Role of M-mode Technique in Today's Echocardiography

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M-mode echocardiography is considered to be obsolete by many. The technique rarely is included in American Society of Echocardiography standards documents, except for M-mode measurements, which have limited value. The superior temporal resolution of M-mode echocardiography is frequently overlooked. Doppler recordings reflect blood velocity, whereas M-mode motion of cardiac structures reflect volumetric blood flow. The 2 examinations are hemodynamically complementary. In the current digital era, recording multiple cardiac cycles of two-dimensional echocardiographic images is no longer necessary. However, there are times when intermittent or respiratory changes occur. The M-mode technique is an effective and efficient way to record the necessary multiple cardiac cycles. In certain situations, M-mode recordings of the valves and interventricular septum can be particularly helpful in making a more accurate and complete echocardiographic cardiac assessment, thus helping to make the examination more cost-effective. (J Am Soc Echocardiogr 2010;23:240-57.)

BACKGROUND

Echocardiography is by definition the examination of the heart using reflected ultrasound. Over the years, the examination has developed into a multitude of different ways to examine the heart ultrasonically. These technologies are frequently described from a historical perspective. I and others began using real-time A-mode (amplitude-based) ultrasonography. The first long-lasting diagnostic cardiac ultrasound application, the detection of pericardial effusion, used A-mode ultrasonic signals. The B-mode (brightness-based) technique converted the ultrasonic A-mode "spike" to a "dot" and amplitude to brightness. This change left a dimension available for "time." Thus, by sweeping the B-mode dot across the oscilloscope, we had M-mode (motion-based) ultrasonography. This M-mode approach was the principle technology available for approximately 10 years. Then a variety of two-dimensional (2D) approaches became available. Shortly thereafter, Doppler techniques for recording intracardiac blood flow were described. The next development was displaying the Doppler signal as a 2D image using color to denote the direction and character of the flow.

Because of these developments, there were 2 approaches to the ultrasonic examination of the heart. The first was a one-dimensional or "ice-pick view" displaying the location and motion of the heart, usually with a sampling rate of approximately 2000 frames per second.[1] The second was a more anatomically correct 2D or cross-sectional display of the heart with an initial frame rate of approximately 30 frames per second. The 2D frame rate is now up to approximately 100 frames per second. A similar approach was done with the Doppler recordings of blood flow. Initially, there was a single-dimensional recording of the Doppler signal recorded against time on a strip chart recorder. This spectral display could be used with either pulsed- or continuous-wave Doppler. Then a 2D approach was developed using color Doppler that was displayed as a moving picture. In many ways, the single-dimensional or spectral Doppler recording of blood flow is essentially equivalent to the M-mode recording of the valves and walls. From a historical point of view, it is interesting that the 1-dimensional recording of spectral Doppler has persisted, but the 1-dimensional M-mode technique for recording tissue has been considered obsolete by many. Although there are still M-

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Target Audience
This activity is designed for all cardiovascular physicians and cardiac sonographers with a primary interest and knowledge base in the field of echocardiography: in addition, residents, researchers, clinicians, intensivists, and other medical professionals with a specific interest in cardiac ultrasound will find this activity beneficial.
Objectives
Upon completing the reading of this article, the participants will better be able to:

1. Describe the evolution of echocardiographic techniques.
2. Recognize clinical situations in which the sampling rate of M-mode provides specific and precise information unavailable with the 2D sampling rate.
3. Predict certain hemodynamic parameters from specific patterns of valve motion as observed on M-mode.
4. Correlate M-mode patterns with spectral Doppler findings.
5. Identify specific M-mode patterns of the interventricular septum in various clinical scenarios, especially left ventricular dysfunction and volume overload, conduction abnormalities, and pericardial disease.

Author Disclosure
The author of this article reported no actual or potential conflicts of interest in relation to this activity.
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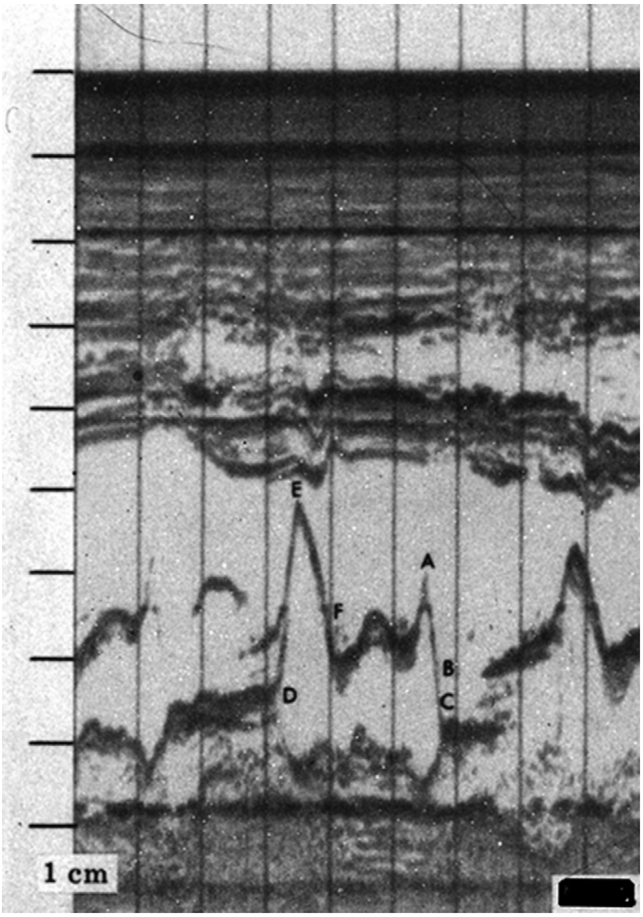

Figure 1 Normal M-mode recording of the mitral valve. (From Feigenbaum H. *Echocardiography.* 1st ed. Philadelphia, PA: Lea and Febiger; 1972.)

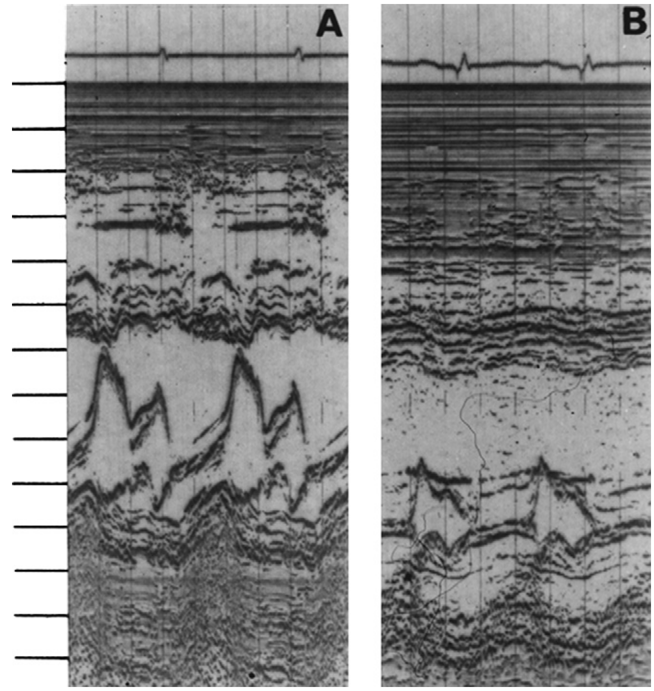

Figure 2 **A,** Mitral valve M-mode of a normal subject. **B,** Mitral valve M-mode recording of a patient with a dilated left ventricle, reduced mitral flow, reduced ejection fraction, and elevated LV end-diastolic pressure. (From Feigenbaum H. *Echocardiography.* 1st ed. Philadelphia, PA: Lea and Febiger; 1972.)

mode questions on the echocardiography board examinations, and they are sometimes a part of "quiz shows" at meetings, M-mode findings are rarely a part of official echocardiography standards documents except for M-mode dimensions, which now only have limited applications because M-mode measurements are heavily influenced by the location of the available acoustic windows. Thus, the M-mode left ventricular (LV) diameter is rarely the true minor dimension and varies depending on the location of the acoustic window. In addition, the M-mode beam is stationary while the heart is moving, that is, the diastolic measurement is at a slightly different location than the systolic measurement. Direct measurements made from 2D echocardiograms overcome these problems.

The exact reason for the clinical disappearance of M-mode recordings of valves and walls is difficult to explain. Admittedly, many of the applications that were done with the M-mode technique became obsolete when 2D echocardiography was developed. The single dimensions that one would record and measure with M-mode were no longer necessary once 2D echocardiography became available. The more correct anatomic shape and size of cardiac structures were now available with the 2D technique. Some M-mode diagnoses, such as fluttering of the mitral valve for the diagnosis of aortic regurgitation, were no longer relevant with the availability of Doppler techniques. However, the almost complete abandonment of M-mode echocardiography ignored the fact that we are still examining a moving object. Some of these structures, especially the valves and interventricular septum, move very quickly. There are circumstances in which temporal resolution or sampling rate can be critical in detecting very rapid or subtle motions. Even with the fastest 2D imaging device, it is unusual to record more than 100 frames per second. The original stand-alone M-mode instruments recorded at a sampling rate of 2000 per second. Even with the 2D-guided M-mode recording of today, the sampling rate is still at least 1000 samples per second. The introduction of 2D or color Doppler certainly did not make the spectral display of Doppler obsolete. The same should have been true with tissue imaging. The introduction of 2D tissue imaging does not make M-mode tissue imaging irrelevant.

This review of what M-mode echocardiography can provide in today's echocardiographic examination will hopefully reintroduce some of the unique advantages of recording cardiac valves and walls with a temporal resolution of 1000 samples per second. This discussion is by no means intended to be an exhaustive review of all the possible uses of M-mode techniques in today's echocardiography. I will only review what I consider to be some of the more relevant uses of the historically older technique.

M-MODE RECORDING OF THE MITRAL VALVE

The fastest moving structure within the heart is probably the mitral valve. Figure 1 describes an M-mode recording of a normal mitral valve. This is an old recording that was taken at a sampling rate of 2000 samples per second. The various labels that were placed on the valve are indicated. This particular normal valve was selected partially because it exhibits a finding that is distinctly different from a similar recording of mitral Doppler flow. In this normal subject, there is

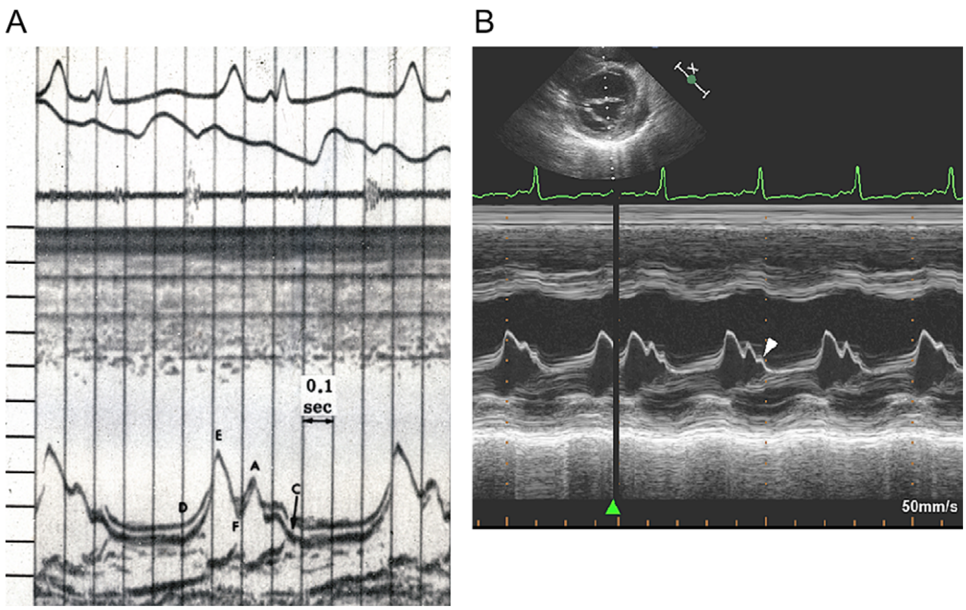

Figure 3 An old 2000 samples per second mitral valve M-mode recording **(A)** and a recent 1000 samples per second M-mode mitral valve recording **(B)** in patients with elevated LV end-diastolic pressure. (**A,** From Feigenbaum H. *Echocardiography.* 1st ed. Philadelphia, PA: Lea and Febiger; 1972.)

