram demonstrated, even in the presence of a fairly advanced degree of pulmonary hypertension, that the murmur of pulmonary insufficiency is crescendo-decrescendo in configuration.

Discussion

The high-frequency phonocardiogram permits the recording of the diastolic murmur of semilunar valve insufficiency. By eliminating the low-frequency vibrations, the components of the second heart sound may be clearly delineated. Thus the insufficient semilunar valve responsible for the murmur may be identified by observing which component of the second heart sound is followed by the diastolic murmur. Although this technic may not be feasible in patients with narrow splitting of the second heart sound, it has proved to be accurate in four patients: two with acquired aortic insufficiency, one with congenital pulmonic insufficiency associated with tetralogy of Fallot, and one with functional pulmonary insufficiency secondary to pulmonary hypertension. In addition to the four patients, we have recently studied an additional patient with functional pulmonary insufficiency secondary to severe pulmonary hypertension. The pulmonary artery pressure was 89/37 mm. Hg. Though the murmur was heard as a decrescendo murmur, high-frequency phonocardiogram revealed a crescendo-decrescendo murmur, starting with the pulmonic component of the second sound.

The advantages of phonocardiography in terms of morbidity, mortality, and expense over retrograde aortography and cardiac catheterization warrant its use before a patient is submitted to these more formidable procedures. This technic is under continued investigation to define its accuracy and feasibility in a larger number of patients with aortic and pulmonic insufficiency confirmed by other technics, such as retrograde aortography, cardiac catheterization, and cardiac surgery.

Summary

A phonocardiographic technic for differentiating the murmurs of aortic and pulmonic insufficiency is described. Four patients with diastolic "decrescendo" murmurs are presented to illustrate this technic.

References

7. Aygen, M. M., and Braunwald, E.: The split-component of the second sound 0.03 second before the dicrotic notch of the carotid pulse; the pulmonic component follows the dicrotic notch by 0.01 second. The very high-pitched diastolic murmur could not be demonstrated with the logarithmic filter system. A phonocardiogram (lower tracing) taken at the fourth left sternal border with the high-frequency filter system demonstrates a diastolic decrescendo murmur starting 0.03 second before the dicrotic notch and completely obscuring the pulmonic component of the second sound. S1, first sound; A2, aortic component of second sound; P2, pulmonic component of second sound; D.M., diastolic murmur; Log., logarithmic; 4L.S.B., fourth left sternal border.

Circulation, Volume XXXII, September 1965

Discovery of the Pulmonary Alveoli and Capillaries—Marcello Malpighi—1628-1694

While holding the chair of Theoretical Medicine at Pisa, Marcello Malpighi (1628-94) addressed two memorable letters, De pulmonibus, to his close friend Borelli, a mathematician who was interested in physiology as a branch of physics. These letters, translated into English by James Young, contain, among other things, observations on the pulmonary alveoli and capillaries seen with the help of a compound microscope. With humility Malpighi announced “a few little observations that might increase the things found out about the lungs.” These little observations were no less than the first description of the air sacs in the lungs of a dog, and of the pulmonary capillaries of the tortoise and frogs, “the whole race” of the latter, he claimed jokingly to “have almost destroyed.” We may well admire the technical ability and the ingenuity which he displayed in observing the movement of blood in the capillary network of the lungs of a living frog while the heart was beating, and in examining, after ligature of the pulmonary veins, its lungs, turgid with blood and dried in that state:

“It is clear to sense that the blood flows away through the tortuous vessels, that it is not poured into spaces but always works through tubules and is dispersed by the multiple winding of the vessels.”—ANDRÉ COURNAND, M.D. Circulation of the Blood. Edited by Alfred P. Fishman, M.D., and Dickinson W. Richards, M.D. New York, Oxford University Press, 1964, p. 28.

Circulation, Volume XXXII, September 1965
The Phonocardiographic Differentiation of Pulmonic and Aortic Insufficiency
ROBERT H. SCHWAB and JOHN H. KILLOUGH

Circulation. 1965;32:352-360
doi: 10.1161/01.CIR.32.3.352

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1965 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/32/3/352

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/