P loops during common and uncommon atrial flutter in man¹

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Atrial flutter has never been satisfactorily defined. The 'common' pattern of flutter was originally described by Lewis in 1913. Less frequently observed forms of flutter are termed 'uncommon'. Sixteen cases of the 'common' and 6 of the 'uncommon' type have been studied using isolated P loop vectorcardiography. All patients had some degree of atrioventricular block but none had evidence of digitalis excess. The atrial rates were regular and were in a range between 250 and 330/minute. Vagal manoeuvres increased AV block in each instance. All those with the 'common' type of flutter had P loops with a caudad-cephalad orientation and fifteen of the sixteen had forces which descended over the right atrium and ascended over the left atrium. The 6 cases of the uncommon type of flutter had rates which ranged between 250 and 300/minute and did not fulfil both of the criteria for 'common' flutter; namely continuous baseline undulation and prominent negative P deflections in the inferior leads. The cases with the 'uncommon' type of flutter had a variety of loop patterns. The most frequent type was oriented inferior slightly to the right and anterior. One patient satisfied criteria for left atrial flutter. In another the loop was oriented inferior leftward and anterior. The vectorcardiogram provides a rich source of descriptive data but does not identify the underlying mechanism(s) of flutter.

Fluttering of the atrium was visualised in animals by MacWilliam (1887) and subsequently recorded by string galvanometer in man by Jolly and Ritchie (1911). In 1913 Sir Thomas Lewis presented electrocardiographic criteria of atrial flutter which are still valid. He described the most frequent form of flutter which is now termed 'classical', 'common', or 'typical'. Less frequently observed patterns of atrial excitation during flutter have been termed 'uncommon', 'rare', or 'atypical'. One obvious difference between the two forms of flutter is that of P wave (flutter wave) morphology and the influence of the P waves on the baseline. Though there does not appear to be an obvious difference between the common and uncommon varieties of flutter in their response to physical or pharmacological interventions, there may be subgroups which vary in mode of onset, maintenance, and termination.

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Sir Thomas Lewis restricted his observations, and thus his definition, to the pattern of the common type of flutter. Most electrical patterns of the 'uncommon' type of flutter do not resemble that of 'common' flutter and consequently do not accord with the historic description of flutter. The dilemma is evident as Marriott and Myerburg, 1974, state in Hurst and Logue's basic cardiac text, 'atrial flutter has never satisfactorily been defined'.

In this study two electrocardiographic criteria were required for the diagnosis of 'common' flutter; namely a continuous undulation of the baseline and a prominent negative component of the P waves in leads II, III, and aVF (Lewis, 1913, 1925; Katz and Pick, 1956). Flutter was considered to be of the 'uncommon' variety if both criteria were not fulfilled.

There are several electrocardiographic description of the 'common' and 'uncommon' patterns of flutter. However, in a search of the published material, the authors were able to find only 19 vectorcardiographic descriptions of atrial excitation during naturally occurring flutter in man, of which 18 were examples of 'common' flutter and only one

an example of 'uncommon' flutter (Dechard *et al.*, 1945; Rosen *et al.*, 1969; Alderman *et al.*, 1972; MacLean *et al.*, 1973). Actual P loops, as opposed to derived loops, had been recorded in only 13 patients.

It is the purpose of this report to present a comprehensive analysis of the spatial vectorcardiograms of atrial excitation during flutter in 22 patients of whom 16 had the 'common' type of flutter and 6 had the 'uncommon' type.

Patients and methods

All patients had stable atrial flutter and were without evidence of digitalis excess. Atrial rates were regular and had a range of 250 to 330 cycles/minute. Vagal manoeuvres increased atrioventricular block in each instance. Electrocardiographic criteria for 'common' flutter followed the definitions of Lewis (1913, 1925), as refined by Katz and Pick (1956). The fluttering P waves were regular with identical size, spacing, and contour. The baseline was 'sawtoothed' with continuous undulation most noticeable in leads II, III, aVF, and less noticeable in lead I. An obvious negative component to the undulating pattern was present in leads II, III, and aVF.

