### CHAPTER e13
Approach to the Patient With a Heart Murmur

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## INTRODUCTION
The differential diagnosis of a heart murmur begins with a careful assessment of its major attributes and response to bedside maneuvers. The history, clinical context, and associated physical examination findings provide additional clues by which the significance of a heart murmur is established. Accurate bedside identification of a heart murmur can inform decisions regarding the indications for noninvasive testing and the need for referral to a cardiovascular specialist. Preliminary discussions can be held with the patient regarding antibiotic or rheumatic fever prophylaxis, the need to restrict various forms of physical activity, and the potential role for family screening.

Heart murmurs are caused by audible vibrations that are due to increased turbulence from accelerated blood flow through normal or abnormal orifices, flow through a narrowed or irregular orifice into a dilated vessel or chamber, or backward flow through an incompetent valve, ventricular septal defect, or patent ductus arteriosus. They traditionally are defined in terms of their timing within the cardiac cycle (Fig. e13-1). **Systolic murmurs** begin with or after the first heart sound (S1) and terminate at or before the component (A2 or P2) of the second heart sound (S2) that corresponds to their site of origin (left or right, respectively). **Diastolic murmurs** begin with or after the associated component of S1 and end at or before the subsequent S2. **Continuous murmurs** are not confined to either phase of the cardiac cycle but instead begin in early systole and proceed through S1 into all or part of diastole. The accurate timing of heart murmurs is the first step in their identification. The distinction between S1 and S2 and, therefore, systole and diastole is usually a straightforward process but can be difficult in the setting of a tachyarrhythmia, in which case the heart sounds can be distinguished by simultaneous palpation of the carotid upstroke, which should closely follow S1.

**Duration**
The duration of a heart murmur depends on the length of time over which a pressure difference exists between two cardiac chambers, the left ventricle and the aorta, the right ventricle and the pulmonary artery, or the great vessels. The magnitude and variability of this pressure difference, coupled with the geometry and compliance of the involved chambers or vessels, dictate the velocity of flow; the degree of turbulence; and the resulting frequency, configuration, and intensity of the murmur. The diastolic murmur of chronic aortic regurgitation (AR) is a blowing, high-frequency event, whereas the murmur of mitral stenosis (MS), indicative of the left atrial–left ventricular diastolic pressure gradient, is a low-frequency event, heard as a rumbling sound with the bell of the stethoscope. The frequency components of a heart murmur may vary at different sites of auscultation. The coarse systolic murmur of aortic stenosis (AS) may sound higher-pitched and more acoustically pure at the apex,

![Diagram depicting principal heart murmurs](image-url)  
**Figure e13-1** Diagram depicting principal heart murmurs.  
**A.** Presystolic murmur of mitral or tricuspid stenosis.  
**B.** Holosystolic (pansystolic) murmur of mitral or tricuspid regurgitation or of ventricular septal defect.  
**C.** Aortic ejection murmur beginning with an ejection click and fading before the second heart sound.  
**D.** Systolic murmur in pulmonic stenosis spilling through the aortic second sound, pulmonic valve closure being delayed.  
**E.** Aortic or pulmonary diastolic murmur.  
**F.** Long diastolic murmur of mitral stenosis after the opening snap (OS).  
**G.** Short mid-diastolic inflow murmur after a third heart sound.  

a phenomenon eponymously referred to as the Gallavardin effect. Some murmurs may have a distinct or unusual quality, such as the “honking” sound appreciated in some patients with mitral regurgitation (MR) due to mitral valve prolapse (MVP).

The configuration of a heart murmur may be described as crescendo, decrescendo, crescendo-decrescendo, or plateau. The decrescendo configuration of the murmur of chronic AR (Fig. e13-1E) can be understood in terms of the progressive decline in the diastolic pressure gradient between the aorta and the left ventricle. The crescendo-decrescendo configuration of the murmur of AS reflects the changes in the systolic pressure gradient between the left ventricle and the aorta as ejection occurs, whereas the plateau configuration of the murmur of chronic MR (Fig. e13-1F) is consistent with the large and nearly constant pressure difference between the left ventricle and the left atrium.

**Intensity**
The intensity of a heart murmur is graded on a scale of 1–6 (or I–VI). A grade 1 murmur is very soft and is heard only with great
SYSTOLIC HEART MURMURS

Early systolic murmurs

Early systolic murmurs begin with \( S_1 \) and extend for a variable period, ending well before \( S_2 \). Their causes are relatively few in number. Acute, severe MR into a normal-sized, relatively noncompliant left atrium results in an early, decrescendo systolic murmur best heard at or just medial to the apical impulse. These characteristics reflect the progressive attenuation of the pressure gradient between the left ventricle and the left atrium during systole owing to the rapid rise in left atrial pressure caused by the sudden volume load into an unprepared chamber and contrast sharply with the auscultatory features of chronic MR. Clinical settings in which acute, severe MR occur include (1) papillary muscle rupture complicating acute myocardial infarction (MI) ( Chap. 245 ), (2) rupture of chordae tendineae in the setting of myxomatous mitral valve disease (MVP, Chap. 237 ), (3) infective endocarditis ( Chap. 124 ), and (4) blunt chest wall trauma.

