Echocardiography in Mechanical Alternans
With a Note on the Findings in Discordant Alternans within the Left Ventricle

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SUMMARY  We describe the echocardiographic manifestations of mechanical alternation of left ventricular (LV) contraction during regular sinus rhythm. Chronic LV dilatation and failure existed in all our four cases. Alternation was observed with respect to the following echocardiographic variables: amplitude and rate of increase of amplitude of systolic excursions of the LV posterior wall and ventricular septum (VS); reciprocal changes in the duration of LV ejection and pre-ejection periods (on the aortic valve echo) such that the total duration of LV electromechanical systole remained constant; reciprocal changes in the duration of RV ejection and pre-ejection periods (on the pulmonic valve echo) such that the total duration of RV electromechanical systole remained constant; systolic anterior excusion of the aortic root as a whole; steepness of the mitral EF slope; septal and LV posterior wall diastolic position; and end-systolic LV diameter. In two patients, discordant alternans of the motion of the LV posterior wall and the VS was observed.

Since Pulsus Alternans was first described by Traube,1 it has been the subject of extensive experimentation and comment, including a recent review.2 In addition, a number of hemodynamic studies have been carried out in man.3-10 Katz and Feil in 1937,11 and more recently, Spodick and St. Pierre12 used phonocardiography and systolic time intervals in external arterial pulse tracings to investigate the pathophysiology of mechanical alternans. Visualization of alternately strong and weak ventricular contractions has been obtained by angiographic methods,5,6 but hitherto, to our knowledge, no echocardiographic description of the phenomenon has appeared.

Case Reports

Patient 1

Patient 1, a 30-year-old woman, had been admitted on several occasions for recurrent heart failure since the postpartum onset of her symptoms five years earlier. On examination she exhibited florid signs of severe left and right heart failure, including dyspnea at rest, orthopnea, basal pulmonary rales, gallop rhythm, and hepatomegaly. Pulsus alternans was evident on palpation of the radial pulse, and confirmed by sphygmomanometry which showed a difference of 15 to 20 mm Hg in systolic pressure between alternate beats. Her electrocardiogram (ECG) showed left ventricular (LV) hypertrophy and strain, and regular sinus rhythm with occasional ventricular premature beats. No electrical alternans was present. Her chest roentgenogram revealed considerable cardiomegaly and pulmonary venous congestion. An external carotid pulse tracing depicted an alternation in the amplitude of the arterial pulse, at a regular heart rate.

Echocardiography was performed using a Picker Echoview 10 ultrasonoscope connected to a Honeywell 1856 strip-chart Visicorder. Echocardiography of the aortic root (fig. 1, top) showed alternation in the amplitude of anterior systolic motion of the aortic root as a whole, and in the velocity of this anterior excusion. Alternation was manifest also in the duration of systolic opening of the aortic cusps, the beats with a longer LV ejection period being the ones with a greater systolic anterior excusion of the aortic root. Measurements made from tracings recorded at a paper speed of 100 mm/sec showed that the LV ejection period (interval between aortic valve opening and aortic valve closure) alternated between 185 and 172 msec and that the pre-ejection period (interval between onset of the QRS complex and aortic valve opening) alternated between 122 and 135 msec (fig. 1, bottom). Thus, the beats with shorter ejection periods had longer pre-ejection periods, so that the total period of electromechanical systole (onset of QRS to aortic valve closure) remained almost constant from beat to beat. Alternation in duration of LV ejection was accentuated after premature beats (fig. 2).

Measurement of right ventricular (RV) pre-ejection and ejection periods made in a similar manner on the pulmonary valve echo revealed an alternation of the RV pre-ejection period between 125 and 105 msec, and alternation of the RV ejection period between 190 and 210 msec (fig. 3). The beats with shorter RV pre-ejection periods had longer RV ejection periods, so that the total period of electromechanical systole for the RV, like the LV, remained virtually constant from beat to beat.

Both the LV posterior wall and ventricular septum (VS) showed poor systolic wall motion. However, the echocardiogram demonstrated an alternation in the amplitude of anterior systolic excusion of the LV posterior wall between 3 and 5 mm, and also in its maximum rate of rise of amplitude, which varied between 25 and 35 mm/sec; the beats with larger systolic excursions had steeper rises (fig. 4). The LV internal diameter at end-diastole, on echocardiography, was 69 mm and did not change appreciably between beats.