The electrocardiographic criteria for 'uncommon' flutter followed in part the observations of Prinzmetal *et al.* (1952). An isoelectric interval was frequently noted between the flutter waves. The baseline did not need to be in constant motion nor was there a requirement for a prominent negative deflection in leads II, III, and aVF.

The study group comprised 17 men and 5 women. The average age of all patients was 67 years, with the average of women being 68 years and that of men being 63 years. The types of underlying heart disease were atherosclerotic coronary disease in 16 patients, rheumatic heart disease with mitral valve involvement in 5 patients, and no identifiable cardiac disease in one patient. The average age of the 16 patients in the 'common' flutter subgroup was 62 years. The 6 patients in the 'uncommon' flutter subgroup had an average age of 69 years and consisted of 4 women and 2 men.

Electrocardiograms and P loops were recorded sequentially during atrial flutter. Five patients also had electrocardiographic and vectorcardiographic P loops after conversion to normal sinus rhythm. Standard 12-lead electrocardiograms were recorded at a paper speed of 25 mm/second. Orthogonal leads and P loops were recorded with the Frank system on a Sanborn 1507A vector system and Hewlett-Packard C04-197A oscilloscopic camera.

The X, Y, and Z leads were recorded at a sweep speed of 100 mm/second and calibrated for a 1.0 mV/cm deflection. The vector recording system had an adjustable 'gate' which permitted the isolation and display of the P wave. P loops were displayed and recorded at 0.05 mV/cm with dash-time intervals of 2.5 ms. The blunt end of the tear drop represented the advancing edge.

One patient in the series with 'common' atrial flutter was studied before open heart surgery for correction of mitral regurgitation secondary to papillary muscle infarction. Pacing electrodes were placed on the left atrial appendage at the operation for the control of the heart during the postoperative period. On the eighth postoperative day, P loops were obtained during atrial pacing from the electrodes on the left atrial appendage.

Results

The results are summarised in the Table and Fig. 1. According to the criteria given above, sixteen patients had 'common' atrial flutter. In the standard electrocardiogram, these cases had an undulating baseline with a 'sawtoothed' pattern of atrial excitation and an obvious negative undulation in leads II, III, or aVF (Fig. 2A). P loops were oriented superiorly slightly to the right and slightly posteriorly (Fig. 1 and 2B). The average mean axis was -96° in the frontal plane and -83° in the left sagittal plane. Frontal plane loops were predominantly counterclockwise (10/16).

'Uncommon' flutter occurred in 6 patients (Fig. 1). In contrast to 'common' flutter, the P waves were discrete in 5 of the cases with positive deflections in leads II, III, or aVF (Fig. 3, 4A). In these 5 patients the average mean P loop is depicted in Fig. 4B. One of the 'uncommon' flutter patterns satisfied Mirowski and Alkan's (1967) definition for left atrial flutter. The electrocardiogram showed P waves with a dome-dart configuration in lead V1 and a negative P wave in lead aVL. The P loop had the most rightward and anterior orientation of the 'uncommon' flutter patterns (Fig. 5A, 5B). The sixth patient with 'uncommon' flutter was so distinct and unusual to be considered separately. The flutter was the most rapid of all 22 cases (330/minute). The P waves were almost diphasic in the inferior leads as well as in lead I (Fig. 6A). The P loops were closed with the mean axis inferior to the left and anterior. The frontal P wave axis was $+22^\circ$ and the left sagittal axis was $+129^\circ$ (Fig. 6B).

The four patients with 'common' flutter who also had P loop study during normal sinus rhythm were noted to have normal atrial excitation during sinus rhythm.