Acute, severe MR from papillary muscle rupture usually accompanies an inferior, posterior, or lateral MI and occurs 2–7 days after presentation. It often is signaled by chest pain, hypotension, and pulmonary edema, but a murmur may be absent in up to 50% of cases. The posteroomedial papillary muscle is involved 6 to 10 times more frequently than the anterolateral papillary muscle. The murmur is to be distinguished from that associated with post-MI ventricular septal rupture, which is accompanied by a systolic thrill at the left sternal border in nearly all patients and is holosystolic in duration. A new heart murmur after an MI is an indication for transthoracic echocardiography (TTE) ( Chap. 229 ), which allows bedside delineation of its etiology and pathophysiologic significance. The distinction between acute MR and ventricular septal rupture also can be achieved with right heart catheterization, sequential determination of oxygen saturations, and analysis of the pressure waveforms (tall \( v \) wave in the pulmonary artery wedge pressure in MR). Post-MI mechanical complications of this nature mandate aggressive medical stabilization and prompt referral for surgical repair.

Spontaneous chordal rupture can complicate the course of myxomatous mitral valve disease (MVP) and result in new-onset or “acute on chronic” severe MR. MVP may occur as an isolated phenomenon, or the lesion may be part of a more generalized connective tissue disorder as seen, for example, in patients with Marfan syndrome. Acute, severe MR as a consequence of infective endocarditis results from destruction of leaflet tissue, chordal rupture, or both. Blunt chest wall trauma is usually self-evident but may be disarmingly trivial; it can result in papillary muscle contusion and rupture, chordal detachment, or leaflet avulsion. TTE is indicated in all cases of suspected acute, severe MR to define its mechanism and severity, delineate left ventricular size and systolic function, and provide an assessment of suitability for primary valve repair.

A congenital, small muscular VSD ( Chap. 236 ) may be associated with an early systolic murmur. The defect closes progressively during septal contraction, and thus, the murmur is confined to early systole. It is localized to the left sternal border ( Fig. e13-2 ) and is usually of grade 4 or 5 intensity. Signs of pulmonary hypertension or left ventricular volume overload are absent. Anatomically large and uncorrected VSDs, which usually involve the membranous portion of the septum, may lead to pulmonary hypertension. The murmur associated with the left-to-right shunt, which earlier may have been holosystolic, becomes limited to the first portion of systole as the elevated pulmonary vascular resistance leads to an abrupt rise in right ventricular pressure and an attenuation of the interventricular pressure gradient during the remainder of the cardiac cycle. In such instances, signs of pulmonary hypertension (right ventricular lift, loud and single or closely split \( S_2 \) ) may predominate. The murmur is best heard along the left sternal border but is softer. Suspicion of a VSD is an indication for TTE.

Tricuspid regurgitation (TR) with normal pulmonary artery pressures, as may occur with infective endocarditis, may produce an early systolic murmur. The murmur is soft (grade 1 or 2), is best heard at the lower left sternal border, and may increase in intensity with inspiration (Carvalho’s sign). Regurgitant “\( v \) -\( r \)” waves may be visible in the jugular venous pulse. TR in this setting is not associated with signs of right heart failure.
### Principal Causes of Heart Murmurs

#### TABLE e13-1

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<th><strong>Early systolic</strong></th>
<th><strong>Mitral</strong></th>
<th><strong>Acute MR</strong></th>
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<td><strong>VSD</strong></td>
<td><strong>Muscular</strong></td>
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<td><strong>Nonrestrictive with pulmonary hypertension</strong></td>
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<td><strong>Tricuspid</strong></td>
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<td><strong>TR with normal pulmonary artery pressure</strong></td>
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<td><strong>Mid-systolic</strong></td>
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<td><strong>Obstructive</strong></td>
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<td><strong>Supravalvular—aortic stenosis, coarctation of the aorta</strong></td>
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<td><strong>Valvular—AS and aortic sclerosis</strong></td>
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<td><strong>Subvalvular— discrete, tunnel or HOCM</strong></td>
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<td><strong>Increased flow, hyperkinetic states, AR, complete heart block</strong></td>
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<td><strong>Dilation of ascending aorta, atheroma, aortitis</strong></td>
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<td><strong>Pulmonary</strong></td>
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<td><strong>Supravalvular—pulmonary artery stenosis</strong></td>
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<td><strong>Valvular—pulmonic valve stenosis</strong></td>
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<td><strong>Subvalvular—infundibular stenosis (dynamic)</strong></td>
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<td><strong>Increased flow, hyperkinetic states, left-to-right shunt (e.g., ASD)</strong></td>
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<td><strong>Dilation of pulmonary artery</strong></td>
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<td><strong>Late systolic</strong></td>
<td><strong>Mitral</strong></td>
<td><strong>MVP, acute myocardial ischemia</strong></td>
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<td><strong>Tricuspid</strong></td>
<td><strong>TVP</strong></td>
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<td><strong>Holosystolic</strong></td>
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<td><strong>Atrioventricular valve regurgitation (MR, TR)</strong></td>
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<td><strong>Left-to-right shunt at ventricular level (VSD)</strong></td>
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#### Early Diastolic Murmurs