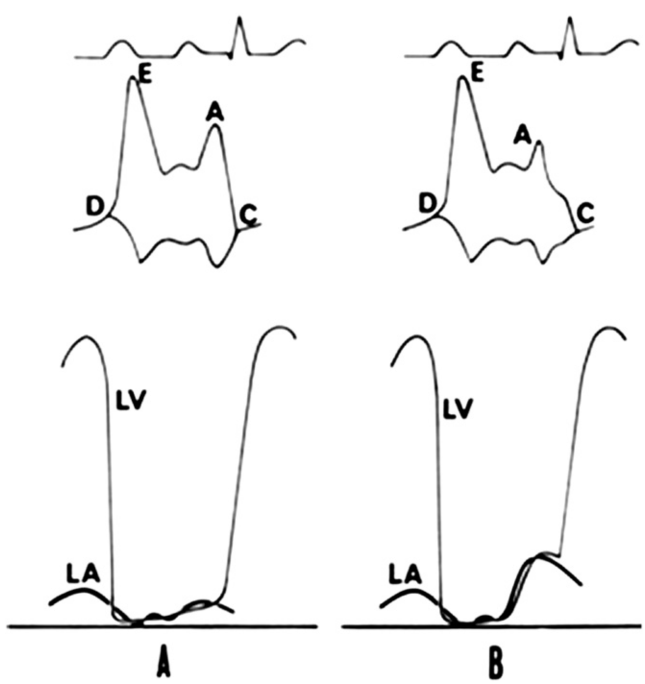

Figure 4 Relationship between LV and left atrial diastolic pressure and mitral valve motion (From Feigenbaum H. *Echocardiography.* 1st ed. Philadelphia, PA: Lea and Febiger; 1972.)

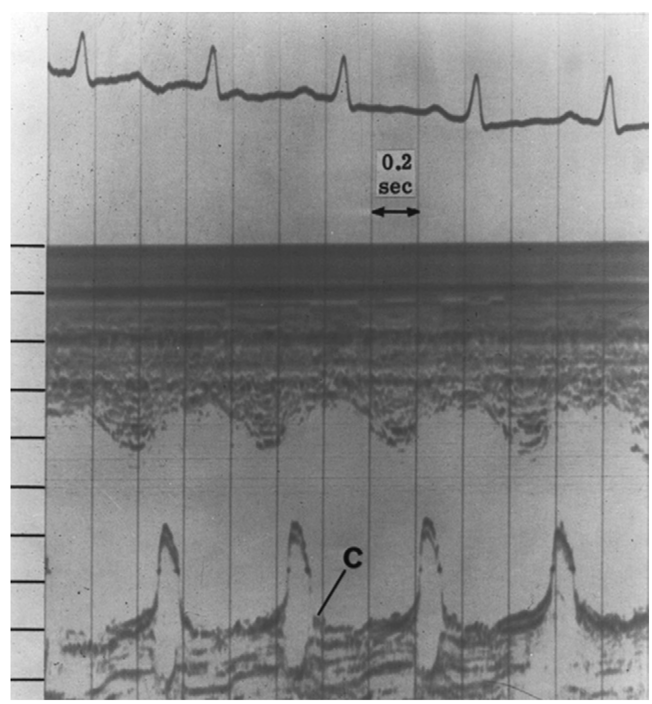

Figure 5 Mitral valve recording in a patient with acute severe aortic regurgitation and elevated LV diastolic pressure. There is a timeline right after the C-point. By following that timeline to the electrocardiogram, one can appreciate that the C-point occurs before the electrical QRS and therefore before ventricular contraction. (From Feigenbaum H. *Echocardiography.* 1st ed. Philadelphia, PA: Lea and Febiger; 1972.)

a mid-diastolic reopening of the mitral valve. This simulates a Doppler signal in mid-diastole called the "L-wave." The L-wave, which reflects flow velocity, is usually considered to be an abnormal sign indicative of diastolic dysfunction or abnormal LV filling. However, the mid-diastolic reopening of the mitral valve in the M-mode recording in Figure 1 represents volumetric blood flow rather than velocity. Although this may also appear in patients with diastolic dysfunction, it is usually a normal finding. A detailed discussion as to the mechanism for the L-wave and mitral valve mid-diastolic reopening might help to explain the differences in these 2 echocardiographic findings; however, the main point is to illustrate that an M-mode recording may

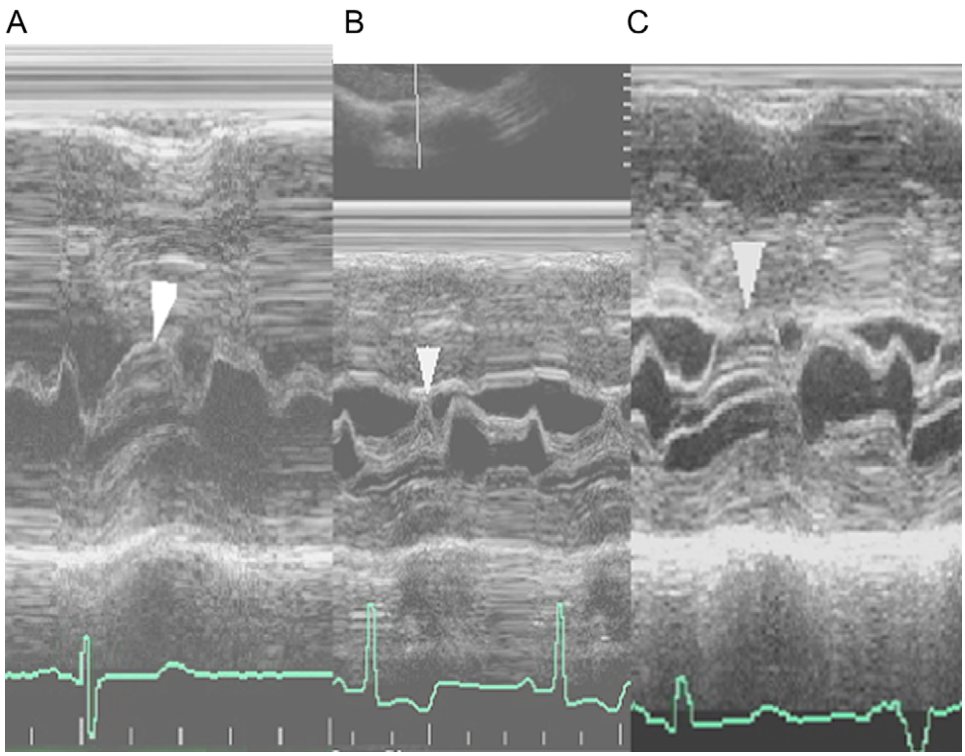

Figure 6 M-mode mitral valve recordings of patients with mitral valve systolic anterior mitral valve motion. **A,** The mitral valve touches the interventricular septum in mid-systole. **B,** The mitral valve touches the septum only briefly in late systole. **C,** The mitral valve strikes the septum in early systole and stays in contact with the septum almost throughout systole in this patient with hypertrophic cardiomyopathy and severe LV outflow tract obstruction.

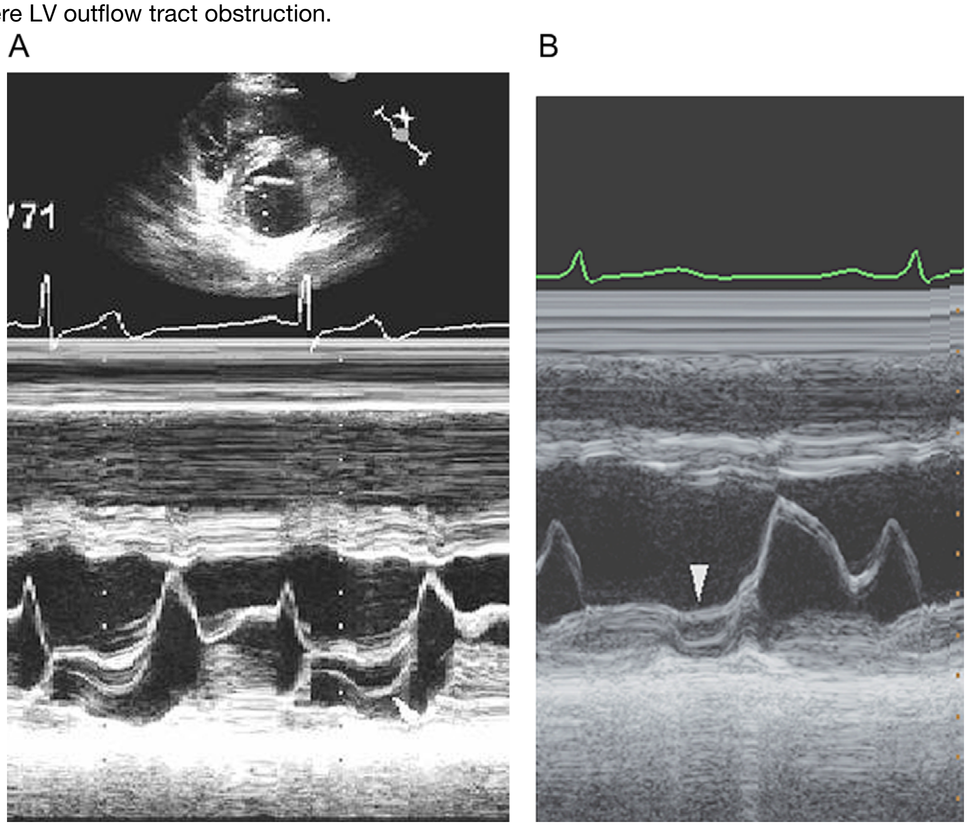

Figure 7 Mitral valve recording in patients with mitral valve prolapse. **A,** The posterior motion of the posterior leaflet begins in early diastole as it separates from the anterior leaflet. In mid-systole both leaflets move abruptly posteriorly. This mid to late displacement of the mitral valve is the characteristic M-mode sign of mitral valve prolapsed (*arrow*). **B,** Mitral valve recording of another patient with mitral valve prolapse. In this case the posterior motion of the leaflets is limited to late systole (*arrow*).