Table Characterisation of patients and flutter

Case No.	Age (y)	Sex	Cardiac disease	Drugs	Atrial rate	NSR 'P' loops		Flutter 'P' loops		Counterclockwise
						F°	SL°	F°	SL°	SL loop
<i>Uncommon flutter</i>										
1	74	M	CAD, MI	None	250			+90	+66	+
2	70	M	CAD, MI	Digoxin	300			+79	+105	-
3	67	M	CAD	Digoxin	300			+101	+105	+
4	58	M	CAD	None	280			+77	+86	-
5	67	F	RHD, MVD	Digoxin	250			+131	+180	+
6	77	F	CAD	Digoxin	330			+22	+129	-
<i>Common flutter</i>										
7	72	M	CAD	Digoxin	300	94	71	-94	-76	+
8	65	M	CAD	Quinidine	280	81	93	-104	-101	+
9	55	M	CAD, MI	Digoxin	250	49	131	-103	-80	-
10	65	M	CAD	None	300	106	40	-92	-62	+
11	65	F	RHD, MVD	Digoxin	280			-92	-46	+
12	62	M	RHD, MVD	Digoxin	300			-82	-85	+
13	82	M	CAD	Digoxin	250			-80	-103	+
14	57	M	CAD	Quinidine	300			-112	-81	+
15	49	M	RHD	Digoxin	300			-74	-93	+
16	58	M	RHD, MVD, AVD	Digoxin	250			-96	-58	+
17	32	M	None	None	315			-88	-77	+
18	70	M	CAD	Digoxin	300			-91	-101	+
19	64	M	CAD	Quinidine	300			-110	-58	+
20	78	F	CAD	Digoxin	300			-132	-121	+
21	53	F	CAD	Procainamide	300			-96	-102	+
22	63	M	CAD	None	300			-93	-80	+

NSR, normal sinus rhythm; M, male; F, female; CAD, coronary arterial disease; MI, myocardial infarction; RHD, rheumatic heart disease; MVD, mitral valve disease; AVD, aortic valve disease. F = frontal; SL = left sagittal.

Fig. 1 Summary figure. Sixteen patients with 'common' flutter P loops had a superior axis in the frontal (-96°) and left sagittal (-83°) planes. Six patients with 'uncommon' flutter had an inferior axis. Five cases of 'uncommon' flutter were similar with frontal plane axis of $+96^\circ$ and left sagittal axis of $+180^\circ$. One unusual case of 'uncommon' flutter is considered separately.

Discussion

Human atrial flutter was first described in 1911 by Jolly and Ritchie. Sir Thomas Lewis (1913) later elaborated on the electrocardiographic description. 'The electrocardiograms which represent the auricular activity are peculiar in more respects than one . . . The auricular complexes in leads II and III are always contiguous that is to say, the separate electrical complexes are so close together that the end of one marks the beginning of the next. The string is in constant motion; there are no isoelectric stretches dividing one auricular electrical cycle from the next.

'The auricular complexes in auricular flutter are remarkable for their constancy of form from case to case. . . P in lead I is either a small and pointed summit, or is so insignificant that it cannot be found. P in leads II and III run on either side of the adjacent complexes, so that a series of such complexes forms a continuous wavy or zigzag line. . .'

Citing experimental observations of flutter in animals, Lewis *et al.* (1920) found that the atrial rate was rapid with a high grade of regularity (0.001 to 0.003 second variation). In addition, auricular complexes were contiguous and uniform in outline. They concluded that, 'It seems desirable that the unqualified term "auricular flutter" should be confined to mechanisms of this kind'. Later, Lewis (1925) expanded on the description of the electrocardiogram as follows:

'Leads II and III ascend sharply to a blunt summit and return more gradually. Lead I is diminutive. The complexes are contiguous. The string is moving continuously and rests for no measurable period on a baseline; as soon as one complex is completed, the next one starts'.

Lewis believed that the arrhythmia resulted from continuous excitation waves which travelled in a circuit; a so-called circus movement. Based upon one experiment in man, performed with simultaneous recording of bipolar electrograms in three planes, Lewis *et al.* (1921) concluded that the circus movement travelled down the right atrium and up the left atrium. Using similar techniques, Cabrera and Sodi-Pallares' (1947) findings were similar in 15 of 16 cases of classical flutter. Their report is of special interest because these eminent electrocardiographers concluded that the exceptional case was most likely one of paroxysmal tachycardia. Marriott and Myerburg's (1974) statement regarding the lack of definition of flutter is thereby reinforced because the exceptional case must have fulfilled electrocardiographic criteria for classical flutter to have been entered into the study.