The mitral valve echo (fig. 4) exhibited an alternation in EF slope, the beats with stronger systolic contraction having a steeper EF slope in the ensuing diastole (average 80 mm/sec) compared to the weaker beats (average 45 mm/sec).

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The ECG at this time showed a regular rate of 104/min, and no variation in QRS contour. The VS (not illustrated) showed an alternation of amplitude of systolic motion, the larger excursions occurring in beats with larger LV posterior wall excursions.

Repeat echocardiography performed one month later, after medical therapy had resulted in disappearance of all the symptoms and signs of heart failure, showed that the echocardiographic signs of mechanical alternans were no longer present. However, the patient was readmitted two weeks later with the symptoms of heart failure, which were promptly controlled by continued medical therapy.

**Figure 1.** Top panel) Echocardiogram of the aortic root in patient I showing alternation in the duration of systolic opening of the aortic valve. The beats with longer systolic opening (LV ejection) exhibit a greater amplitude and velocity of anterior systolic motion of the aortic root as a whole. The ECG shows regular sinus rhythm. ECG = electrocardiogram; AAR = anterior aortic root; AV = aortic valve; PAR = posterior aortic root; LA = left atrium; LAPW = left atrial posterior wall; PP = parietal pericardium. Bottom panel) Echocardiogram of the aortic root in patient I at fast paper speed showing alternation in duration of the LV pre-ejection periods, such that beats with shorter LV ejection periods have longer pre-ejection periods and vice versa. LVPEP = left ventricular pre-ejection period (measured from onset of QRS to aortic valve opening); LVEP = left ventricular ejection period (measured from aortic valve opening to aortic valve closure).

**Figure 2.** Echocardiogram of the aortic root in patient I showing accentuation of mechanical alternans after a premature ventricular beat, as reflected in the duration of systolic opening of the aortic valve. The first thin arrow indicates the short LV ejection period of the premature beat; the postextrasystolic beat is a strong one and shows a long LV ejection period (thick arrow). The subsequent beats exhibit alternation of duration of LV ejection between weak beats (thin arrow) and strong beats (thick arrow).
weeks later in severe cardiac failure; pulsus alternans had reappeared and echocardiography revealed all the manifestations of mechanical alternans observed during her earlier admission. Repeat echocardiography two weeks later, after clinical relief of her cardiac failure, once again showed disappearance of mechanical alternans.

Patient 2

Patient 2 was an 80-year-old man who had a history of inferior wall myocardial infarction one year earlier coupled with systemic hypertension and electrocardiographic evidence of LV hypertrophy for many years. He was admitted with symptoms of left heart failure. The chest roentgenogram showed marked cardiomegaly, and the ECG showed sinus bradycardia, healed inferior wall infarction, LV hypertrophy with strain pattern, and ventricular premature beats occurring with occasional to moderate frequency. Electrical alternans was not manifest.

Echocardiography of the LV (fig. 5) revealed an enlarged diastolic diameter of 56 mm. The end-diastolic positions of the LV posterior wall and the VS were relatively anterior preceding beats 1, 3, 5, and 7, and relatively posterior preceding beats 2, 4, 6, and 8. Absolute values for end-diastolic diameters did not change, but end-systolic diameters alternated slightly from beat to beat. The onset of LV posterior wall systole occurred slightly later than VS systole. Greater excursions of the septal wall occurred in association with its more anterior end-diastolic position; conversely, greater excursions of the LV posterior wall occurred in association with its more posterior end-diastolic position. Thus, ventricular alternans during systole was discordant when movement of the VS was compared to movement of the LV posterior wall. The greater LV posterior wall excursions produced smaller systolic diameters than the greater VS excursions. In this patient the aortic cusps could not be visualized adequately, so no data are available on the duration of LV pre-ejection or ejection periods.

Patient 3

Patient 3, a 75-year-old woman with a previous history of myocardial infarction, was admitted with symptoms of left heart failure. Cardiomegaly and gallop rhythm were noted on examination. The ECG showed LV hypertrophy and changes suggestive of anterolateral and inferior wall ischemia. The echocardiogram showed alternans limited to three or four postextrasystolic beats. Alternation in magnitude and alternation in rate of increase in magnitude of systolic excursions of the LV posterior wall and VS were concordant, i.e., beats that exhibited larger LV posterior wall excursions also had larger septal excursions, and beats
showing smaller LV posterior wall excursions had smaller VS excursions. The beats with large LV posterior wall and VS systolic excursions were preceded by larger end-diastolic diameters. In the segment of the echocardiogram reproduced (fig. 6), alternation was well seen in systolic excursions of the posterior chordae which was better delineated than the LV posterior wall and VS.