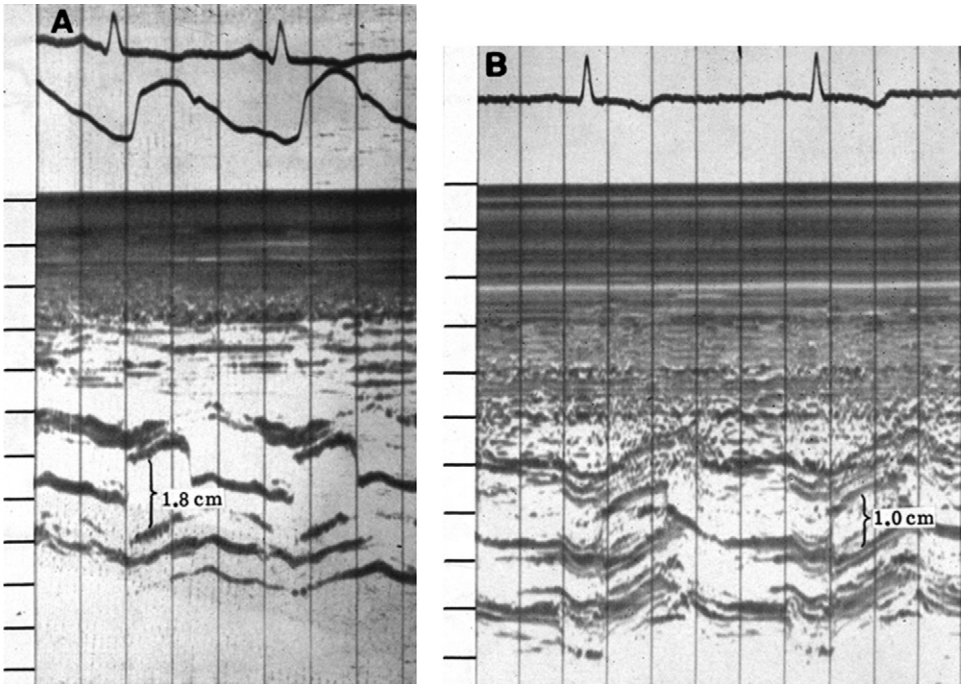

Figure 8 M-mode recordings of the aortic valve in a patient with a normal valve **(A)** and a patient with valvular aortic stenosis **(B)**. Both valves produce a parallelogram on the M-mode tracing; however, the stenotic valve is more echogenic and the separation of the leaflets is reduced. Although this recording provides no quantitative information, it does confirm that if there is LV outflow obstruction, then the aortic valve is at least a contributor of, if not the sole reason for, the obstruction. (From Feigenbaum H. *Echocardiography.* 1st ed. Philadelphia, PA: Lea and Febiger; 1972.)

look similar to a Doppler recording and the 2 findings may occur in the same patient, but in reality they are not the same but rather complementary. One represents blood velocity, and the other reflects volumetric flow.

Figure 2 shows some of the obvious diagnostic value of an M-mode mitral valve recording. Figure 2A again exhibits a normal M-mode mitral valve. The excursions of the anterior and posterior leaflets virtually fill the LV cavity. The mitral anterior leaflet reaches its peak at the E-wave that almost touches the interventricular septum. The posterior leaflet moves in an opposite direction as the 2 leaflets separate from each other. The M-mode recording in Figure 2B, which has the same calibration as Figure 2A, is grossly different. The LV cavity is much larger with the location of the posterior ventricular wall being much further from the transducer. The size and shape of the mitral valve in Figure 2B are strikingly different from that in Figure 2A. The distance between the anterior and posterior leaflets is substantially less than in Figure 2A. This finding is indicative of decreased blood flow passing through the mitral orifice, or at least reduced flow relative to the size of the ventricle. The increased distance or separation between the peak of the mitral valve opening or E-point and the septum is obvious. This E-point septum separation (EPSS) has been used for years as an indicator of global LV function.[2-5] Any EPSS greater than 1 cm is considered to be abnormal.[4] There is a good theoretic reason why EPSS correlates with ejection fraction. Ejection fraction is stroke volume divided by diastolic volume. The flow going through the mitral valve is related to stroke volume. Therefore, the E-point is reduced because of the small amount of blood flowing through the mitral orifice. As the left ventricle dilates, the mitral valve apparatus, which is more closely aligned to the posterior ventricular wall, moves away from the interventricular septum. Thus, the E-point septal separation is related to the LV end-diastolic volume and the transmitral stroke volume, which are the 2 components of ejection fraction. The EPSS is not valid in some patients with primary valvular abnormalities. Mitral valve motion in patients with mitral stenosis and patients with aortic regurgitation is distorted by factors other than flow passing through the valve and cannot be used to measure EPSS.

Another observation in Figure 2 is that the A-wave of the mitral valve looks decidedly different between Figure 2A and B. In Figure 2B the amplitude of the A-wave is reduced and the slope of the mitral motion after the peak of the A-wave is much different than the slope in the normal recording. In Figure 2B there is a more gradual closure of the mitral valve after the peak of the A-wave. There is also a slight interruption of mitral closure. Clearer examples of interrupted mitral valve closure are illustrated in Figure 3. This finding is helpful in identifying patients with an elevated LV end-diastolic pressure.

Figure 4 shows how mitral valve closure is related to LV and left atrial pressures.[6,7] Normally, mitral valve closure begins with atrial relaxation and then is completed with LV contraction. This process is usually smooth and uninterrupted. The corresponding pressure between the left atrium and the left ventricle is characterized by a gradual increase in left atrial pressure after atrial contraction, which in turn produces a gradual increase in LV pressure. When there is an elevated LV end-diastolic pressure as a result of the left atrium contracting against a stiff or already fully dilated left ventricle, there is a rapid increase in the LV pressure to a point that it exceeds the left atrial pressure earlier than is normal.[8] This earlier reversal in the pressures causes the peak of the mitral valve A-wave to be earlier. Then there is a more prolonged closure of the mitral valve before ventricular contraction with a frequent interruption or plateau caused by equalization of the pressures. This interruption is called a "B-bump,"

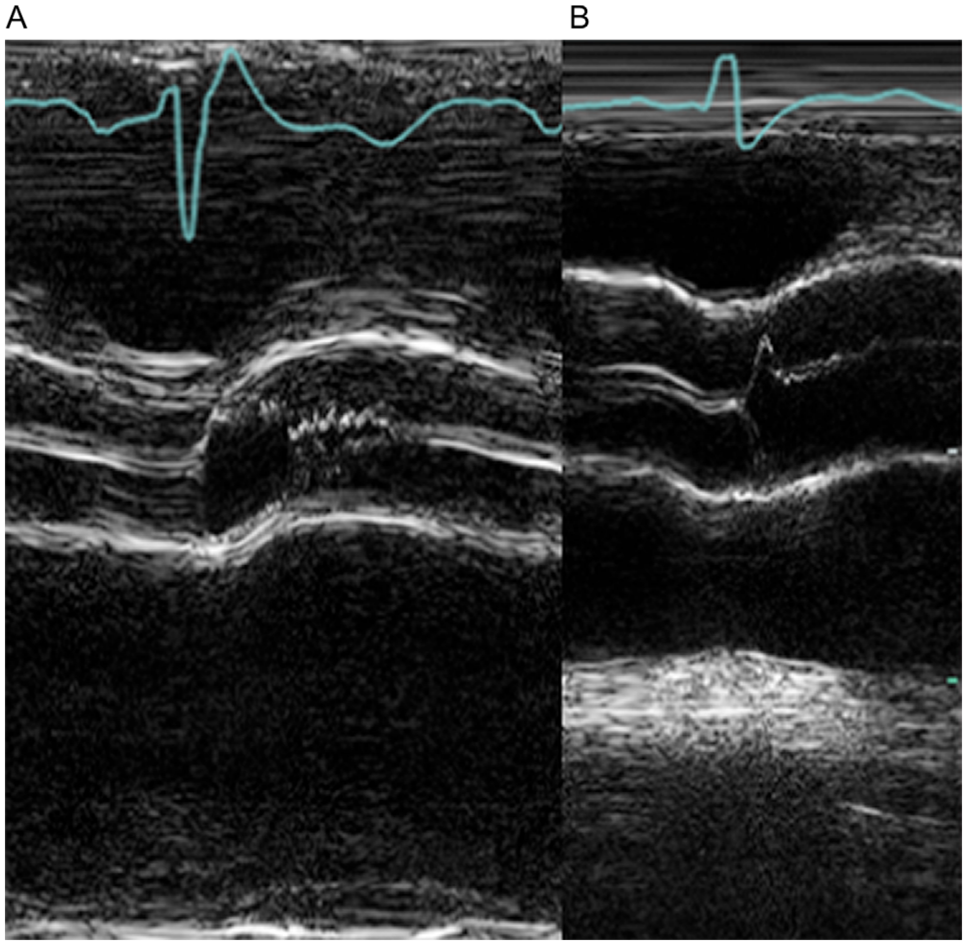

Figure 9 **A,** Mid-systolic closure of the aortic valve caused by dynamic obstruction of the LV outflow tract in a patient with hypertrophic obstructive cardiomyopathy. **B,** M-mode aortic valve recording in a patient with discreet membranous subaortic stenosis. The valve initially opens fully and then abruptly closes. (Courtesy of Alan S. Pearlman, MD.)

or "notch" or "shoulder," between the A and C points of the mitral valve.

In current discussions of diastolic function and LV pressure, the M-mode mitral valve "B-bump" is almost never mentioned. It is not a strictly quantitative assessment; however, it almost never occurs unless the LV end-diastolic pressure is more than 20 mm Hg.[6] Figure 3A shows a distinct plateau between the A and C points of the mitral valve. This recording was made with the older technique using 2000 samples per second. Figure 3B shows a more recent study with standard 2D-guided M-mode echocardiography again showing the interrupted closure of the mitral valve after the A-wave. This M-mode finding is still relevant today. It may be one of the easier ways to help identify mitral flow Doppler "pseudo-normalization" and an elevated LV end-diastolic pressure. A "B-bump" is not a normal finding and should not occur if the LV diastolic pressure is normal and the mitral flow is truly normal. This M-mode finding can also be useful in differentiating patients who have a mitral Doppler E/A ratio less than 1 because of abnormal LV relaxation from those in whom the abnormal ratio is caused by low LV filling pressures. Patients with diastolic dysfunction frequently may have elevated diastolic pressures and an M-mode B-bump, which will not be present with low LV filling pressures. This situation is another example of how M-mode and Doppler recordings can provide complementary hemodynamic information.