- **Aortic regurgitation**
  - Valvular: congenital (bicuspid valve), rheumatic deformity, endocarditis, prolapse, trauma, post-valvulotomy
  - Dilation of valve ring: aorta dissection, annulo-aortic ectasia, cystic medial degeneration, hypertension, ankylosing spondylitis
  - Widening of commissures: syphilis
- **Pulmonic regurgitation**
  - Valvular: post-valvulotomy, endocarditis, rheumatic fever, carcinoid
  - Dilation of valve ring: pulmonary hypertension; Marfan syndrome
  - Congenital: isolated or associated with tetralogy of Fallot, VSD, pulmonic stenosis

#### Mid-Diastolic Murmurs

- **Mitral**
  - Mitral stenosis
  - Carey-Coombs murmur (mid-diastolic apical murmur in acute rheumatic fever)
  - Increased flow across nonstenotic mitral valve (e.g., MR, VSD, PDA, high-output states, and complete heart block)
- **Tricuspid**
  - Tricuspid stenosis
  - Increased flow across nonstenotic tricuspid valve (e.g., TR, ASD, and anomalous pulmonary venous return)
- **Left and right atrial tumors (myxoma)**
- **Severe AR (Austin Flint murmur)**

#### Continuous Murmurs

- **Patent ductus arteriosus**
- **Coronary AV fistula**
- **Ruptured sinus of Valsalva aneurysm**
- **Aortic septal defect**
- **Cervical venous hum**
- **Anomalous left coronary artery**
- **Proximal coronary artery stenosis**
- **Mammary souffle of pregnancy**
- **Pulmonary artery branch stenosis**
- **Bronchial collateral circulation**
- **Small (restrictive) ASD with MS**
- **Intercostal AV fistula**

**Abbreviations:** AR, aortic regurgitation; AS, aortic stenosis; ASD, atrial septal defect; AV, arteriovenous; HOCM, hypertrophic obstructive cardiomyopathy; MR, mitral regurgitation; MS, mitral stenosis; MVP, mitral valve prolapse; PDA, patent ductus arteriosus; TR, tricuspid regurgitation; TVP, tricuspid valve prolapse; VSD, ventricular septal defect.

Mid-systolic murmurs

Mid-systolic murmurs begin at a short interval after S₁, end before S₂ (Fig. e13-1C), and are usually crescento-decrescendo in configuration. Aortic stenosis is the most common cause of a mid-systolic murmur in an adult. The murmur of AS is usually loudest to the right of the sternum in the second intercostal space (aortic area, Fig. e13-2) and radiates into the carotids. Transmission of the mid-systolic murmur to the apex, where it becomes higher-pitched, is common (Gallavardin effect; see above).

Differentiation of this apical systolic murmur from MR can be difficult. The murmur of AS will increase in intensity, or become louder, in the beat after a premature beat, whereas the murmur of MR will have constant intensity from beat to beat. The intensity of the AS murmur also varies directly with the cardiac output. With a normal cardiac output, a systolic thrill and a grade 4 or higher murmur suggest severe AS. The murmur is softer in the setting of heart failure and low cardiac output. Other auscultatory findings of severe AS include a soft or absent A₂, paradoxical splitting of S₂, an apical S₃, and a late-peaking systolic murmur. In children, adolescents, and young adults with congenital valvular AS, an early ejection sound (click) is usually audible, more often along the left sternal border than at the base. Its presence signifies a flexible, non-calcified bicuspid valve (or one of its variants) and localizes the left ventricular outflow obstruction to the valvular (rather than sub- or supravalvular) level.

Assessment of the volume and rate of rise of the carotid pulse can provide additional information. A small and delayed upstroke (parvus et tardus) is consistent with severe AS. The carotid pulse examination is less discriminatory, however, in older patients with stiffened arteries. The electrocardiogram (ECG) shows signs of left ventricular hypertrophy (LVH) as the severity of the stenosis increases. TTE is indicated to assess the anatomic features of the aortic valve, the severity of the stenosis, left ventricular size, wall thickness and function, and the size and contour of the aortic root and proximal ascending aorta.

The obstructive form of hypertrophic cardiomyopathy (HOCM) is associated with a mid-systolic murmur that is usually loudest along the left sternal border or between the left lower sternal border and the apex (Chap. 238, Fig. e13-2). The murmur is produced by both dynamic left ventricular outflow tract obstruction and MR, and thus, its configuration is a hybrid between ejection and regurgitant phenomena. The intensity of the murmur may vary from beat to beat and after provocative maneuvers but usually does not exceed grade 3. The murmur classically will increase in intensity with maneuvers that result in increasing degrees of outflow tract obstruction, such as a reduction in preload or afterload (Valsalva, standing, vasodilators), or with an augmentation of contractility (inotropic stimulation). Maneuvers that increase preload (squatting, passive leg raising, volume administration) or afterload (squatting, vasopressors) or that reduce contractility (β-adrenoreceptor blockers) decrease the intensity of the murmur. In rare patients, there may be reversed splitting of S₂. A sustained left ventricular apical impulse and an S₃ may be appreciated. In contrast to AS, the carotid upstroke is rapid and of normal volume. Rarely, it is bisferiens or bifid in contour (see Fig. 227-2D) due to mid-systolic closure of the aortic valve. LVH is present on the ECG, and the diagnosis is confirmed by TTE. Although the systolic murmur associated with MVP behaves similarly to that due to HOCM in response to the Valsalva maneuver and to standing/squatting (Fig. e13-3), these two lesions can be distinguished on the basis of their associated findings, such as the presence of LVH in HOCM or a nonejection click in MVP.

