Normal and Prosthetic Atrioventricular Valve Motion in Atrial Flutter

Correlation of Ultrasound, Vectorcardiographic, and Phonocardiographic Findings

By Edwin L. Alderman, M.D., David A. Rytand, M.D., Richard S. Crow, M.D., Robert E. Finegan, M.D., and Donald C. Harrison, M.D.

SUMMARY
In order to correlate the electrical and mechanical events occurring in atrial flutter, three patients have been studied using the standard electrocardiogram, a computer-processed vectorcardiogram, and reflected ultrasound recordings of valvular motion. Anterior motion of the mitral valve leaflet occurs in the region of the nadir of the atrial flutter wave in lead II of the electrocardiogram. In one patient in whom it was possible to obtain a tricuspid leaflet echocardiogram, anterior motion was also initiated close to the nadir of the flutter wave. The probable sequence of electrical and mechanical events in atrial flutter is discussed. In one patient with a prosthetic mitral valve, correlation of diastolic clicking sounds with respect to the poppet echocardiogram provided some insight into irregularities in timing of previously reported flutter sounds.

Additional Indexing Words:
Atrial flutter Atrial vectorcardiogram Echocardiography Mitral valve motion Starr-Edwards prosthesis Flutter sounds Phonocardiography Diastolic click

Atrial Flutter has been associated with a variety of hemodynamic, phonocardiographic, and echocardiographic findings. Atrial flutter pressure waves originating from both right and left atria have been recorded. \(^1,^2\) A wide variety of sounds, both systolic and diastolic, have been reported in patients with atrial flutter, \(^3,^4\) most often at or near the nadir in lead II of the electrocardiogram. \(^4-^7\) Ultrasound technics have demonstrated “fluttering” of the anterior mitral leaflet occurring at the same frequency as the electrocardiographic atrial flutter waves. \(^8,^9\)

Correlation of these mechanical events in atrial flutter with the atrial activation sequence was indirectly ascertained. Ultrasound and phonocardiographic recordings were timed against lead II of the electrocardiogram. A computer-processed vector analysis of the electrical flutter waves was utilized to identify the sequence of atrial activation as delineated in other reported studies utilizing direct endocardial or epicardial recording technics. \(^10-^12\)

Methods
Three patients were studied who had classical atrial flutter as defined by the criteria of Lewis. \(^13\) Twelve-lead electrocardiograms and computer-processed electrocardiograms were obtained from all three patients. The latter technic \(^14\) employs the Frank lead placement. The outputs of six unweighted leads I-A, E-M, C-M, F-H, I-C, and...
H-E are simultaneously transmitted to a 14-channel Ampex FM tape recorder which interfaces with a PDP-8 computer. The computer digitizes the data at 1000 samples/sec/lead, applies the Frank weighting equations, and displays on an incremental Calcomp plotter the instantaneous spatial vectors in the frontal, horizontal, and left sagittal planes. The computer was programmed to plot the three planar loops for a complete flutter cycle taking as an arbitrary onset time the nadir, i.e., the lowest voltage point of the flutter wave as seen in the Y lead. The Y lead nadir corresponds very closely with the nadir of the flutter wave as seen in standard leads II, III, and aVF. A complete flutter wave cycle occurring just prior to a QRS complex was used, in order to avoid contamination by a preceding T wave.

Echocardiograms of the mitral and tricuspid valves were obtained using a Smith-Kline Instruments Ekoline-20 ultrasound device with attached Polaroid camera for permanent film recording. The time-motion display ("B" scan) was utilized at a sweep speed of 30 mm/sec to record details of valvular motion. Phonocardiograms were obtained using a Hewlett-Packard four-channel photographic recording unit with heart sound preamplifiers. The gated mitral valve echo signal from the ultrasound machine and lead II of the electrocardiogram were recorded simultaneously with the phonocardiogram.