Figure 5 shows another mitral valve M-mode recording indicative of an elevated LV diastolic pressure. This older recording shows premature closure (C) of the mitral valve before electric depolarization. This finding is indicative of a patient with severe aortic regurgitation in whom the LV diastolic pressure increases dramatically to the point that it closes the mitral valve before ventricular contraction.[1]

Several well-recognized findings on an M-mode recording of the mitral valve are also seen with 2D echocardiography, and the hemodynamic consequences are recorded with Doppler techniques. One of these is systolic anterior motion (SAM) of the mitral valve, which is indicative of a dynamic obstruction of the LV outflow tract.[9,10] Historically, the M-mode technique was the first to describe this phenomenon. Figure 6 shows 3 different varieties of SAM. Figure 6A shows a recording in a patient with known hypertrophic cardiomyopathy where the SAM gradually approaches the interventricular septum and then falls away before the onset of diastole. Figure 6B shows another patient with SAM whereby the mitral valve apparatus only briefly touches the interventricular septum late in systole. Figure 6C shows yet a more severe form of SAM that is almost undoubtedly caused by hypertrophic cardiomyopathy and fairly significant LV outflow tract obstruction. There is early apposition of the mitral valve to the interventricular septum, and the valve stays in contact with the septum almost throughout systole. The duration of contact between the mitral valve and the septum is one

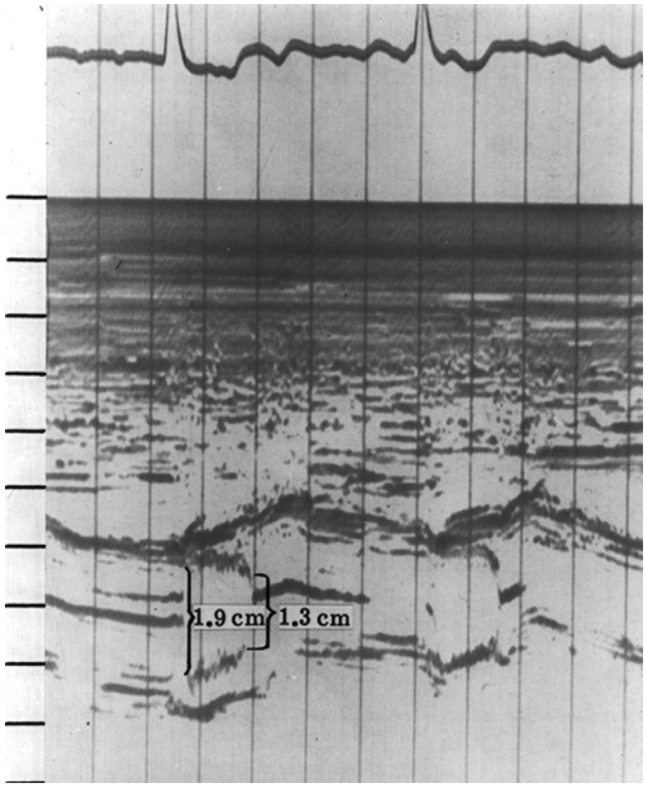

Figure 10 M-mode aortic valve recording showing gradual closure of the valve throughout systole. This finding indicates that blood flow through the valve is constantly decreasing during systole either because a left ventricle is too weak to maintain constant flow or the blood is leaving the left ventricle via a regurgitant mitral valve rather than via the aorta. (From Feigenbaum H. *Echocardiography.* 1st ed. Philadelphia, PA: Lea and Febiger; 1972.)

way of judging the severity of obstruction.[10] However, now we rely on Doppler recordings for making this assessment.

SAM can be recorded with 2D echocardiography; however, the timing of the SAM in 2D echocardiography does not come close to appreciating the timing and duration of contact between the valve and the interventricular septum. The M-mode recording of SAM may not be considered critical in today's management of patients with hypertrophic cardiomyopathy, but it does add to our understanding of the mechanism underlying any LV outflow obstruction and is confirmatory or complementary to the Doppler recording of dynamic LV outflow obstruction, especially if there is any question about the Doppler recording.

Figure 7 represents another M-mode recording that many would think has only historical value. These recordings are of patients with mitral valve prolapse.[11-14] The M-mode criteria are rarely used today as a definitive way to make the diagnosis. The only real value is that the timing of the prolapse is better appreciated with the M-mode technique. For example, in Figure 7A the posterior displacement of the posterior leaflet seems to begin fairly early in systole and peaks in the latter half of systole. This leaflet motion produces essentially holosystolic separation and regurgitation with late systolic accentuation. In contrast, Figure 7B shows separation of the leaflets to occur only in the latter half of systole, resulting in a shorter duration of the separation and regurgitation, and becomes a factor in quantifying the degree of regurgitation.

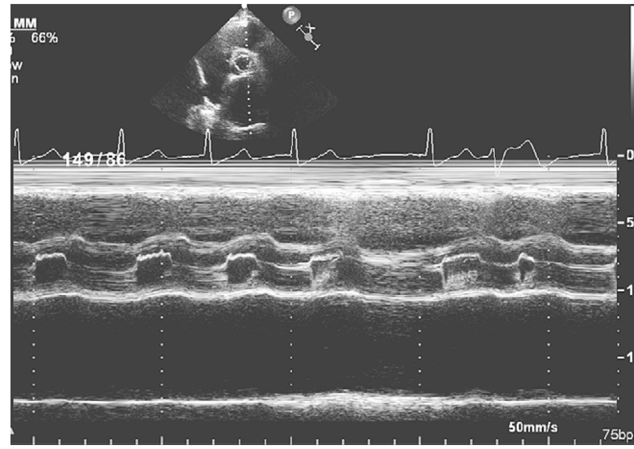

Figure 11 Aortic valve M-mode recording demonstrating variations in systolic valve motion reflecting changes in volume of blood passing through the valve. In this patient with atrial fibrillation and very poor cardiac function, there is also diminished amplitude of motion of the posterior aortic wall reflecting poor overall cardiac function and changes in left atrial volume. PA, pulmonary artery; RV, right ventricular.

M-MODE RECORDING OF THE AORTIC VALVE

Although the motion of the aortic valve is not as complex as the mitral valve, an M-mode recording of this structure also can provide useful clinical information even in today's practice of echocardiography. Figure 8A shows a normal recording of the aortic valve. The aortic valve produces a characteristic parallelogram whereby 2 of the 3 leaflets are seen moving parallel to each other throughout systole. Figure 8B shows an M-mode recording of a thickened, somewhat stenotic aortic valve. Originally, we thought we could judge the severity of the aortic stenosis by seeing the separation of the 2 leaflets; however, this proved to be unreliable, especially with congenital aortic stenosis. The real value in looking at the valve in Figure 8B is the observation that the leaflets are thickened and, more important, moving parallel to each other. In the setting of LV outflow obstruction, this finding clearly denotes that at least part if not all of the obstruction is at the aortic valve level because the leaflets are separated to the maximum degree throughout systole.

Figure 9 shows different types of aortic valve patterns. In Figure 9A, there is an abrupt closure of the valve in the latter half of systole. This finding represents a dynamic obstruction of flow, usually as a result of subaortic obstruction. This obstruction could be dynamic or due to a fixed abnormality. Although valve closure in early systole occasionally occurs with dynamic obstruction,[1] the lateness of this valve closure in mid-systole indicates that this obstruction is dynamic. The Doppler flow velocity will usually make a more definitive diagnosis as to whether or not it is dynamic with late systolic peaking of the Doppler flow velocity. However, with severe obstructive cardiomyopathy, one can get a fairly holosystolic Doppler flow and the dynamic nature might be more difficult to identify without seeing this M-mode phenomenon of the aortic valve.

A fixed form of subaortic obstruction is noted in Figure 9B. This aortic valve recording is from a patient with a fixed membranous subaortic stenosis. There is a brief full opening of the valve followed by an abrupt closure of the anterior leaflet. Contrary to a dynamic obstruction, this type of outflow obstruction almost always has early systolic closure of the valve. An M-mode recording in a patient with

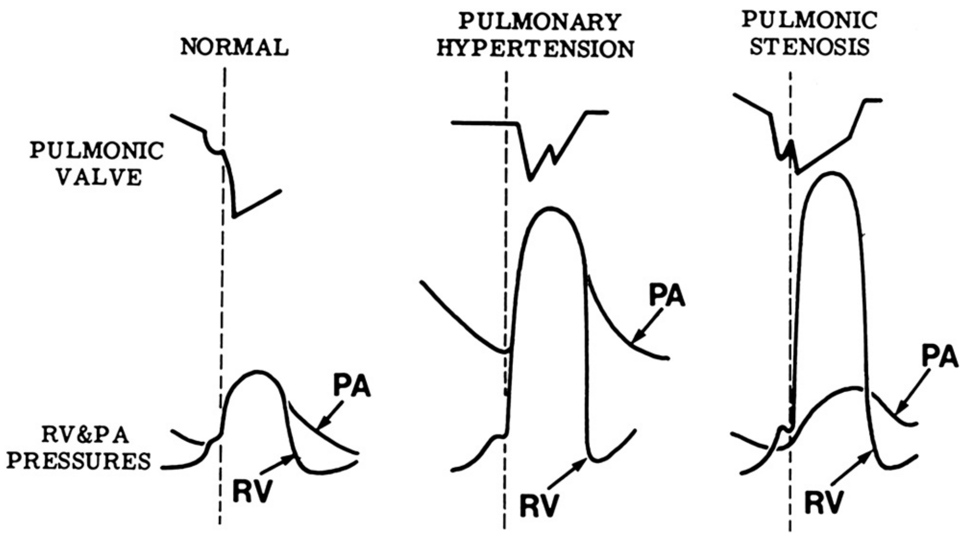

Figure 12 Relationship between the M-mode recording of the pulmonic valve and the pressures in the right ventricle and pulmonary artery. (From Feigenbaum H. *Echocardiography.* 1st ed. Philadelphia, PA: Lea and Febiger; 1972.)

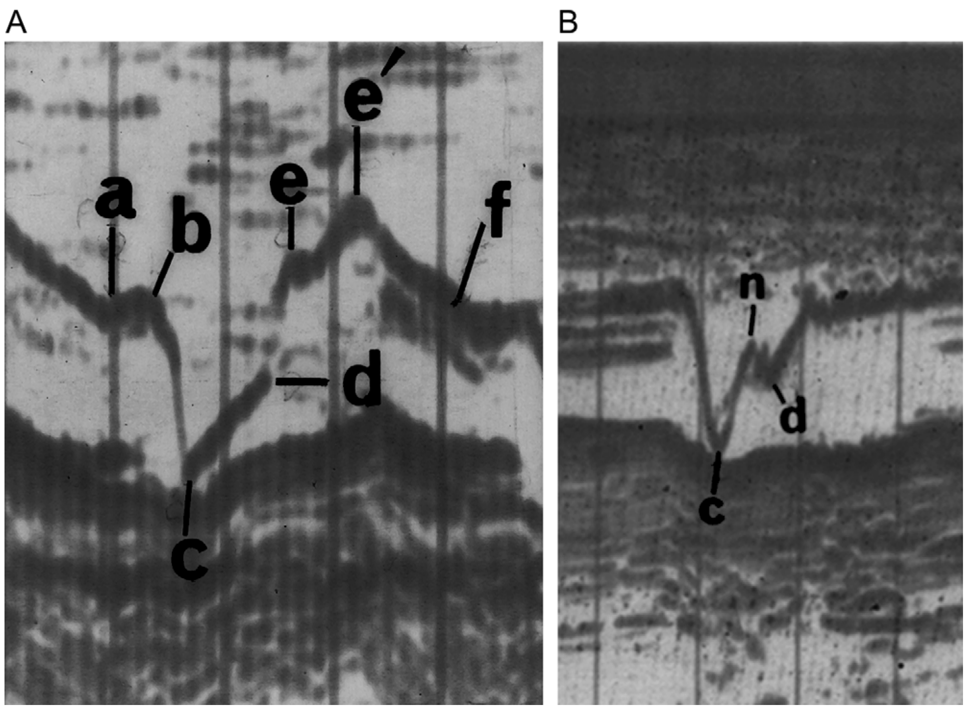

Figure 13 **A,** M-mode examination of a normal pulmonic valve. Only 1 of the leaflets is usually recorded. **B,** M-mode pulmonic valve recording from a patient with pulmonary hypertension. The "a" wave is absent, and there is mid-systolic closure (n) in mid-systole. This finding has been called the "flying W" sign. (From Feigenbaum H. *Echocardiography.* 1st ed. Philadelphia, PA: Lea and Febiger; 1972.)

a membranous discrete subaortic stenosis is particularly useful because the differentiation between valvular and subvalvular aortic stenosis is not always perfectly obvious. The membrane can be very thin and may not be recorded well echocardiographically or even angiographically. Furthermore, the early or mid-systolic closure of the aortic valve rules out significant valvular obstruction.