The mid-systolic, crescendo-decrescendo murmur of congenital pulmonic stenosis (FS, Chap. 236) is best appreciated in the second and third left intercostal spaces (pulmonic area) (Figs. e13-2 and e13-4).

The duration of the murmur lengthens and the intensity of P₂ diminishes with increasing degrees of valvular stenosis (Fig. e13-1D). An early ejection sound, the intensity of which decreases with inspiration, is heard in younger patients. A parasternal left and ECG evidence of right ventricular hypertrophy indicate severe pressure overload. If obtained, the chest x-ray may show poststenotic dilation of the main pulmonary artery. TTE is recommended for complete characterization.

Significant left-to-right intracardiac shunting due to an ASD (Chap. 236) leads to an increase in pulmonary blood flow and a grade 2–3 mid-systolic murmur at the middle to upper left sternal border attributed to increased flow rates across the pulmonic valve with fixed splitting of S₂. Ostium secundum ASDs are the most common cause of these shunts in adults. Features suggestive of a primum ASD include the coexistence of MR due to a cleft anterior mitral valve leaflet and left axis deviation of the QRS complex on the ECG. With sinus venosus ASDs, the left-to-right shunt is usually not large enough to result in a systolic murmur, although the ECG may show abnormalities of sinus node function. A grade 2 or 3 mid-systolic murmur may also be heard best at the upper left sternal border in patients with idiopathic dilation of the pulmonary artery; a pulmonary ejection sound is also present in these patients. TTE is indicated to evaluate a grade 2 or 3 mid-systolic murmur when there are other signs of cardiac disease.

An isolated grade 1 or 2 mid-systolic murmur, heard in the absence of symptoms or signs of heart disease, is most often a
Late systolic murmurs

A late systolic murmur that is best heard at the left ventricular apex is usually due to MVP (Chap. 237). Often, this murmur is introduced by one or more nonejection clicks. The radiation of the murmur can help identify the specific mitral leaflet involved in the process of prolapse or flail. The term flail refers to the movement made by an unsupported portion of the leaflet after loss of its chordal attachment(s). With posterior leaflet prolapse or flail, the resultant jet of MR is directed anteriorly and medially, as a result of which the murmur radiates to the base of the heart and masquerades as AS. Anterior leaflet prolapse or flail results in a posteriorly directed MR jet that radiates to the axilla or left infrascapular region. Leaaf flail is associated with a murmur of grade 3 or 4 intensity that can be heard throughout the precordium in thin-chested patients. The presence of an S₃ or a short, rumbling mid-diastolic murmur due to enhanced flow signifies severe MR.

Bedside maneuvers that decrease left ventricular preload, such as standing, will cause the click and murmur of MVP to move closer to the first heart sound, as leaflet prolapse occurs earlier in systole. Standing also causes the murmur to become louder and longer. With squatting, left ventricular preload and afterload are increased abruptly, leading to an increase in left ventricular volume, and the click and murmur move away from the first heart sound as leaflet prolapse is delayed; the murmur becomes softer and shorter in duration (Fig. e13-3). As noted above, these responses to standing and squatting are directionally similar to those observed in patients with HOCM.

A late, apical systolic murmur indicative of MR may be heard transiently in the setting of acute myocardial ischemia; it is due to apical tethering and malcoaptation of the leaflets in response to structural and functional changes of the ventricle and mitral annulus. The intensity of the murmur varies as a function of left ventricular afterload and will increase in the setting of hypertension. TTE is recommended for assessment of late systolic murmurs.

Holosystolic murmurs

(Figs. e13-1B and e13-5) Holosystolic murmurs begin with S₁ and continue through systole to S₂. They are usually indicative of chronic mitral or tricuspid valve regurgitation or a VSD and warrant TTE for further characterization. The holosystolic murmur of chronic MR is best heard at the left ventricular apex and radiates to the axilla (Fig. e13-2); it is usually high-pitched and plateau in configuration because of the wide difference between left ventricular and left atrial pressure throughout systole. In contrast to acute MR, left atrial compliance is normal or even increased in chronic MR. As a result, there is only a small increase in left atrial pressure for any increase in regurgitant volume.

Several conditions are associated with chronic MR and an apical holosystolic murmur, including rheumatic scarring of the leaflets, mitral annular calcification, postinfarction left ventricular remodeling, and severe left ventricular chamber enlargement. The circumference of the mitral annulus increases as the left ventricle enlarges and leads to failure of leaflet coaptation with central MR in patients with dilated cardiomyopathy (Chap. 238). The severity of the MR is worsened by any contribution from apical displacement of the papillary muscles and leaflet tethering (remodeling). Because the mitral annulus is contiguous with the left atrial endocardium, gradual enlargement of the left atrium from chronic MR will result in further stretching of the annulus and more MR; thus, “MR begets MR.” Chronic severe MR results in enlargement and leftward displacement of the left ventricular apex beat and, in some patients, a diastolic filling complex, as described previously.