**Patient 4**

Patient 4, a 63-year-old woman, presented with moderately severe cardiomegaly and congestive heart failure. The ECG showed left bundle branch block (QRS duration, 0.16 sec) with regular sinus rhythm and occasional ventricular premature beats. Echocardiography demonstrated an LV internal diameter in diastole of 70 mm, which did not change detectably from beat to beat. Alternation in the magnitude and velocity of systolic excursions of the LV posterior wall and ventricular septum were noted, but beats exhibiting large LV posterior wall excursions invariably showed small septal excursions and vice versa (fig. 7). This discordant alternation was sometimes enhanced in postextrasystolic beats. However, the disparity between alternate beats varied considerably for no apparent reason over periods of a minute or longer, even in the absence of any change in heart rate or premature beats. Alternation of end-systolic LV internal diameter was present. As in patient 2, this variable was smaller in beats with greater LV posterior wall excursions.

**Discussion**

Pulsus alternans is almost always a manifestation of myocardial damage, especially at normal or slow heart rates. All our patients had chronic LV failure with considerable LV dilatation.

In one or more of our four patients, echocardiography demonstrated alternation in the following variables:

a) amplitude of systolic excursion of the LV posterior wall and VS
b) rate of increase of amplitude of the LV posterior wall and VS
c) magnitude of end-systolic LV internal diameter (larger in the weaker beats)
d) duration of LV and RV ejection, as reflected by the systolic motion of the aortic valve and pulmonic valve
e) duration of the LV and RV pre-ejection periods (longer in the beats with shorter ejection periods)
f) amplitude and velocity of anterior systolic motion of the aortic root
g) steepness of the mitral EF slope (steeper in the diastole after a strong systole)
h) diastolic VS position (toward the transducer preceding the stronger septal beats, away from it preceding the weaker septal beats)
i) LV posterior wall position (away from the transducer preceding stronger LV posterior wall beats and toward the transducer preceding weaker LV posterior wall beats).

The findings mentioned above in (a), (b), (c), (d), and (e)
are in accordance with data from several hemodynamic and noninvasive studies in man, as well as numerous experimental reports. The magnitude of anterior systolic excursion of the aortic root has been shown to bear a linear relationship to the stroke volume of the LV, which is relevant to our finding (f).

Alternans of diastolic blood velocity at the mitral valve has recently been detected using the Doppler ultrasonic flowmeter catheter. This report and our finding (g) suggest that mechanical alternans may involve diastole as well as systole. The explanation for our findings (h) and (i) may also involve diastolic phenomena. The alternation of end-diastolic septal position (fig. 5) was associated with alternation of posterior LV wall end-diastolic position such that during LV filling the septum and the LV posterior wall both were moved anterior in the diastole preceding beats with stronger contractions of the VS, and both were more posterior in the diastole preceding beats with stronger contractions of the LV posterior wall. If alternation of diastolic relaxation of the VS and the LV posterior wall occurs discordantly, then one wall of the LV chamber may be stretched relatively more than the other wall during one diastole, but stretched relatively less than the other wall during the next diastole. These changes could balance each other, so that no change in overall end-diastolic diameter is observed. The more stretched wall, however, will produce the more forceful systole. Thus, if diastolic stretching is discordant, the subsequent systolic contraction will also be discordant.

Ferrer et al. demonstrated that mechanical alternans could affect either the left or right ventricle independently. Subsequently DeRabago et al., McIntosh, and Desser and Benchimol presented data indicating the existence in some instances of discordant mechanical alternans: the occurrence of beats showing strong LV systole and weak RV systole alternating with beats exhibiting weak LV and strong RV systoles. These authors noted that discordant alternans was a transient phenomenon in patients who, at other times during the same study, showed concordant alternans or alternans persisting with respect to one ventricle while it disappeared in the other. We suggest that analogous discordant alternans may occur in the VS and free wall of the same ventricle. Echocardiography in two of our patients (1 and 3) showed discordant alternans of the LV posterior wall and VS. However, the other two patients (2 and 4) exhibited larger systolic excursions of the LV posterior wall in beats that had smaller septal excursions and vice versa. Neither showed significant changes in the end-diastolic LV diameter from beat to beat. Alternation of end-diastolic volume has been considered an essential feature of mechanical alternans by some authors, but not by others.