Finding non-parallel aortic valve leaflets can be critical in making the proper diagnosis in many situations. Normally, aortic valve flow is constant throughout systole so that the leaflets remain parallel (Figure 8A). Figure 9 shows the effects of subvalvular obstruction. Figure 10 demonstrates another form of non-parallel aortic valve leaflet motion. In this situation the leaflets gradually close throughout systole. This gradual closure of the valve indicates that the blood flowing through the aortic valve is not being sustained but gradually diminishes throughout systole.[15] This finding may occur in patients with mitral regurgitation who have a significant degree of regurgitation. The initial LV stroke volume may pass into the aorta, fully opening the aortic valve. As systole progresses, more of the blood is moving into the

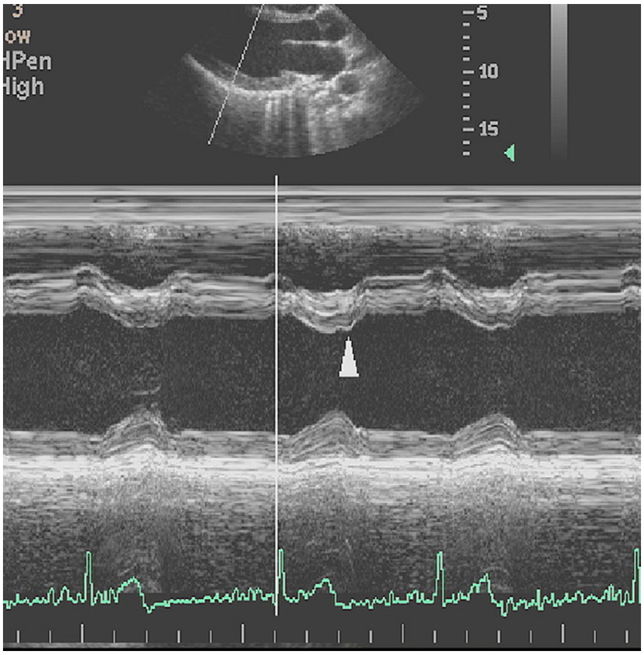

Figure 14 M-mode recording through the body of the left ventricle illustrating the motion of the interventricular septum and the posterior LV wall. There is a slight pause between the onset of electrical depolarization (*vertical line*) and opposing motion of the 2 walls. The peak downward motion of the interventricular septum slightly precedes the peak upward motion of the posterior wall. In early diastole, there is a small downward motion of the septum (*arrow*, diastolic "dip") as the result of early RV filling preceding filling of the left ventricle.

left atrium and less is going through the aortic valve. In some patients with significant mitral regurgitation, the gradual aortic valve closure may occur later in systole. Gradual aortic valve closure may also occur with low cardiac output because of a poorly contracting left ventricle. Under these circumstances even the initial opening may be reduced as well. Figure 11 is an aortic valve M-mode recording from a patient with very poor cardiac function, atrial fibrillation, and ventricular ectopy. There is marked variation in aortic valve opening according to the amount of blood passing through the valve with each cardiac cycle.

Figure 11 also shows another indicator of cardiac function, that is, motion of the posterior aortic wall, which is also the anterior wall of the left atrium. In this patient the amplitude of motion of the left atrial wall is markedly reduced, which is another indicator of poor overall cardiac function.[16,17] A fairly recent study found that the diastolic slope of the M-mode aortic motion could help identify pseudonormalization of mitral Doppler recordings.[18]

M-MODE RECORDING OF THE PULMONIC VALVE

The pulmonic valve is sometimes considered to be the forgotten valve. It is not the easiest valve to record with M-mode or 2D echocardiography, especially in adults. We frequently merely rely on the easier to record Doppler pulmonic valve velocity for the valve evaluation. Even in those laboratories where M-mode echocardiography is still a part of the examination, the pulmonic valve is frequently not interrogated. The diagram in Figure 12 shows some of the diagnostic findings of an M-mode recording of the pulmonic valve.[19] Because of the orientation of the valve to the M-mode beam, only the motion of one of the leaflets is usually recorded. The normal valve has a small "a"-wave secondary to atrial contraction. The valve then opens and stays open throughout systole. Figure 13A illustrates an M-mode recording of a normal pulmonic valve.

The most important use of the M-mode recording of the pulmonic valve today is for those few patients who have pulmonary hypertension and may not have a good enough tricuspid regurgitation jet to fully appreciate the severity of the pulmonary hypertension. In these patients, the pulmonary artery is frequently dilated and the recording of the pulmonic valve is technically easier. With pulmonary hypertension one will see an absence of the "a" wave.[19-22] However, the "a" wave might reappear if the right ventricular (RV) diastolic pressure becomes elevated. The more striking finding is that in systole there is mid-systolic closure and then reopening of the valve before diastole (Figure 13B). This pattern is sometimes referred to as the "flying W" sign. It is a fairly specific finding of severe pulmonary hypertension and usually elevated pulmonary vascular resistance.

The M-mode pulmonic valve finding of pulmonic stenosis with its exaggerated "a" wave (Figure 12) is hardly used anymore. We rely almost entirely on a Doppler gradient for that diagnosis.

OTHER VALVULAR M-MODE RECORDINGS

The M-mode recording of the tricuspid valve has a few isolated uses; however, it is not nearly as relevant in today's practice of echocardiography and is not going to be discussed in this article.

There also are some useful M-mode signs for prosthetic valves. They again are rarely being used. However, there are a couple of situations in which they can be useful, especially with some older mechanical valves. The tilting disk valve, especially the Bjork-Shiley valve (Pfizer, New York, NY), was a popular valve for a long time. One of the first signs of malfunction was that the peak opening of the valve was rounded rather than producing a sharp E point. That finding indicated that there was something (ie, fibrosis or clot) impairing the full opening of the valve. The other valve that was commonly used in the early days was the Starr-Edwards (Edwards Lifesciences, Irvine, CA) ball-in-cage valve. This valve would intermittently stick at times, and a long recording of this valve might show intermittent partial or incomplete opening of the valve. Because both valves are rarely used today, the M-mode techniques are rarely used for looking at prosthetic valves. If, however, a patient has one of these older valves and even one of the newer disk valves, then an M-mode recording should be seriously considered to document the timing and pattern of prosthetic leaflet motion.

M-MODE RECORDING OF THE INTERVENTRICULAR SEPTUM

In my judgment, probably the most important use of the M-mode technique today is using it to record the interventricular septum. Although the septum by and large does not move with the same rapidity as the valves, it is amazing how rapidly the septum can move in certain situations. This septal motion can provide important clinical information, especially in today's practice. Figure 14 shows an M-mode recording of a patient with normal septal motion. The relationship of septal motion to the onset of the electrocardiographic QRS is shown with the vertical line. The septum essentially functions as one of the

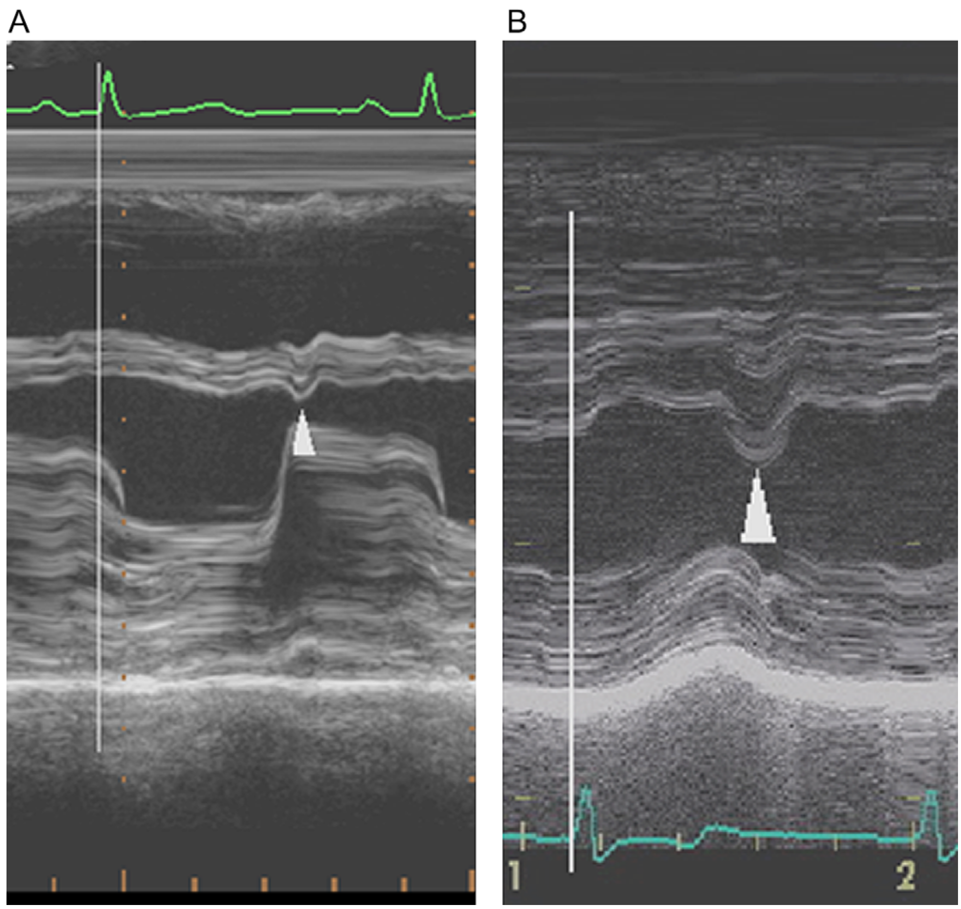

Figure 15 **A,** M-mode recording showing an exaggerated septal diastolic "dip" (*arrow*) in a patient with mitral stenosis. This finding highlights the fact the RV filling is unimpeded while the stenotic mitral valve restricts LV filling. **B,** This recording is taken from a patient with severe pulmonary hypertension and severe tricuspid regurgitation. The RV volume overload produces an upward motion of the septum immediately after ventricular depolarization (*vertical line*), because the septum is flattened toward the left ventricle in diastole and "pops out" with onset of systole. The second finding is a very exaggerated diastolic "dip" (*arrow*).

walls of the left ventricle. Of special note, however, there is a small notch in the septal motion at the onset of diastole (*arrow*). This motion is sometimes referred to as the diastolic "dip." The explanation for this phenomenon is that aside from essentially being one of the walls of the left ventricle, the septum also reflects the relative volume flow in the 2 ventricles. Because the right ventricle is a more compliant ventricle with a larger tricuspid orifice, the right ventricle fills slightly before the left ventricle, and this filling of the right ventricle produces a brief displacement of the interventricular septum toward the left ventricle. The left ventricle then fills, and the septum then moves back toward the neutral zone. One can frequently see relatively flat or slightly upward motion of the septum throughout diastole with another slight upward motion of the septum with atrial contraction. It should be noted that the peak downward motion of the septum, which precedes the diastolic "dip," also slightly precedes the peak upward motion of the posterior LV wall.

Figure 15 demonstrates that the diastolic "dip" may be exaggerated in some situations, especially with mitral stenosis (Figure 15A). With the mechanism for the diastolic "dip" being that it reflects relative early filling of the ventricles, the exaggerated diastolic "dip" with mitral stenosis should not come as a surprise. With mitral stenosis, there is impeded diastolic flow into the left ventricle; therefore, the unimpeded early RV filling is even relatively greater than normal and thus there is an increased diastolic "dip." Figure 15B shows an even greater exaggerated diastolic "dip." This recording is of a patient with pulmonary hypertension, severe tricuspid regurgitation, and RV failure. Under these circumstances the filling of the right ventricle was significantly greater than that of the left ventricle and the diastolic "dip" was more striking in depth and duration.