**Results**

In discussing the correlation of mechanical and electrical events in atrial flutter, the terminology introduced by Lewis will be employed. All three patients studied had flutter waves of very similar contour in lead II of the electrocardiogram, the pattern of which is illustrated in figure 1. From the lowest voltage point referred to as the nadir \( N_D \), the curve ascends sharply to a blunt summit \( S \) and then falls via a gentle downsweep \( d \). The downsweep is then abruptly altered at a point called the notch \( N_T \), where the curve drops sharply back to the nadir, continuing the cycle again. In subsequent figures the notch-to-nadir interval will be referred to by the letter N.

**Case 1**

An 87-year-old man (I.N.—SMC 16-40-93), with a 5-year history of chronic atrial flutter and a high degree of heart block, had no history of cardiac symptoms. Examination revealed a variable ventricular rate, no flutter sounds, and a grade III/VI harsh systolic ejection murmur along the left sternal border. The cardiac silhouette was minimally enlarged on chest X-ray, and the left atrium was not enlarged. The patient's electrocardiogram, which is illustrated in figure 2, shows atrial flutter at a rate of 266 cycles/min and a cycle length of 225 msec. The computer-processed atrial vectorcardiogram is also shown in figure 2. The nadir, summit, downsweep, and notch of the flutter wave, as seen in lead II of the electrocardiogram, are indicated on the corresponding portions of the vector loops. In the frontal plane, the vector loops reveal rapid inferiorly directed forces over a 60-msec period between the nadir and the summit. The subsequent 110 msec, corresponding to the downsweep, is occupied by superiorly and somewhat posteriorly directed forces. The next 55 msec, corresponding to the interval from the notch to the nadir, is occupied by rapid superiorly directed forces. These latter forces are posterior to the forces occupying the nadir-to-summit interval.

Figure 3 illustrates this patient's mitral echocardiogram prior to and during carotid sinus massage. This vagal maneuver substantially increased the degree of atrioventricular block, making apparent a “fluttering” motion of the anterior leaflet of the mitral valve which occurred synchronously with the electrical flutter waves. The onset of opening motion (forward direction) of the anterior leaflet of the mitral valve coincided with the notch-to-nadir interval of the flutter wave in lead II.

**Figure 1**

A typical flutter wave as seen in lead II of the electrocardiogram is illustrated. From the lowest voltage point, or nadir \( N_D \), the curve rises to a peak voltage, or summit \( S \). A gentle downsweep \( d \) leads to the notch \( N_T \) where the rate of descent steepens sharply.

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The 12-lead electrocardiogram from case 1 shows atrial flutter waves of typical configuration in leads II, III, and aVF. The frontal, left sagittal, and horizontal vector loops are illustrated using the nadir (N_d) as an arbitrary starting point. The direction of inscription of the loops is indicated by the arrows, and times are in msec. The nadir, summit, downsweep, and notch of the flutter wave as seen in lead II of the electrocardiogram are indicated next to the corresponding portions of the vector loops.

**Case 2**

A 37-year-old man (F.B.—SMC 14-07-32), with a long history of rheumatic valvular disease, had aortic valve replacement 5 years earlier. Because of increasing symptoms of congestive heart failure, he was undergoing cardiac reevaluation, at which time atrial flutter was discovered. Physical examination revealed a regular rhythm, marked cardiac enlargement, and normal opening and closing Starr-Edwards aortic prosthetic clicks. At the apex there was a grade II/VI systolic murmur radiating to the axilla, an opening snap, and a protodiastolic rumble. The patient's electrocardiogram, illustrated in figure 4, shows atrial flutter at a rate of 280 cycles/min with a cycle length of 215 msec. The vector loops of the flutter waves are similar to those of case 1. The rapid superiorly directed notch-to-nadir forces are posterior to the immediately succeeding rapid inferiorly directed nadir-to-summit forces.