The holosystolic murmur of chronic TR is generally softer than that of MR, is loudest at the left lower sternal border, and usually increases in intensity with inspiration (Carvallo’s sign). Associated signs include c-v waves in the jugular venous pulse, an enlarged and pulsatile liver, ascites, and peripheral edema. The abnormal jugular venous waveforms are the predominant finding and are seen very often in the absence of an audible murmur despite Doppler echocardiographic verification of TR. Causes of primary TR include...
myxomatous disease (prolapse), endocarditis, rheumatic disease, carcinoid, Ebstein’s anomaly, and chordal detachment after the performance of right ventricular endomyocardial biopsy. TR is more commonly a passive process that results secondarily from chronic elevations of pulmonary artery and right ventricular pressures, leading to right ventricular enlargement, annular dilation, papillary muscle displacement, and failure of leaflet coaptation.

The holosystolic murmur of a VSD is loudest at the mid- to lower left sternal border (Fig. e13-2) and radiates widely. A thrill is present at the site of maximal intensity in the majority of patients. There is no change in the intensity of the murmur with inspiration. The intensity of the murmur varies as a function of the anatomic size of the defect. Small, restrictive VSDs, as exemplified by the maladie de Roger, create a very loud murmur due to the significant and sustained systolic pressure gradient between the left and right ventricles. With large defects, the ventricular pressures tend to equalize, shunt flow is balanced, and a murmur is not appreciated. The distinction between post-MI ventricular septal defect and MR has been reviewed previously.

**DIASTOLIC HEART MURMURS**

Early diastolic murmurs

(Fig. e13-1E) Chronic AR results in a high-pitched, blowing, decrescendo, early to mid-diastolic murmur that begins after the aortic component of S2 (A2) and is best heard at the second right interspace (Fig. e13-6). The murmur may be soft and difficult to hear unless auscultation is performed with the patient leaning forward at end expiration. This maneuver brings the aortic root closer to the anterior chest wall. Radiation of the murmur may provide a clue to the cause of the AR. With primary valve disease, such as that due to congenital bicuspid disease, prolapse, or endocarditis, the diastolic murmur tends to radiate along
the left sternal border, where it is often louder than appreciated in the second right interspace. When AR is caused by aortic root disease, the diastolic murmur may radiate along the right sternal border. Diseases of the aortic root cause dilation or distortion of the aortic annulus and failure of leaflet coaptation. Causes include Marfan syndrome with aneurysm formation, annulo-aortic ectasia, ankylosing spondylitis, and aortic dissection.

Chronic, severe AR also may produce a lower-pitched mid- to late, grade 1 or 2 diastolic murmur at the apex (Austin Flint murmur), which is thought to reflect turbulence at the mitral inflow area from the admixture of regurgitant (aortic) and forward (mitral) blood flow (Figs. e13-1G). This lower-pitched, apical diastolic murmur can be distinguished from that due to MS by the absence of an opening snap and the response of the murmur to a vasodilator challenge. Lowering afterload with an agent such as amyl nitrite will decrease the duration and magnitude of the aortic–left ventricular diastolic pressure gradient, and thus, the Austin Flint murmur of severe AR will become shorter and softer. The intensity of the diastolic murmur of mitral stenosis (Fig. e13-6) may either remain constant or increase with afterload reduction because of the reflex increase in cardiac output and mitral valve flow.

Although AS and AR may coexist, a grade 2 or 3 crescendo-decrescendo mid-systolic murmur frequently is heard at the base of the heart in patients with isolated, severe AR and is due to an increased volume and rate of systolic flow. Accurate bedside identification of coexistent AS can be difficult unless the carotid pulse examination is abnormal or the mid-systolic murmur is of grade 4 or greater intensity. In the absence of heart failure, chronic severe AR is accompanied by several peripheral signs of significant diastolic run-off, including a wide pulse pressure, a “water-hammer” carotid upstroke (Corrigan’s pulse), and Quincke’s pulsations of the nail beds. The diastolic murmur of acute, severe AR is notably shorter in duration and lower-pitched than the murmur of chronic AR. It can be very difficult to appreciate in the presence of a rapid heart rate. These attributes reflect the abrupt rate of rise of diastolic pressure within the unprepared and noncompliant left ventricle and the correspondingly rapid decline in the aortic–left ventricular diastolic pressure gradient. Left ventricular diastolic pressure may increase sufficiently to result in premature closure of the mitral valve and a soft first heart sound. Peripheral signs of significant diastolic run-off are not present.