Figure 16 demonstrates probably one of the most important uses of M-mode echocardiography in today's practice of cardiology. This M-mode examination of the interventricular septum shows the classic findings in a patient with left bundle branch block (LBBB). There is a typical brief downward dip or "beak" followed by upward motion of the septum shortly after the onset of electrical depolarization (*left arrow*).[23] This "beak" is presumably a result of the abnormal depolarization of the septum inherent in an LBBB abnormality and occurs during the isovolumic contraction period. Because this "beak" septal motion occurs during isovolumic contraction, it has no effect on the ejection of blood from the left ventricle.

The critical septal motion in the patient in Figure 16 is that during the ejection of blood from the left ventricle the septum is moving paradoxically or toward the right ventricle.[24-26] With the onset of diastole there is a somewhat exaggerated early diastolic "dip" (*right arrow*). One can appreciate that this septum is not contributing to the LV function of ejecting blood.[27] Septal motion toward the left ventricle

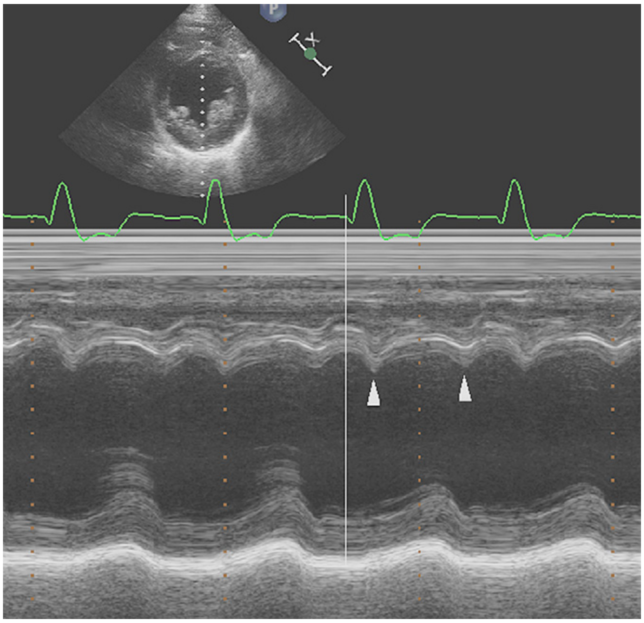

Figure 16 Septal motion in a patient with LBBB. The characteristic M-mode finding with LBBB is a downward and then upward motion of the septum (*first arrow*, "early systolic beak") shortly after electrical depolarization. The septum moves paradoxically or toward the right ventricle during ventricular ejection of blood. The diastolic "dip" (*second arrow*) is frequently exaggerated. There is also delayed upward motion of the posterior wall.

is only during isovolumic contraction (*left arrow*) and early diastole (*right arrow*). Thus, LBBB with paradoxical septal motion during systole is a negative inotropic event. It is the equivalent to having an akinetic or dyskinetic septum with a myocardial infarction. One can easily appreciate how an LBBB with paradoxical septal motion is a significant negative inotropic phenomenon for LBBB. In this particular patient, the ventricle is also dilated.

Figure 17 presents M-mode septal recordings from other patients with LBBB. The early systolic "beak" (*left arrow*) is again seen in all 3 examples, although it may not be as prominent as in the previous illustration. In Figure 17A the septal motion during ejection of blood is flat and followed by the diastolic "dip" (*second arrow*). In Figure 17B, one again sees the early systolic "beak" (*left arrow*) and the diastolic "dip" (*right arrow*). However, in this patient, during systole the septum is moving toward the left ventricle and contributing to LV function. This is a so-called benign or nonparadoxical LBBB. The LV cavity is not dilated, and this type of LBBB does not cause significant deterioration in global LV function. Another example of a nonparadoxical LBB is shown in Figure 17C. Again, the classic left bundle "beak" is visible (*left arrow*). However, during systolic ejection of blood the septum is moving normally. In this particular patient, the normal systolic motion is combined with the diastolic dip so that it is somewhat difficult to know exactly when systole ends. Again, the left ventricle is not dilated and global LV function is intact.

Figure 18A shows a patient with a dilated cardiomyopathy, supposedly caused by chemotherapy. There is a paradoxical LBBB pattern with the "beak" and diastolic "dip" separated by a totally akinetic septum and dilatation of the left ventricle (5.5 cm). There was recovery of the myopathic process as the chemotherapy was removed, and the patient reverted to a more benign or nonparadoxical form of LBBB (Figure 18B). Now the septum is moving toward the left ventricle during the ejection of blood, and the ventricle has shrunken to a normal size. The patient also obviously improved clinically.

Figure 19 shows the more frequent consequence of today's management of patients with cardiomyopathy and LBBB. Figure 19A shows a somewhat broadened systolic "beak" of the left bundle pattern. Again the septal systolic motion is akinetic and the left ventricle is dilated (6.6 cm). After resynchronization therapy (Figure 19B), there is dramatic improvement with the absence of any left bundle "beak" and normal septal motion during ejection of blood. The LV end-diastolic diameter now decreased to 5.4 cm. The patient was obviously clinically improved.

This patient can be compared with the patient seen in Figure 20, who had a dilated cardiomyopathy and met the usual criteria for resynchronization therapy with a wide QRS but no LBBB. The echocardiograms before and after resynchronization are shown. There was no echocardiographic evidence of LBBB, and there was no improvement after resynchronization therapy.

Those who currently use M-mode echocardiography to evaluate patients for resynchronization therapy frequently use the "shortest interval between the maximal posterior displacement of the septum and the maximal displacement of the posterior wall using a monodimensional short-axis view at the papillary muscle level."[28] In the M-mode recording illustrated in that article (Figure 21), the interval demonstrated is from the septal "beak" to the peak upward posterior wall motion.[28] The theory behind resynchronization is that the walls of the left ventricle are not contracting synchronously for the efficient ejection of blood. The septal "beak" is not involved in the ejection of blood. On the basis of my own experience when selecting patients for resynchronization therapy, the pattern of septal motion is an important factor and may be more important than the recommended M-mode time interval measurements. The M-mode pattern of septal motion should be included as one of the criteria in future studies evaluating echocardiography's role in identifying patients for resynchronization therapy.

One of the most difficult diagnoses to make in echocardiography is the diagnosis of constrictive pericarditis. Multiple echocardiographic criteria have been used. Many of these criteria include a variety of Doppler techniques. There are several 2D echocardiographic findings for making the diagnosis. One of these findings is a "septal bounce." The "septal bounce" is fairly nonspecific because there are several different reasons for the septum to move abnormally. In my judgment, any abnormal septal motion on a 2D echocardiogram is a clear indication for an M-mode recording of the septum to identify the cause of the apparent septal "bounce." Figure 22A is a recording from a patient with constrictive pericarditis. This M-mode echocardiogram demonstrates the reason for the septal bounce with constrictive pericarditis.[29,30] First, there are several different downward motions of the septum, each of which could produce a "bounce." There is normal systolic motion that is not indicated by an arrow in this recording. There is then an exaggerated diastolic "dip" (*left arrow*). The finding that is characteristic of constrictive pericarditis is the additional diastolic "dip" that occurs in early or mid-diastole (*right arrow*). The explanation for these 2 diastolic "dips" is that the thickened pericardium encases the 2 ventricles and limits their ability to expand and fill normally. As a result, the septum has to facilitate alternate filling of the 2 chambers. Motion of the septum downward toward the left ventricle represents RV filling, and upward motion toward the right ventricle indicates LV filling. This phenomenon has also been called "ventricular interdependence." The diastolic "dips" disappear, and the oscillating septum returns to normal after surgical removal of the constricting pericardium (Figure 22B).

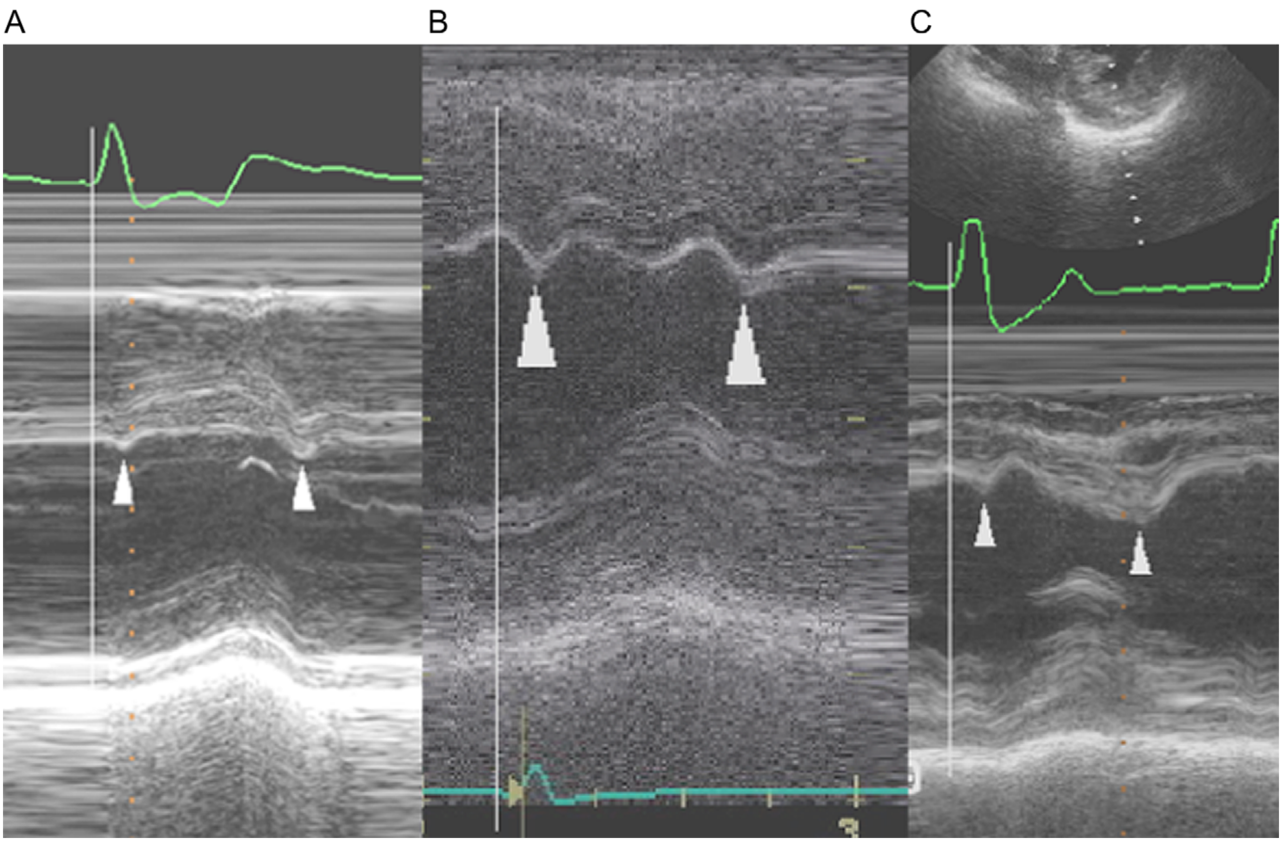

Figure 17 **A,** Another M-mode recording of septal motion in a patient with LBBB. Septal motion during LV systole, that is, between the septal "beak" (*first arrow*) and the diastolic "dip" (*second arrow*), is flat. **B,** In this patient with nonparadoxical LBBB, septal motion during systole (between the 2 *arrows*) is normal, moving downward toward the left ventricle. **C,** This patient also has LBBB as noted by the classic septal "beak" (*first arrow*). However, septal motion during the ejection of blood is completely normal. The peak downward motion of the septum is actually a prominent diastolic "dip" (*second arrow*).