Figure 5 illustrates an echocardiogram of the mitral valve leaflet, which was obtained at a tissue depth of 10 cm from the chest wall. The normal diastolic motion is interrupted by an anterior deflection of the mitral leaflet, the onset of which occurs during the notch-to-nadir interval of the flutter wave as seen in lead II of the electrocardiogram. An echocardiogram of the tricuspid leaflet was located at a tissue depth of 4 cm from the transducer.
The mitral valve echo (MVE) and lead II of the electrocardiogram (ECG-II) from case 1 are illustrated. The maximum anterior excursion of the anterior leaflet of the mitral valve occurs immediately following the onset of diastole at point E, posterior to the interventricular septum (IVS). Following carotid sinus pressure (CSP), complete block occurs which allows an uninterrupted "fluttering" of the mitral leaflet (F). The vertical arrow indicates that the onset of anterior motion of the "fluttering" leaflet occurs during the notch-to-nadir interval (N) of the flutter wave in lead II.

The 12-lead electrocardiogram from case 2 illustrates a typical atrial flutter contour in leads II, III, and aVF. The frontal, left sagittal, and horizontal loops for a single flutter wave cycle are shown in the same manner as in figure 1.
The tricuspid valve echo (TVE) from case 2 was located at a depth of 4 cm from the anterior chest wall (ACW) and just anterior to the interventricular septum (IVS). The mitral valve echo (MVE) was found at a depth of 10 cm between the interventricular septum (IVS) and the posterior wall (PW) of the heart. Maximum anterior excursion of the leaflets occurs at point E, and "fluttering" of the leaflets is apparent at point F. The onset of anterior motion of the "fluttering" tricuspid and mitral leaflets occurs in the region of the notch-to-nadir interval (N) in lead II of the electrocardiogram (ECG-II).

Figure 5

Artifact. The tricuspid leaflet displayed a diastolic "fluttering" similar to that observed with the mitral valve. The onset of forward motion of the tricuspid valve occurred at about the same time as mitral valve opening, i.e., in the region of the nadir of the flutter wave.

Case 3

A 34-year-old woman (L.S.-SMC 20-13-12), with a 4-year history of rheumatic mitral insufficiency and stenosis, was undergoing cardiac evaluation for symptoms of palpitation and exertional dyspnea. Three years earlier she had had a no. 2 Starr-Edwards prosthesis placed into the mitral position. Physical examination revealed flutter waves in the neck and a regular pulse rate of 63 beats/min. Auscultation revealed normal prosthetic opening and closing clicks. Following the mitral prosthetic opening click, multiple additional clicking sounds were heard which occurred in a repetitive pattern from diastole to diastole. This patient's electrocardiogram (fig. 6) illustrates atrial flutter at a rate of 250 cycles/min and a cycle length of 240 msec. The planar loops of the vectorcardiogram indicate that rapid superiorly directed forces occurring over the 70 msec between the notch and nadir were posterior and leftward to the rapid inferiorly directed forces occurring between the nadir and summit.

An echocardiogram of the prosthetic mitral valve, which is illustrated in figure 7, was obtained by placing the transducer at the apex of the heart and aiming in a medial and superior direction. A prominent echo was obtained from the anterior portion of the cage where the metal struts converge. Behind these strut echoes, the less prominent echo of the anterior surface of the poppet appeared. When the patient was in atrial flutter the poppet moved back and forth with each flutter cycle. During the initial portion of diastole the poppet was held firmly in the open position by the rapid inflow of blood into the left ventricle. As diastole proceeded, the mitral poppet moved back and forth between a fully open and fully closed position. During the latter portion of diastole the poppet
Valve motion in atrial flutter

Figure 6

The 12-lead electrocardiogram from case 3 illustrates a typical atrial flutter pattern in leads II, III, and aVf. The frontal, left sagittal, and horizontal loops for a single flutter wave cycle are shown in the same manner as in figure 1. Rapid superiorly directed forces occurring during the notch-to-nadir interval are posterior and leftward to the rapid inferiorly directed forces which immediately follow.

tended to remain closed for a longer duration of each flutter cycle and conversely moved to the open position more slowly with each flutter cycle (fig. 8). Following cardioversion, the mitral poppet had a normal pattern of motion similar to that described by Siggers et al.\textsuperscript{15} The normal mitral prosthetic poppet motion is very similar to that of a stenotic mitral valve.