Pulmonic regurgitation (PR) results in a decrescendo, early to mid-diastolic murmur (Graham Steel murmur) that begins after the pulmonic component of $S_2$ ($P_2$), is best heard at the second left interspace, and radiates along the left sternal border. The intensity of the murmur may increase with inspiration. PR is most commonly due to dilation of the valve annulus from chronic elevation of the pulmonary artery pressure. Signs of pulmonary hypertension, including a right ventricular lift and a loud single or narrowly split $S_2$, are present. These features also help distinguish PR from AR as the cause of a decrescendo diastolic murmur heard along the left sternal border. PR in the absence of pulmonary hypertension can occur with endocarditis or a congenitally deformed valve. It is usually present after repair of tetralogy of Fallot in childhood. When pulmonary hypertension is not present, the diastolic murmur is softer and lower-pitched than the classic Graham Steel murmur, and the severity of the PR can be difficult to appreciate.

TTE is indicated for the further evaluation of a patient with an early to mid-diastolic murmur. Longitudinal assessment of the severity of the valve lesion and ventricular size and systolic function help guide a potential decision for surgical management. TTE also can provide anatomic information regarding the root and proximal ascending aorta, although computed tomographic or magnetic resonance angiography may be indicated for more precise characterization (Chap. 229).

Mid-diastolic murmurs
(Figs. e13-1H and e13-7) Mid-diastolic murmurs result from obstruction and/or augmented flow at the level of the mitral or tricuspid valve. Rheumatic fever is the most common cause of MS (Fig. e13-6). In younger patients with pliable valves, $S_2$ is loud and the murmur begins after an opening snap, which is a high-pitched sound that occurs shortly after $S_2$. The interval between the pulmonic component of the second heart sound ($P_2$) and the opening snap is inversely related to the magnitude of the left atrial–left ventricular pressure gradient. The murmur of MS is low-pitched and thus is best heard with the bell of the stethoscope. It is loudest at the left ventricular apex and often is appreciated only when the patient is turned in the left lateral decubitus position. It is usually of grade 1 or 2 intensity but may be absent when the cardiac output is severely reduced despite significant obstruction. The intensity of the murmur increases during maneuvers that increase cardiac output and mitral valve flow, such as exercise. The duration of the murmur reflects the length of time over which left atrial pressure exceeds left ventricular diastolic pressure. An increase in the intensity of the murmur just before $S_2$, a phenomenon known as preystolic accentuation (Figs. e13-14A, e13-6), occurs in patients in sinus rhythm and is due to a late increase in transmural flow with atrial contraction. Preystolic accentuation does not occur in patients with atrial fibrillation.

The mid-diastolic murmur associated with tricuspid stenosis is best heard at the lower left sternal border and increases in intensity with inspiration. A prolonged y descent may be visible in the jugular venous waveform. This murmur is very difficult to hear and often is obscured by left-sided acoustical events.

There are several other causes of mid-diastolic murmurs. Large left atrial myxomas may prolapse across the mitral valve and cause variable degrees of obstruction to left ventricular inflow (Chap. 240). The murmur associated with an atrial myxoma may change in duration and intensity with changes in body position. An opening snap is not present, and there is no preystolic accentuation. Augmented mitral diastolic flow can occur with isolated severe MR or with a large left-to-right shunt at the ventricular or great vessel level and produce a soft, rapid filling sound ($S_2$) followed by a short, low-pitched mid-diastolic apical murmur. The Austin Flint murmur of severe, chronic AR has already been described.

A short, mid-diastolic murmur is rarely heard during an episode of acute rheumatic fever (Carey-Coombs murmur) and probably is due to flow through an edematous mitral valve. An opening snap is not present in the acute phase, and the murmur dissipates with resolution of the acute attack. Complete heart block with dysynchronous atrial and ventricular activation may be associated with intermittent mid- to late diastolic murmurs if atrial contraction occurs when the mitral valve is partially closed. Mid-diastolic murmurs indicative of increased tricuspid valve flow can occur with severe, isolated TR and with large ASDs and significant left-to-right shunting. Other signs of an ASD are present (Chap. 236), including fixed splitting of $S_2$ and a mid-systolic murmur at the mid- to upper left sternal border. TTE is indicated for evaluation of a patient with a mid- to late diastolic murmur. Findings specific to the diseases discussed above will help guide management.

CONTINUOUS MURMURS
(Figs. e13-1H and e13-7) Continuous murmurs begin in systole, peak near the second heart sound, and continue into all or part of diastole. Their presence throughout the cardiac cycle implies a pressure gradient between two chambers or vessels during both systole and diastole. The continuous murmur associated with a patent ductus arteriosus is best heard at the upper left sternal border. Large, uncorrected shunts may lead to pulmonary hypertension, attenuation or obliteration of the diastolic component
of the murmur, reversal of shunt flow, and differential cyanosis of the lower extremities. A ruptured sinus of Valsalva aneurysm creates a continuous murmur of abrupt onset at the upper right sternal border. Rupture typically occurs into a right heart chamber, and the murmur is indicative of a continuous pressure difference between the aorta and either the right ventricle or the right atrium. A continuous murmur also may be audible along the left sternal border with a coronary arteriovenous fistula and at the site of an arteriovenous fistula used for hemodialysis access. Enhanced flow through enlarged intercostal collateral arteries in patients with aortic coarctation may produce a continuous murmur along the course of one or more ribs. A cervical bruit with both systolic and diastolic components (a to-fro murmur, Fig. e13-7) usually indicates a high-grade carotid artery stenosis.

