Europace (2008) 10, 786–796
doi:10.1093/europace/eun106

EUROPEAN SOCIETY OF CARDIOLOGY®

REVIEW

Prediction of the atrial flutter circuit location from the surface electrocardiogram

Caroline Medi[1,2] and Jonathan M. Kalman[1,2]*

[1]*Department of Cardiology, Royal Melbourne Hospital; and* [2]*Department of Medicine, The University of Melbourne, Melbourne 3050, Victoria, Australia*

Received 24 February 2008; accepted after revision 2 April 2008; online publish-ahead-of-print 2 May 2008

KEYWORDS
Typical atrial flutter;
Atypical atrial flutter;
Surface electrocardiogram;
P-wave morphology;
Left atrial flutter

Identification of atypical atrial flutter (AFL) (non-cavo-tricuspid isthmus-dependent) prior to the electrophysiology laboratory is potentially useful because it allows appropriate procedural planning and enables discussion of the likely success rates and risks of the procedure with the patient. Typical counterclockwise AFL has a stereotypic appearance, the electrocardiogram (ECG) is predictive of the diagnosis in the majority of cases, and ablation procedures are associated with a high degree of safety and success. Atypical right atrial and left AFLs have a highly variable flutter wave morphology and may appear atypical, resemble typical flutter or appear to be focal in origin. Targeting these complex and often multiple re-entrant circuits is aided by expertise and use of electroanatomic mapping systems. This review will address whether there are clues from the 12-lead ECG which assist in the localization of AFL circuits.

Introduction

It is well recognized that focal atrial tachycardia *in the absence of significant structural heart disease* (*SHD*) *or prior extensive ablation* has a signature P-wave morphology which can provide much information regarding the site of tachycardia origin. This review will address the question of whether there are clues from the 12-lead electrocardiogram (ECG) which assist in the localization of atrial flutter (AFL) circuits.

The continued use of the designation AFL owes most to historical and traditional considerations as in the modern era, the term conveys very little information about tachycardia mechanism. In currently accepted definitions, AFL refers to the presence of a continuously undulating pattern on the surface ECG without an isoelectric baseline.[1] As such it is an electrocardiographic description which is frequently used by general cardiologists and general physicians. Although the appearance of flutter is suggestive of macro-re-entry, it may also be seen in focal arrhythmias under certain conditions. There is no suggestion from the term as to whether a circuit is dependent on the cavo-tricuspid isthmus or indeed whether it originates in the left or right atrium (RA). Thus, for the sake of clarity, it is important to briefly review current definitions.[1] The AFLs comprise a heterogeneous group of atrial arrhythmias that are underpinned by macro-re-entrant circuits. The macro-re-entry is supported by conditions of slowed conduction, and constrained by barriers that may be anatomical, functional, or both.

Macro-re-entrant atrial arrhythmias can be considered in terms of those that are dependent on the cavo-tricuspid isthmus and those that are not. Cavo-tricuspid isthmus-dependent arrhythmias include what has been traditionally designated as typical counterclockwise AFL in addition to 'typical' clockwise flutter and lower loop re-entry. These arrhythmias can be cured with ablation with success rates in excess of 95% and very low procedural risk. Non-cavo-tricuspid isthmus (CTI)-dependent atrial macro-re-entry can occur in either the right or left atrium (LA). A further important designation in classification is the presence of surgical atrial scars (lesion or incisional re-entry). This may include surgery for correction of congenital heart disease (Atrial septal defect, Fontan, Tetralogy of Fallot, etc.) or for acquired lesions (mitral valve surgery, occasionally with coronary surgery depending on the location of cardiopulmonary bypass return). Furthermore, when non-CTI 'flutter' is present, particularly in the presence of prior atrial surgery or significant SHD, multiple circuits may occur, at times simultaneously (e.g. dual-loop re-entry). Finally, as considered above, focal arrhythmias may

* Corresponding author. Tel: +61 3 93495400; fax: +61 3 93495411.
E-mail address: jon.kalman@mh.org.au

present an ECG appearance of continuous undulation. This is often the case for very rapid focal tachycardias, particularly if there is some atrial conduction slowing due to atrial disease or surgery which will result in a broad P-wave.