Direct exploratory mapping of hearts with the 'common' flutter pattern has been performed twice at the time of surgery. In one instance there was agreement with surface recordings in showing that excitation advanced down the anterior and lateral right atrium and up the posterior left atrium

Fig. 2 (A) Top panel: Electrocardiogram of 'common' atrial flutter. Flutter waves result in an undulating baseline with prominent negative deflections in the inferior leads. Bottom panel: electrocardiogram after reversion to normal sinus rhythm. P waves have a normal orientation and are positive in the inferior leads (Case 9). (B) Vectorcardiogram of 'common' flutter reveals a mean frontal plane axis of -104° and left sagittal plane axis of -101° . The frontal plane loop is in a figure-of-eight. The loop is moving in a caudad to cephalad direction, rightward and slightly anterior. Vectorcardiogram during sinus rhythm reveals a frontal plane axis of $+81^\circ$ and a left sagittal axis of $+93^\circ$. The loop is moving in a superior to inferior direction from right to left and slightly anterior (Case 8).

Fig. 3 Electrocardiogram of 'uncommon' flutter. Simultaneous standard leads I, III, and V1 and intra-atrial lead show atrial excitation at a rate of 300 per minute with positive deflections in lead III separated by isoelectric intervals (Case 3).

(Rytand, 1966); in the other case, excitation did not proceed in a circuit but rather radiated from low in the atria (Wellens *et al.*, 1971).

Of the 12 reports of classical flutter that we have found with illustrative P loops (Decherd *et al.*, 1945; Rosen *et al.*, 1969; Alderman *et al.*, 1972; MacLean *et al.*, 1973), all have had a loop with an anterior component directed inferiorly and a posterior component directed superiorly. Such was also the case in all but one of our examples of 'common' flutter. The direction of the P loops representing 'common' atrial flutter generally conformed to that described by Lewis. It is of interest that the possibility of reversal of the loop, as noted by Cabrera and Sodi-Pallares (1947) and by our exception, was anticipated by Lewis *et al.* (1920). In contrast to 'common' flutter, MacLean *et al.*'s (1973) sole case of 'uncommon' flutter had a posterior component of the loop which advanced inferiorly and an anterior component which advanced superiorly. Similarly, our series of

Fig. 4 (A) Electrocardiogram of 'uncommon' flutter. Positive P waves are present in the inferior leads. Isoelectric intervals are better seen in Fig. 3 (Case 3). (B) P loop of 'uncommon' flutter. Atrial excitation is oriented inferior, slightly to the right and slightly anterior. Frontal plane axis $+101^{\circ}$, left sagittal plane $+105^{\circ}$ (Case 3).

Fig. 5 (A) Electrocardiogram of 'uncommon' (left atrial) flutter. The P wave is negative in aVL and V6 and has a dome-dart configuration in lead V1 (Case 5). (B) Vectorcardiogram of 'uncommon' (left atrial) flutter. The P loop is orientated inferior, to the right, and anterior. Frontal plane axis +131°, left sagittal plane axis +180° (Case 5).

Fig. 6 (A) Unusual example of 'uncommon' flutter. Electrocardiogram shows diphasic P waves in lateral and inferior leads at a rate of 330 per minute. The baseline has continuous undulation (Case 6). (B) Unusual example of 'uncommon' flutter. P loops are closed with the mean axis inferior to the left and anterior. Frontal plane axis +220°, left sagittal axis +129° (Case 6).

'uncommon' flutter had three examples (50%) with a clockwise loop in the left sagittal plane (Table).

The 'uncommon' flutter loops are of great interest because of their general variety and individual conformity to description of supraventricular loci for arrhythmias. Three of the cases of 'uncommon' flutter had a normal P axis. Prinzmetal *et al.* (1952) noted that one form of 'uncommon' flutter had P waves similar to normal sinus P waves and occurred in 15 per cent of all cases of flutter. This form of atrial flutter theoretically might have a genesis in a rapid sinoatrial re-entrant mechanism (Childers *et al.*, 1973; Paulay *et al.*, 1973; Amat-y-Leon *et al.*, 1974; Narula, 1974; Wu *et al.*, 1975) or in a circuit which is primarily involving the so-called right internodal tracts (James, 1963; Hudson, 1970).