Not all continuous murmurs are pathologic. A continuous venous hum can be heard in healthy children and young adults, especially during pregnancy; it is best appreciated in the right supraventricular fossa and can be obliterated by pressure over the right internal jugular vein or by having the patient turn his or her head toward the examiner. The continuous mammary souffle of pregnancy is created by enhanced arterial flow through engorged breasts and usually appears during the late third trimester or early puerperium. The murmur is louder in systole. Firm pressure with the diaphragm of the stethoscope can eliminate the diastolic portion of the murmur.

**Dynamic Auscultation**

(Tables e13-2 and 227-1) Careful attention to the behavior of heart murmurs during simple maneuvers that alter cardiac hemodynamics can provide important clues to their cause and significance.

**Respiration**

Auscultation should be performed during quiet respiration or with a modest increase in inspiratory effort, as more forceful movement of the chest tends to obscure the heart sounds. Left-sided murmurs may be best heard at end expiration, when lung volumes are minimized and the heart and great vessels are brought closer to the chest wall. This phenomenon is characteristic of the murmur of AR. Murmurs of right-sided origin, such as tricuspid or pulmonic regurgitation, increase in intensity during inspiration. The intensity of left-sided murmurs either remains constant or decreases with inspiration.

Bedside assessment also should evaluate the behavior of S1 with respiration and the dynamic relationship between the aortic and pulmonic components (Fig. e13-8). Reversed splitting can be a feature of severe AS, HOCM, left bundle branch block, right ventricular apical pacing, or acute myocardial ischemia. Fixed splitting of S1 in the presence of a grade 2 or 3 mid-systolic murmur at the mid- or upper left sternal border indicates an ASD. Physiologic but wide splitting during the respiratory cycle implies either premature aortic valve closure, as can occur with severe MR, or delayed pulmonic valve closure due to PS or right bundle branch block.

**Alterations of systemic vascular resistance**

Murmurs can change characteristics after maneuvers that alter systemic vascular resistance and left ventricular afterload. The systolic murmurs of MR and VSD become louder during sustained handgrip, simultaneous inflation of blood pressure cuffs on both upper extremities to pressures 20–40 mmHg above systolic pressure for 20 s, or infusion of a vasopressor agent. The diastolic murmur of AR becomes louder in response to interventions that raise systemic vascular resistance.

Opposite changes in systolic and diastolic murmurs may occur with the use of pharmacologic agents that lower systemic vascular resistance. Inhaled amyl nitrite is now rarely used for this purpose but can help distinguish the murmur of AS or HOCM from that of either MR or VSD, if necessary. The former two murmurs increase in intensity, whereas the latter two become softer after exposure to amyl nitrite. As noted previously, the Austin Flint murmur of severe AR becomes softer, but the mid-diastolic rumble of MS becomes louder, in response to the abrupt lowering of systemic vascular resistance with amyl nitrite.

**Changes in venous return**

The Valsalva maneuver results in an increase in intrathoracic pressure, followed by a decrease in venous return, ventricular filling, and cardiac output. The majority of murmurs decrease in intensity during the strain phase of the maneuver. Two notable exceptions are the murmurs associated with MVP and obstructive HOCM, both of

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**TABLE e13-2 Dynamic Auscultation: Bedside Manuevers That Can Be Used to Change the Intensity of Cardiac Murmurs (See Text)**

<table>
<thead>
<tr>
<th>1. Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Isometric exercise (handgrip)</td>
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<tr>
<td>3. Transient arterial occlusion</td>
</tr>
<tr>
<td>4. Pharmacologic manipulation of preload and/or afterload</td>
</tr>
<tr>
<td>5. Valsalva maneuver</td>
</tr>
<tr>
<td>6. Rapid standing/squatting</td>
</tr>
<tr>
<td>7. Passive leg raising</td>
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<tr>
<td>8. Post-premature beat</td>
</tr>
</tbody>
</table>
outflow obstruction, including that due to AS, increase in intensity transmitted to the apex. Systolic murmurs due to left ventricular particularly in an older patient in whom the murmur of AS is well

A change in the intensity of a systolic murmur in the first beat after a premature beat may lead to a decrease in the intensity of the murmur in a similar and parallel fashion with standing. Both the click and the murmur of MVP may also become longer as leaflet prolapse occurs earlier which become louder during the Valsalva maneuver. The murmur of MVP may move closer in timing to S1 on rapid standing in systole at smaller ventricular volumes. These murmurs behave in a similar and parallel fashion with standing. Both the click and the murmur of MVP may move closer in timing to S1 with squatting. Passive leg raising can be used to increase in both venous return (preload) and left ventricular afterload that which occurs with reduced ventricular filling. Squatting results in abrupt increases in venous return (preload) and left ventricular afterload that increases ventricular volume, changes that predictably cause a decrease in the intensity and duration of the murmurs associated with MVP and HOCM; the click and murmur of MVP move away from S1 with squatting. Passive leg raising can be used to increase venous return in patients who are unable to squat and stand. This maneuver may lead to a decrease in the intensity of the murmur associated with HOCM but has less effect in patients with MVP.