M-MODE RECORDINGS OF THE RIGHT VENTRICULAR FREE WALL WITH PERICARDIAL EFFUSION

The one M-mode recording that is probably still being used is RV wall diastolic collapse as an indicator of hemodynamic compromise secondary to pericardial effusion.[31-34] Figure 23 shows the usual M-mode finding of RV diastolic collapse with pericardial effusion. One can make the same assessment using 2D echocardiography. In fact, the small 2D echocardiogram in Figure 23 shows an indentation of the RV wall. However, the M-mode recording can help determine that the collapse is truly in diastole. In addition to the electrocardiogram, one also has either the mitral valve or the aortic valve to help with more precise timing of wall motion. RV collapse is not always dramatic. Figure 24A shows a very subtle RV collapse that is clearly in diastole as judged by the aortic valve recording. This type of collapse can easily be missed by using just 2D echocardiography. There are also other varieties of RV collapse. Figure 24B illustrates holodiastolic collapse of the right ventricle whereby the RV cavity is virtually obliterated with severe hemodynamic compromise.

Figure 25 shows 2 phenomena that make the M-mode technique still relevant. There is not only collapse of the RV wall (*arrow*) but also a pattern of cardiac motion that covers 2 cardiac cycles, so that every other electrical depolarization finds the heart in a different location.[35-37] This alternating cardiac displacement affects the electrocardiogram and is the mechanism for the classic electrical alternans that is seen with a large pericardial effusion.[37] This recording also shows one of the advantages of M-mode echocardiography, especially in the era of digital echocardiography. One feature of digital echocardiography is that one no longer needs to record numerous cardiac cycles as with videotape. The ability to record only 1 digital cardiac cycle offers several advantages. However, there are certain situations, such as with intermittent or respiratory changes or a swinging heart, when one clearly needs more than 1 cardiac cycle to appreciate what is taking place. One may only need to record 3 cardiac cycles, but frequently one might need more. M-mode echocardiography is a convenient and efficient way to record multiple cardiac cycles.

Figures 26 and 27 illustrate another common use of M-mode echocardiography based on the ease with which multiple cardiac cycles can be displayed. In this case, the issue is whether or not the inferior vena cava collapses with inspiration.

CONCLUSIONS

It is hoped that this article will not merely be considered by many to be a historical review of an obsolete technique. I have tried to present enough evidence, without describing every possible use of M-mode echocardiography, to indicate that this technique should be taken seriously. Because of its superior temporal resolution, its complementary relationship to Doppler recordings, and its ability to record

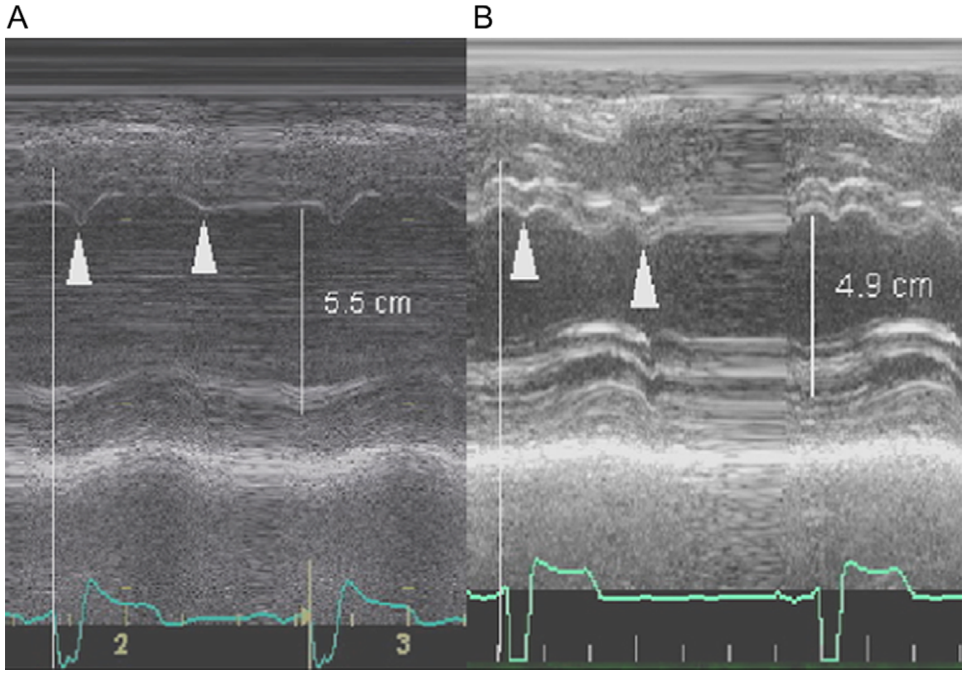

Figure 18 **A,** M-mode recording of a patient undergoing chemotherapy who developed LBBB, with a classic "beak" (*first arrow*), flat septal motion during systole, and dilated LV cavity. The *second arrow* indicates a relatively flat diastolic "dip." **B,** M-mode recording of the same patient after cessation of the chemotherapy. There is still a septal "beak" caused by the LBBB that is still present, but the LBBB is now non-paradoxical with the septum moving normally during systole. The left ventricle is no longer dilated. The *left arrow* is the LBBB "beak," and the *right arrow* is the diastolic "dip."

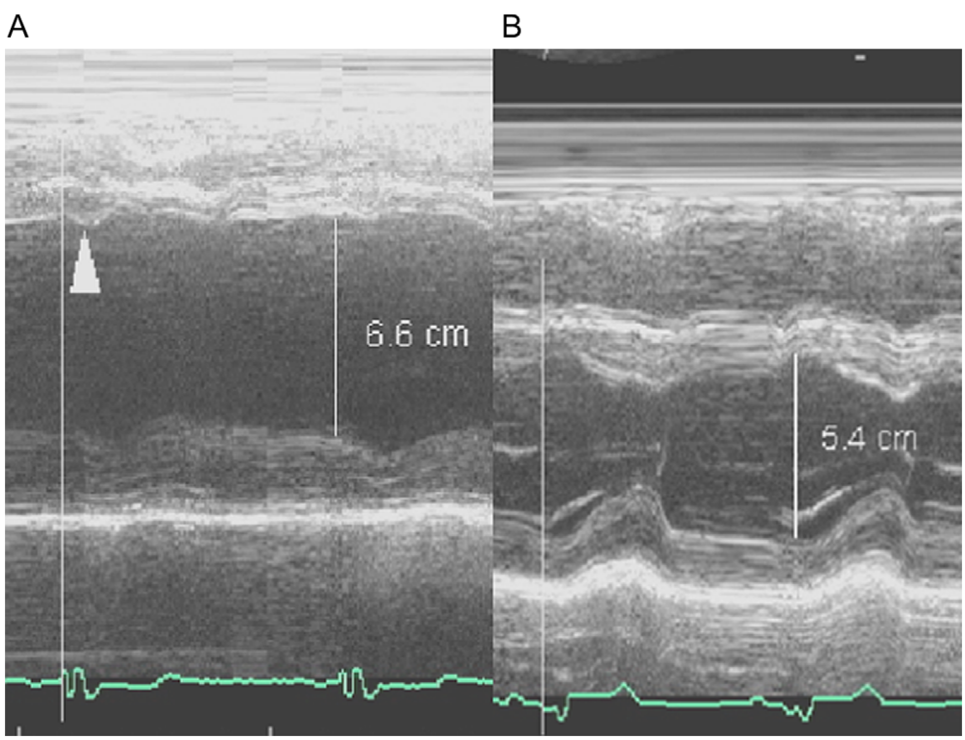

Figure 19 **A,** This patient has a dilated left ventricle with a broad septal LBBB "beak" and flat systolic septal motion. **B,** Same patient as in 28A after resynchronization therapy. Septal motion is now normal, the LV cavity is smaller, and the posterior wall is moving better.

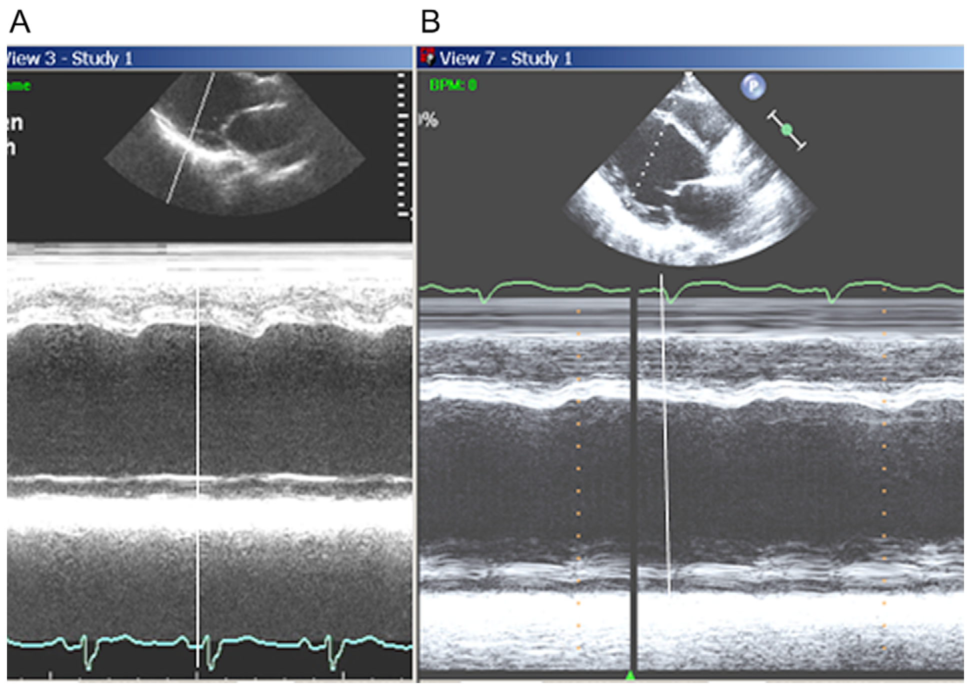

Figure 20 M-mode recordings before **(A)** and after **(B)** resynchronization of a patient with a dilated, poorly functioning left ventricle and no echocardiographic findings of LBBB. There is no improvement.

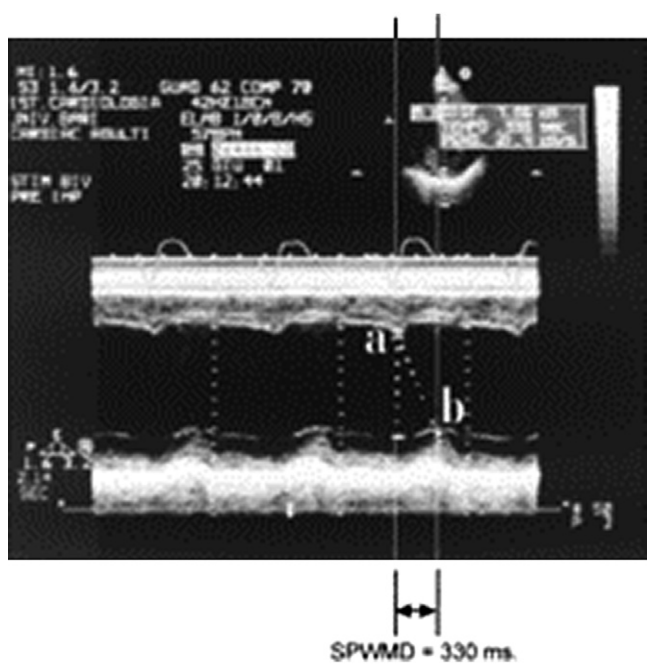

Figure 21 M-mode recording taken from the literature describing the time interval to be measured for identifying a patient suitable for resynchronization therapy. The time interval is from the early systolic "beak" to the peak upward motion of the posterior wall in this patient with LBBB. (From Pitzalis MV, Iacoviello M, Romito R, Massari F, Rizzon B, Luzzi G, et al. Cardiac resynchronization therapy tailored by echocardiographic evaluation of ventricular asynchrony. J Am Coll Cardiol 2002;40:1615-22.).