The phonocardiogram recorded from case 3 is illustrated in figure 8. Four diastolic clicks (O\textsubscript{1}, C\textsubscript{1}, O\textsubscript{2}, and C\textsubscript{2}), in addition to the usual opening and closing prosthetic sounds, are present. The onset of forward motion of the mitral poppet occurs immediately after the notch of the flutter wave, as seen in lead II of the electrocardiogram. Very shortly after the poppet reaches the fully open (anterior) position, a prominent click is recorded which is referred to as the "O" click. The poppet then returns to a closed position, at which point a brief deflection in the motion of the poppet occurs, corresponding to clicks of lower amplitude referred to as "C" clicks. The time from the initial O click to the initial C click is 130 msec, whereas the time from the second O click to the second C click is 90 msec. This shortening of the O-to-C interval reflects the tendency of the mitral poppet to reach an open position more slowly and to return to a closed position more rapidly as diastole proceeds. Following cardioversion, an echocardiogram and phonocardiogram were obtained, which are illustrated in figure 9. No diastolic clicking sounds are present, and mitral prosthetic motion is normal.

Discussion

The studies in these three subjects provide information concerning the relationship be-
The ultrasound recordings of the mitral poppet motion from case 3 are shown both in atrial flutter and in sinus rhythm. CAGE refers to the echo from the anterior convergence of struts of the Starr-Edwards prosthesis. Maximal anterior motion of the mitral poppet (MPE) occurs at point E immediately following the onset of diastole. As diastole proceeds “fluttering” of the mitral poppet (F) is observed. The onset of forward motion of the “fluttering” poppet occurs in the region of the notch-to-nadir interval. During diastole, shortly after the “fluttering” poppet reaches an open position, sharp clicks (O₁ and O₂) are recorded. Following return of the poppet to a closed position, lower intensity clicks (C₁ and C₂) are recorded which are associated with a deflection in the poppet motion. The O-to-C interval shortens from 130 to 90 msec as diastole proceeds, reflecting a slowed rate of anterior motion and a more rapid return to the closed position.

The simultaneous apex phonocardiogram (APC), mitral poppet echo (MPE), and lead II electrocardiogram (ECG-II) from case 3 are illustrated. Maximal anterior motion of the mitral poppet is indicated by point E immediately following the onset of diastole. As diastole proceeds “fluttering” of the mitral poppet (F) is observed. The onset of forward motion of the “fluttering” poppet occurs in the region of the notch-to-nadir interval. During diastole, shortly after the “fluttering” poppet reaches an open position, sharp clicks (O₁ and O₂) are recorded. Following return of the poppet to a closed position, lower intensity clicks (C₁ and C₂) are recorded which are associated with a deflection in the poppet motion. The O-to-C interval shortens from 130 to 90 msec as diastole proceeds, reflecting a slowed rate of anterior motion and a more rapid return to the closed position.

Between mitral valve motion in patients with atrial flutter and the extent of left ventricular filling. “Fluttering” of the poppet was apparent in the patient with a mitral prosthesis, and its motion was influenced by the extent of left ventricular filling. As diastole began, the poppet was held in a fully open position during the rapid inflow period. Later in diastole, oscillation of the poppet with each atrial flutter wave with associated clicking
The apex phonocardiogram (APC), mitral poppet echo (MPE), and lead II of the electrocardiogram (ECG-II) from case 3 are illustrated following cardioversion. First-degree heart block is present. The mitral poppet reaches the most anterior position (E) immediately following the onset of diastole and is associated with a normal prosthetic opening click (OCL). No additional sounds are present, and mitral poppet motion is undisturbed in diastole. S₁ = first heart sound; S₂ = second heart sound.