Post-premature ventricular contraction
A change in the intensity of a systolic murmur in the first beat after a premature beat, or in the beat after a long cycle length in patients with atrial fibrillation, can help distinguish AS from MR, particularly in an older patient in whom the murmur of AS is well transmitted to the apex. Systolic murmurs due to left ventricular outflow obstruction, including that due to AS, increase in intensity in the beat after a premature beat because of the combined effects of enhanced left ventricular filling and postextrasystolic potentiation of contractile function. Forward flow accelerates, causing an increase in the gradient and a louder murmur. The intensity of the murmur of MR does not change in the post-premature beat as there is relatively little further increase in mitral valve flow or change in the left ventricular–left atrial gradient.

THE CLINICAL CONTEXT
Additional clues to the etiology and importance of a heart murmur can be gleaned from the history and other physical examination findings. Symptoms suggestive of cardiovascular, neurologic, or pulmonary disease help focus the differential diagnosis, as do findings relevant to the jugular venous pressure and waveforms, the arterial pulses, other heart sounds, the lungs, the abdomen, the skin and the extremities. In many instances, laboratory studies, an ECG, and/or a chest x-ray may have been obtained earlier and may contain valuable information. A patient with suspected infective endocarditis, for example, may have a murmur in the setting of fever, chills, anorexia, fatigue, dyspnea, splenomegaly, petechiae, and positive blood cultures. A new systolic murmur in a patient with a marked fall in blood pressure after a recent MI suggests myocardial rupture. By contrast, an isolated grade 1 or 2 mid-systolic murmur at the left sternal border in a healthy, active, and asymptomatic young adult is most likely a benign finding for which no further evaluation is indicated. The context in which the murmur is appreciated often dictates the need for further testing.

ECHOCARDIOGRAPHY
(See Fig. e13-9, Chaps. 227 and 229) Echocardiography with color flow and spectral Doppler is a valuable tool for the assessment of cardiac murmurs. Information regarding valve structure and function, chamber size, wall thickness, ventricular function, estimated pulmonary artery pressures, intracardiac shunt flow, pulmonary and hepatic vein flow, and aortic flow can be ascertained readily. It is important to note that Doppler signals of trace or mild valvular regurgitation of no clinical consequence can be detected with structurally normal tricuspid, pulmonic, and mitral valves. Such signals are not likely to generate enough turbulence to create an audible murmur.

Echocardiography is indicated for the evaluation of patients with early, late, or holosystolic murmurs and patients with grade 3 or louder mid-systolic murmurs. Patients with grade 1 or 2 mid-systolic murmurs but other symptoms or signs of cardiovascular disease, including those from ECG or chest x-ray, should also undergo echocardiography. Echocardiography is indicated for the evaluation of any patient with a diastolic murmur and for patients with continuous murmurs not due to a venous hum or mammary souffle. Echocardiography also should be considered when there is a clinical need to verify normal cardiac structure and function in a patient whose symptoms and signs are probably noncardiac in origin. The performance of serial echocardiography to follow the course of asymptomatic individuals with valvular heart disease is a central feature of their longitudinal assessment and provides valuable information that may have an impact on decisions regarding the timing of surgery. Routine echocardiography is not recommended for asymptomatic patients with a grade 1 or 2 mid-systolic murmur without other signs of heart disease. For this category of patients, referral to a cardiovascular specialist should be considered if there is doubt about the significance of the murmur after the initial examination.

The selective use of echocardiography outlined above has not been subjected to rigorous analysis of its cost-effectiveness. At least one study has suggested that initial referral of pediatric patients with heart murmurs to a specialist results in modest cost savings.

Figure e13-8  Top. Normal physiologic splitting. During expiration, the aortic (A1) and pulmonic (P2) components of the second heart sound are separated by <30 ms and are appreciated as a single sound. During inspiration, the splitting interval widens, and A1 and P2 are clearly separated into two distinct sounds. Bottom, Audible expiratory splitting. Wide physiologic splitting is caused by a delay in P2. Reversed splitting is caused by a delay in A1, resulting in paradoxical movement; i.e., with inspiration P2 moves toward A1, and the splitting interval narrows. Narrow physiologic splitting occurs in pulmonary hypertension, and both A1 and P2 are heard during expiration at a narrow splitting interval because of the increased intensity and high-frequency composition of P2. (From JA Shaver, JJ Leonard, DF Leon, Examination of the Heart, Part IV, Auscultation of the Heart. Dallas, American Heart Association, 1990, p 17. Copyright, American Heart Association.)
The accurate identification of a heart murmur begins with a systematic approach to cardiac auscultation. Characterization of its major attributes, as reviewed above, allows the examiner to construct a preliminary differential diagnosis, which is then refined by integration of information available from the history, associated cardiac findings, the general physical examination, and the clinical context. The need for and urgency of further testing follow sequentially. Correlation of the findings on auscultation with the noninvasive data provides an educational feedback loop and an opportunity for improving physical examination skills. Cost constraints mandate that noninvasive imaging be justified on the basis of its incremental contribution to diagnosis, treatment, and outcome. Additional study is required to assess the cost-effective application of newer imaging technology in patients with heart murmurs.

**FURTHER READINGS**


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