The substrate underlying typical AFL (either counterclockwise or clockwise) has been well-defined and demonstrated to be amenable to curative radiofrequency catheter ablation with a high degree of safety and long-term success. In atypical AFL, the location of the circuit is variable and may involve dual-loop re-entry or complex re-entrant mechanisms. Predicting a non-isthmus-dependent AFL prior to an ablation procedure is potentially useful as it allows appropriate procedural planning and discussion of the success rate and risks with the patient. These latter may be quite different for a left AFL (where there is often significant SHD and multiple circuits) when compared with a routine isthmus-dependent flutter. The clinical context and flutter wave appearance on the surface ECG may suggest the underlying macro-re-entrant substrate and aid in facilitating early recognition of these cases.

Typical AFL involves stereotyped rotation (either counterclockwise or clockwise) of the tachycardia circuit around the tricuspid valve annulus, and flutter wave appearance in these subtypes is generally consistent and predictive of the underlying mechanism. However, the correlation between flutter wave appearance and the underlying re-entrant circuit is imperfect, as some atypical non-isthmus-dependent flutters may manifest typical ECG patterns (*Figure 1*), and some typical flutters do not conform to the classic ECG appearance (*Figure 2*).

Cavo-tricuspid isthmus-dependent atrial flutter

Typical atrial flutter (counterclockwise atrial flutter)

Typical AFL represents the most common type of AFL. The re-entrant circuit is defined by well-described anatomic barriers and as such has a relatively stereotypic appearance (*Figure 3*).

Although the general physician and cardiologist will speak of a characteristic 'sawtooth' pattern in leads II, III, and avF, a closer examination of the flutter wave yields much additional information. The inferior leads demonstrate an initial gradual downsloping segment followed by a sharp steep descent, then a sharp ascent with a low amplitude terminal positive component, which continues into the gradual descent of the subsequent flutter wave. The appearance in the precordial leads can be described as comprising two components. Lead V1 classically demonstrates an initial isoelectric component followed by an upright component. With progression across the precordium, the initial component rapidly becomes inverted and the second component isoelectric usually by V2 to V3. This produces the overall impression of an upright flutter wave in V1 which becomes inverted by V6. Lead I is low amplitude/isoelectric and aVL usually upright.[2–4] Although this classic appearance rarely shows much variation, occasionally unusual morphologies occur (*Figure 2*), or a left AFL may mimic a counterclockwise flutter appearance (*Figure 1*).

Lower loop re-entry (counterclockwise) is 'cavo-tricuspid isthmus-dependent'.[5,6] The flutter wave appearance on the surface ECG in lower loop re-entry (LLR) is variable