On the basis of our findings, we suggest that in conditions of advanced LV disease or LV failure portions of the myocardium may contract with alternate strong or weak contractions in successive beats, while other portions of the ventricular myocardium contract with a discordant alternans without any alternans. It seems reasonable to speculate that such discordant alternans would occur most often in patients with patchy involvement of the myocardium such as is seen in ischemic heart disease.

The presence and magnitude of alternation in the LV or arterial pressure record would depend on the resultant or overall force of contraction of the LV as a whole; conceivably, even a marked degree of alternans in one part of the ventricular muscle would not be manifest in the arterial or LV pressure pulse if it were accompanied by a discordant alternans of equal or balancing magnitude in some other portion of the ventricular myocardium. Such a situation could be detected by echochardiography but not by recordings of the external arterial pulse or by intraventricular or intra-arterial pressure tracings.

Our studies suggest that alternans can occur in "fractionate contraction of the myocardium" while other myocardial fractions show no alternans or discordant alternans. Such systolic discordance could be explained by differences in degrees of the preceding diastolic stretch in two myocardial frations, and so would support the "intrinsic myocardial" theory of mechanical alternans if this theory can be applied to diastole. Thus, diastolic changes would be intrinsic whereas systolic changes would be secondary. This possible combination of intrinsic events in diastole associated with secondary events in systole, even in the absence of changes in overall diastolic diameter, might explain the controversy that has existed for 60 years since Wenckebach suggested the explanation that is based on the Frank-Starling law and which depends on the presence of alternation in end-diastolic myocardial fiber length which leads, in turn, to alternation in the force of systolic contraction. It should be noted, however, that our data do not preclude a primary alternation in systolic contraction.

It is conceivable that the apparent discordant alternans that we have noted may represent the effect of concordant right ventricular alternans. Thus, the strong beat on the left side may be associated with a larger stroke volume of the
right ventricle, which may allow the VS, with the LV chamber, to reach a more anterior position, thus attenuating the systolic posterior excursion of the VS. After completion of the stronger systole, the end-systolic volume will be less in the right ventricle and the septum more anterior. The next beat will be weak and associated with a small RV stroke volume and less attenuation of septal movement. The resultant greater excursion during the weaker beat is then the result of factors operating on both sides of the septum.

The initiation or accentuation of pulsaties alternans by premature beats was noted by Mackenzie and Rihl, and subsequently documented both experimentally and clinically by numerous workers. In a series of 71 patients with pulsaties alternans (recorded by sphygmograph) reported by White, alternation occurred only after premature beats in 55. Ventricular premature beats occurred, with varying frequency, in all our patients; in three of them, postextrasystolic beats enhanced alternans, but mechanical alternans was observed even on occasions when no premature beats occurred over long periods exceeding 50 beats. In one patient (3), alternans was apparent only in the three or four postextrasystolic beats, and not during regular, uninterrupted sinus rhythm.

In conclusion, echocardiography allows the detection of mechanical alternans and thereby provides a helpful additional sign to the clinician, suggesting or confirming the presence of LV failure. Moreover, it provides further insights into the mechanical basis for alternans.

References

Esophageal Echocardiography

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SUMMARY  Esophageal echocardiography has been developed for use in patients with chronic obstructive pulmonary disease and is a safe diagnostic procedure which provides high resolution mirror image echoes of many cardiac structures. Conventional anterior and esophageal echocardiograms were performed in 38 subjects. Esophageal echocardiographic sub- since its introduction in 1954, the major drawback in pease were of diagnostic quality in all 38 subjects; anterior echocardiographs were of diagnostic quality in only 18. Measurements from anterior and esophageal echocardiograms correlated well for aortic valve diameter (r = 0.87), left atrium diameter (r = 0.96), mitral valve E' slope (r = 0.97) and less well for aortic root diameter (r = 0.69).

chronic obstructive pulmonary disease, barrel chests, and obesity. In veterans hospitals, where these patients represent a considerable portion (20%) of echocardiographic subjects, results are frequently poor. In order to obviate this problem, an esophageal echocardiographic transducer was developed and clinically tested.

Method

A 9 mm nonfocussed Acrotech 3.5 MHz transducer was designed and instrumented to permit easy swallowing by

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