Two patients had a right axis P wave (Fig. 4B, 5B) one of which fulfilled electrocardiographic criteria of left atrial rhythm and had a P loop which was similar to constructs of left atrial P vectors. One patient with 'common' flutter had left atrial appendage stimulation postoperatively after mitral valve replacement (Fig. 7A, 7B). During left atrial pacing, lead V1 did not have a dome-dart configuration. However, the electrocardiogram and P loop satisfied recently advanced criteria for left atrial

excitation (Mirowski and Alkan, 1967; Lau *et al.*, 1970; Mirowski *et al.*, 1970). The P loop was oriented to the right, inferior and anterior.

The distinctly unusual case of 'uncommon' flutter (Fig. 6A, 6B) had a rapid rate and an undulating baseline. The loop appeared to close and to

have an almost equal right-left, superior-inferior, and anterior-posterior orientation. This pattern may correspond to the most infrequent of Prinzmetal's 'uncommon' flutter categories—the sine wave group (Prinzmetal *et al.*, 1952).

It has been stated that electrocardiographic analysis and P loop vectorcardiography cannot resolve the mechanism of flutter (Scherf and Schott, 1973). Based upon experimental evidence it is generally accepted that P loops can be inscribed by macrocircuit atrial pathway or by a focus of excited atrium. In fact, experimental and clinical studies of the mechanism of flutter have found evidence for both a circus movement and focal atrial excitation in the same study (Giraud *et al.*, 1955; Kato *et al.*, 1956; Marques *et al.*, 1962; Kishon and Smith, 1969). Macrocircuits have been suggested to explain a variety of supraventricular (Amat-y-Leon *et al.*, 1974; Narula, 1974) as well as ventricular arrhythmias (Wellens *et al.*, 1972; Spurrell *et al.*, 1973; Wellens *et al.*, 1974). The specialised conductive pathways within the atria were described in part by Wenckebach (1908), Thorel (1910), and Bachmann (1916). In 1922 Rothberger-Wein, one of the first proponents of a focal theory commented on Lewis' work as follows: 'It still remains that the theory of the circus movement has some theoretical difficulties. Why should a wave return to its origin? Thorel has described a conductive path, but what about the return path?' In 1963, James described several routes for excitation to travel from the sinoatrial node to the atrioventricular node and vice versa. He also carefully delineated the possible combinations of internodal circuits. In spite of James' clear presentation, this concept is not completely established, and a recent review concluded that the evidence did not firmly support the existence of specialised internodal pathways (Janse and Anderson, 1974).

Our data are compatible with several mechanisms of flutter. 'Common' flutter could originate from a preferred continuous circuit of excitation or alternatively could originate from an area of focal excitation or re-entry at the coronary sinus or AV junction. Focal excitation or re-entry in these areas may be associated with or be independent of a preferred circuit of excitation. 'Uncommon' flutter may represent a variety of unusual circuits or a variety of unusual supraventricular pacemaker tissues (Amat-y-Leon *et al.*, 1974) in association with or independent of nonpreferred atrial circuits of excitation. Perhaps subgroups could be identified through analysis of flutter loops which, when subjected to electrophysiological interventions (Wellens, 1971) would differ in mode of onset, maintenance, and termination.

Fig. 7 (A) Examples of 'common' flutter and left atrial pacing in the same patient. Top panel: electrocardiographic pattern of 'common' atrial flutter. Bottom panel: left atrial appendage pacing 8 days after operation for mitral valve replacement. P waves are negative in I, aVL, and V6. Lead V1 does not have dome-dart P (Case 21). (B) P loops of 'common' flutter and left atrial pacing in the same patient. Top panel: flutter P loop is oriented caudad-cephalad, slightly to the left and anterior. Bottom panel: left atrial appendage pacing results in P loop which is oriented inferior, to the right, and anterior (Case 21).

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