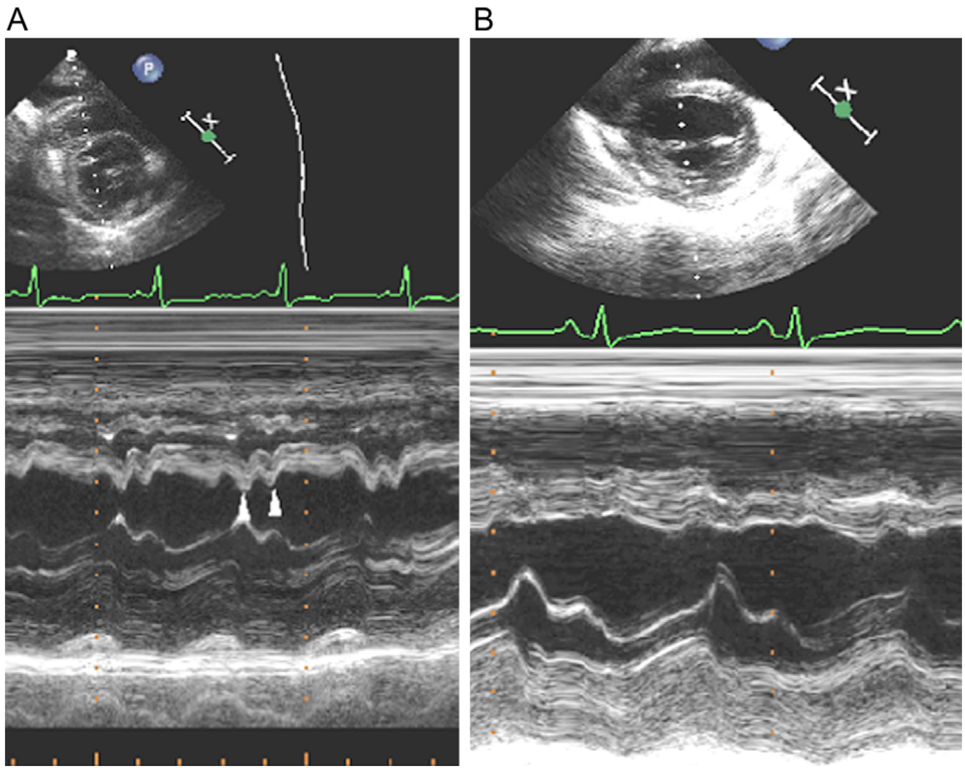

Figure 22 **A,** Interventricular septal motion in a patient with constrictive pericarditis. There is a prominent early diastolic "dip" (*left arrow*). Now there is also a second diastolic "dip" (*right arrow*). This illustrates how septal motion reflects filling of the 2 ventricles. Because the free walls of the ventricles are not free to expand properly, the chambers appear to fill alternately through changes in septal motion. **B,** M-mode recording of the same patient after pericardial stripping and relief of the constriction. Septal motion is now normal.

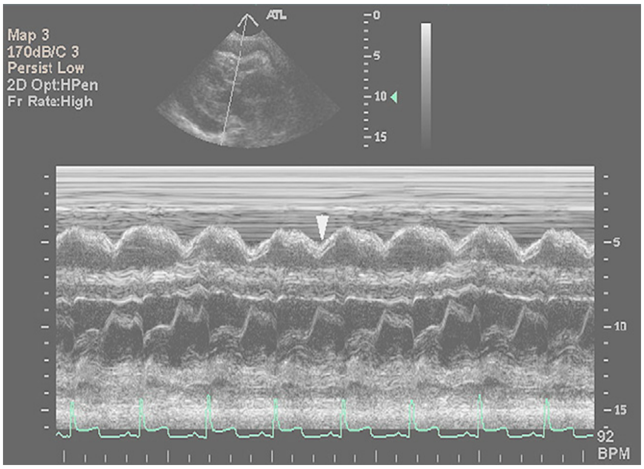

Figure 23 RV diastolic collapse (*arrow*) in a patient with pericardial effusion.

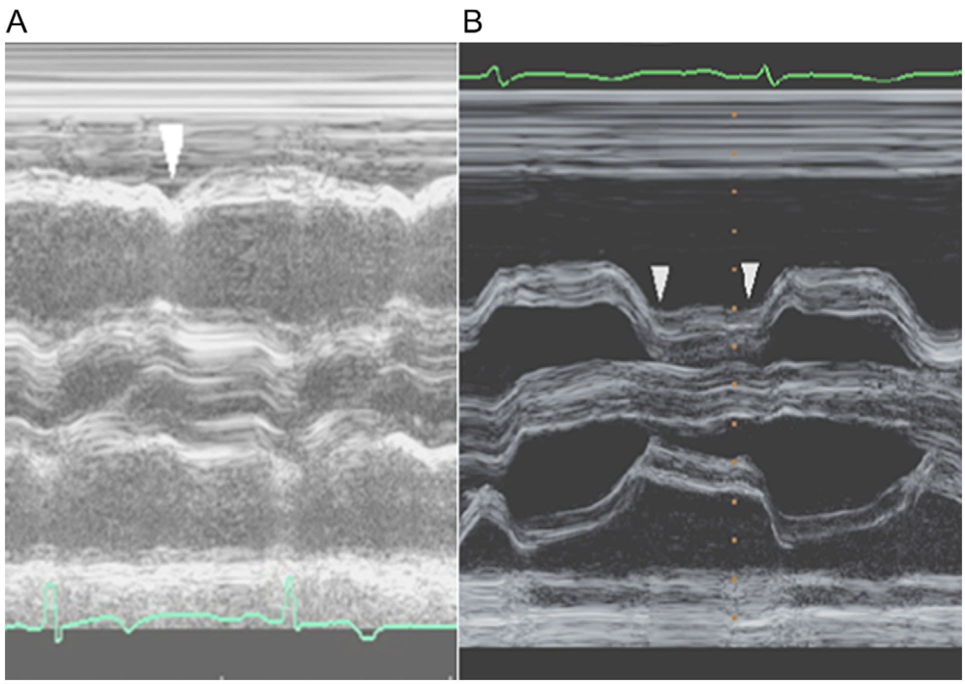

Figure 24 **A,** Mild RV early diastolic collapse in a patient with pericardial effusion. **B,** Extreme form of holodiastolic RV collapse (*arrows*) in a patient with a large pericardial effusion.

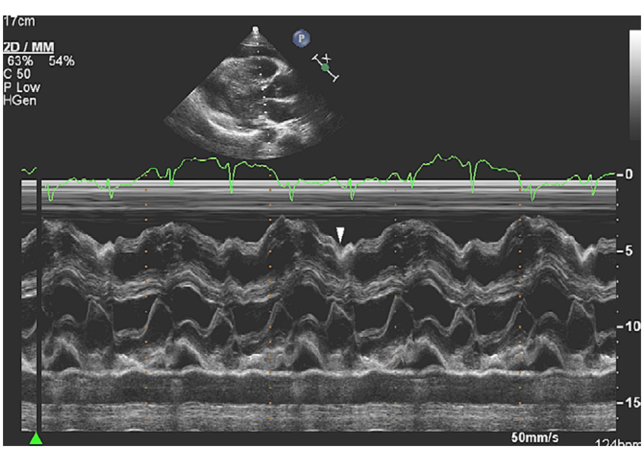

Figure 25 M-mode recording of a patient with a larger pericardial effusion and a “swinging” heart. RV diastolic collapse (*arrow*) is shown, and the heart is moving excessively so that it takes 2 cardiac cycles before the heart returns to its baseline position. The resulting alternating position of the heart produces electrical alternans on the electrocardiogram.

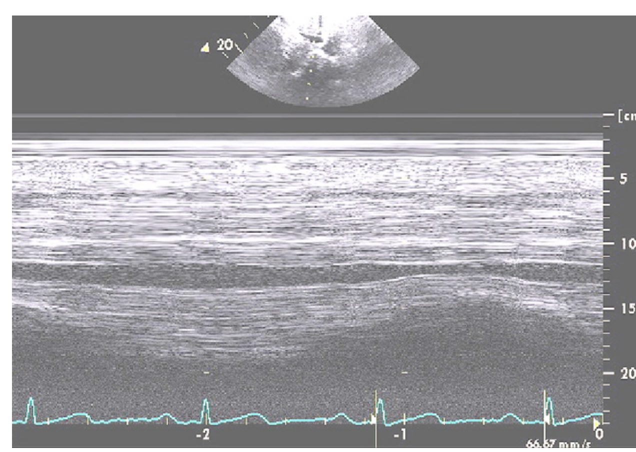

Figure 26 Respiratory change in size of the inferior vena cava in a patient with normal central venous pressure.

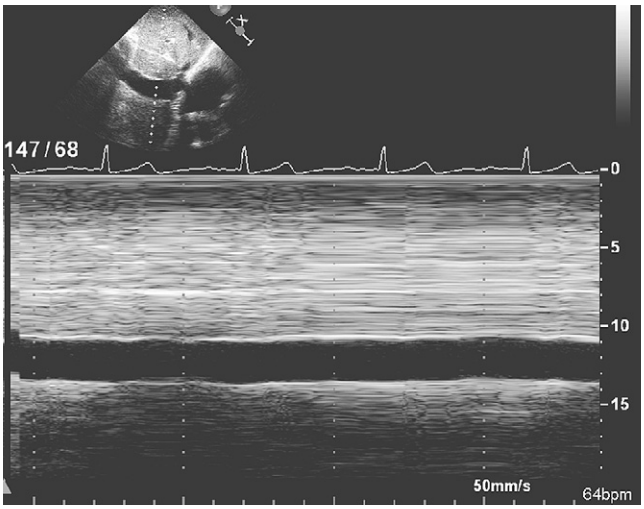

Figure 27 M-mode recording of an inferior vena cava that is dilated and does not vary in size with respiration in a patient with elevated central venous pressure.

multiple cardiac cycles efficiently and conveniently especially in the digital echocardiography era, M-mode echocardiography is alive and well. It should be a part of every routine transthoracic echocardiogram. M-mode recordings usually can be limited to the valves, especially the mitral and aortic, the interventricular septum, and the inferior vena cava. Situations where M-mode recordings are particularly useful are when the 2D echocardiogram exhibits abnormal interventricular septal motion or the Doppler tracings show abnormal hemodynamics. In these patients, ancillary M-mode information is frequently helpful. For example, it is likely that a careful analysis of septal motion with M-mode echocardiography should be a part of every patient being evaluated for cardiac resynchronization therapy.

We are entering a new era in the practice of medicine. Ordering multiple "complementary" tests will no longer be consistent with the necessity of being "cost-effective." Every test has to provide as much accurate information as possible while using time and equipment efficiently. M-mode recordings meet this criterion. No extra equipment is required. The recordings take very little time, and the interpretation is basically "pattern recognition" without any required time-consuming measurements. We need to remember that the most expensive test is one that produces wrong information. The second most expensive test is one that gives incomplete or nondiagnostic information. The addition of M-mode recordings should help make a routine transthoracic echocardiographic study more accurate, complete, and potentially more cost-effective.

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