The sounds became apparent. It might therefore be expected that flutter sounds, if caused by motion of the mitral valve apparatus, would not be present during early diastole and might gain in intensity as diastole proceeds. Massumi et al.¹⁶ noted that in a patient without valvular disease the diastolic flutter sounds became progressively more prominent as diastole proceeded. A similar diastolic accentuation of flutter sounds is present in an early phonocardiographic record reported by Hecht and Myers.⁴

Lead II of the electrocardiogram in classical atrial flutter demonstrates a typical notch, nadir, summit, and downsweep pattern.¹¹ Vector analysis of the flutter waves confirms that rapid superiorly directed forces corresponding to the notch-to-nadir interval are followed almost immediately by rapid inferiorly directed forces corresponding to the nadir-to-summit interval. These inferiorly directed forces are anterior and generally to the right of the superiorly directed forces. In patients with this typical type of flutter activity, the vector loops of atrial activity are consistently of the above pattern, with the left sagittal loop being most constant in appearance (Rytand DA: Unpublished data).

Mitral leaflet "fluttering" in atrial flutter is a readily identifiable finding by means of ultrasound technics when sufficient atrioventricular block is present.⁸,⁹ Those patients with moderate to severe mitral stenosis, who have markedly restricted motion of their mitral leaflets, do not exhibit this finding. In the three subjects reported in this study, the

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onset of late diastolic forward motion of the mitral leaflet occurs between the notch and nadir of the flutter wave as recorded in lead II of the electrocardiogram. The ultrasound picture illustrated in the paper by Effert\textsuperscript{8} also shows the onset of forward motion at a similar time.

The fact that the onset of forward motion of the mitral leaflet is coincident with the notch-to-nadir interval in lead II of the electrocardiogram suggests that left atrial activation occurs at that time. The onsets of left atrial activation and contraction coincide with the region of the notch of the electrical flutter wave, which, in turn, corresponds to the rapid superiorly directed, posteriorly situated, forces on the vectorcardiogram. Esophageal and right atrial recording technics in subjects with classical flutter have shown that the sequence of left atrial excitation proceeds caudocephalad,\textsuperscript{10,12} corresponding to these rapid superiorly directed forces. Direct atrial epicardial mapping technics have been applied in only two reported cases. One reported patient\textsuperscript{11} had a caudocephalad left atrial activation pattern similar to that determined from catheter recording methods. The patient reported by Wellens et al.,\textsuperscript{12} had a different pattern of left atrial activation in association with an atypical inverted form of flutter.

In case 2, in which both mitral and tricuspid echocardiograms were obtained, the onset of opening motion of both valves occurred approximately coincident with the nadir of the flutter wave. Studies of the sequence of atrial activation in subjects with typical atrial flutter suggest that no more than 50 msec separates the onset of left and right atrial activation, irrespective of whether a circus or ectopic sequence of activation is demonstrated.\textsuperscript{10,12} Differences in onset of valve opening of this order of magnitude could not be resolved accurately at the ultrasound recording speed employed in this study.

Figure 10 summarizes the relationship of the electrocardiogram, vectorcardiogram, and echocardiogram observed in this study, with the sequence of atrial activation using the circus movement model. Left atrial activation is manifested as rapid superiorly directed forces corresponding to the dip from the notch to the nadir in the atrial flutter wave, as seen in lead II of the electrocardiogram. Mitral valve opening occurs at this time. Right atrial activation then occurs, manifested as rapid inferiorly directed forces which coincide with the rise from the nadir to the summit in the flutter wave. Mitral leaflet “fluttering” occurs synchronously with electrical atrial flutter and its opening is coincident with left atrial activation. The “fluttering” motion of the mitral valve in diastole is strongly influenced by the left atrioventricular pressure gradient, which in turn affects the timing of atrial flutter sounds.

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EDWIN L. ALDERMAN, DAVID A. RYTAND, RICHARD S. CROW, ROBERT E. FINEGAN and DONALD C. HARRISON

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