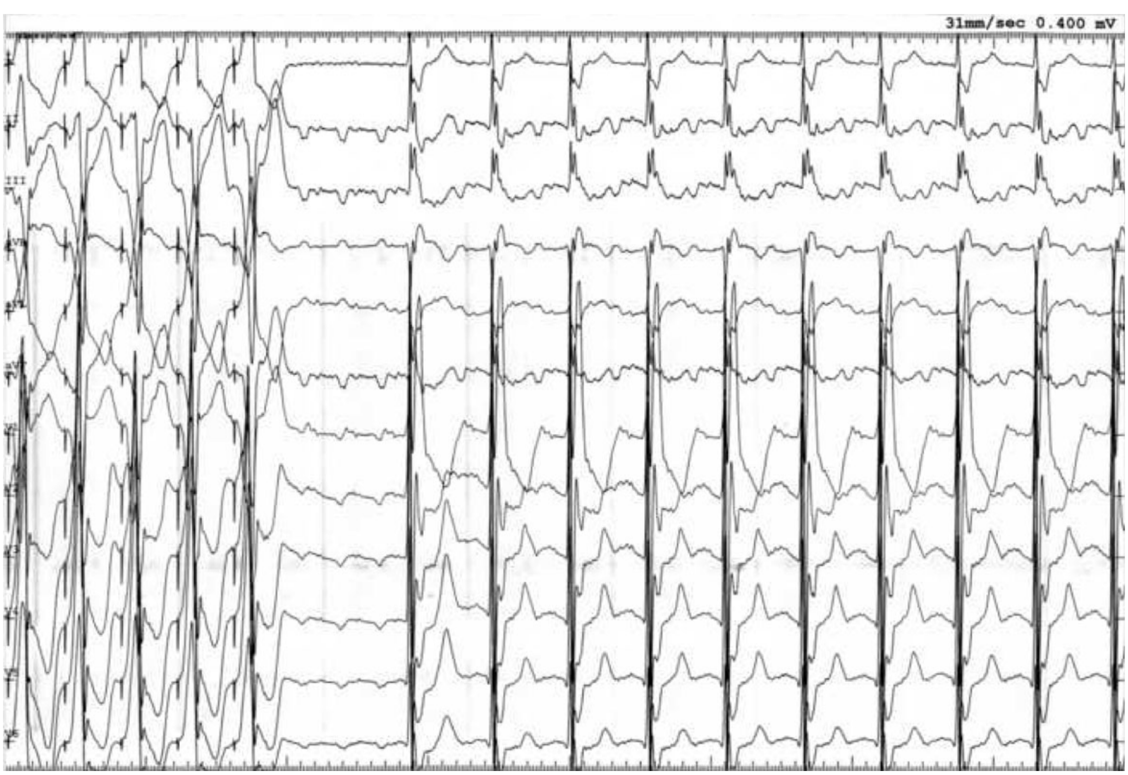

Figure 1 Atypical (left atrial) atrial flutter resembling typical counterclockwise atrial flutter. Ventricular pacing has been used to expose the P-waves more clearly. Flutter waves in inferior leads are inverted with a terminal upright component. The flutter waves in lead V1 are negative/positive, and negative across the precordial leads, with a similar overall appearance to typical counterclockwise atrial flutter.

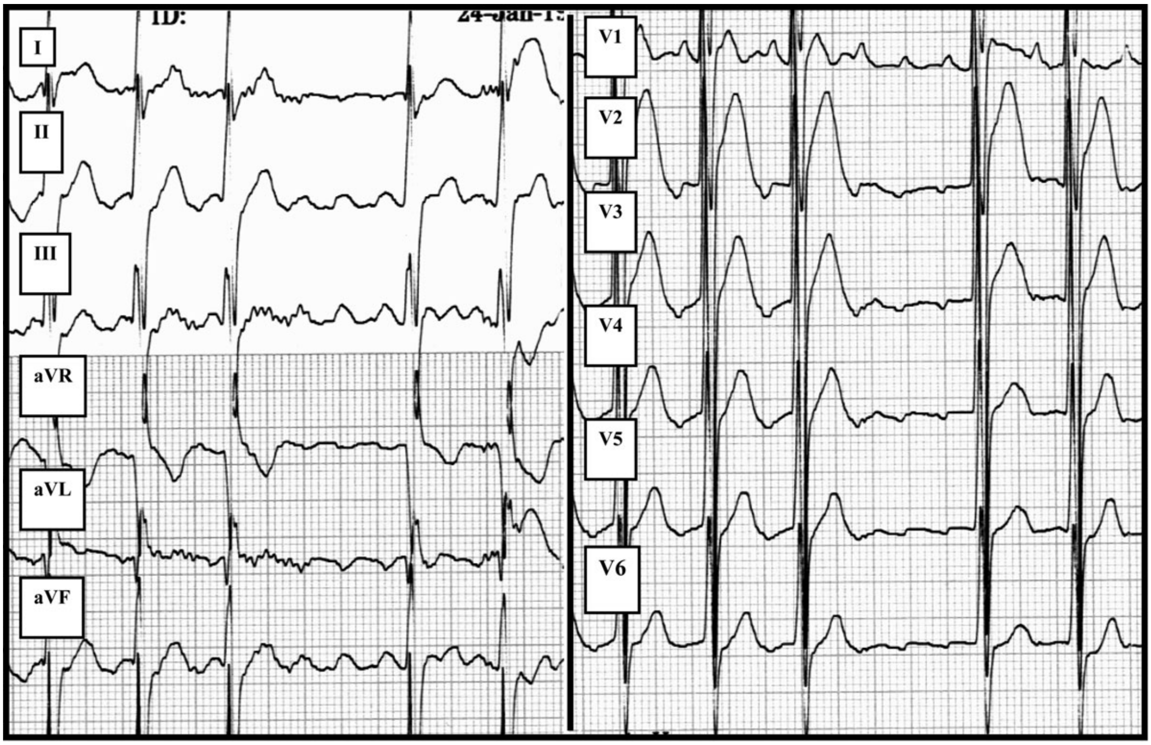

Figure 2 'Atypical' typical counterclockwise atrial flutter. In the inferior leads, the flutter waves are broad-based with a notched appearance, and a prominent upright component, not characteristic of typical atrial flutter. The precordial leads are more characteristic of counterclockwise cavo-tricuspid isthmus (CTI)-dependent flutter. Detailed mapping confirmed that this was typical CTI-dependent flutter, and successful ablation was performed in the usual manner.

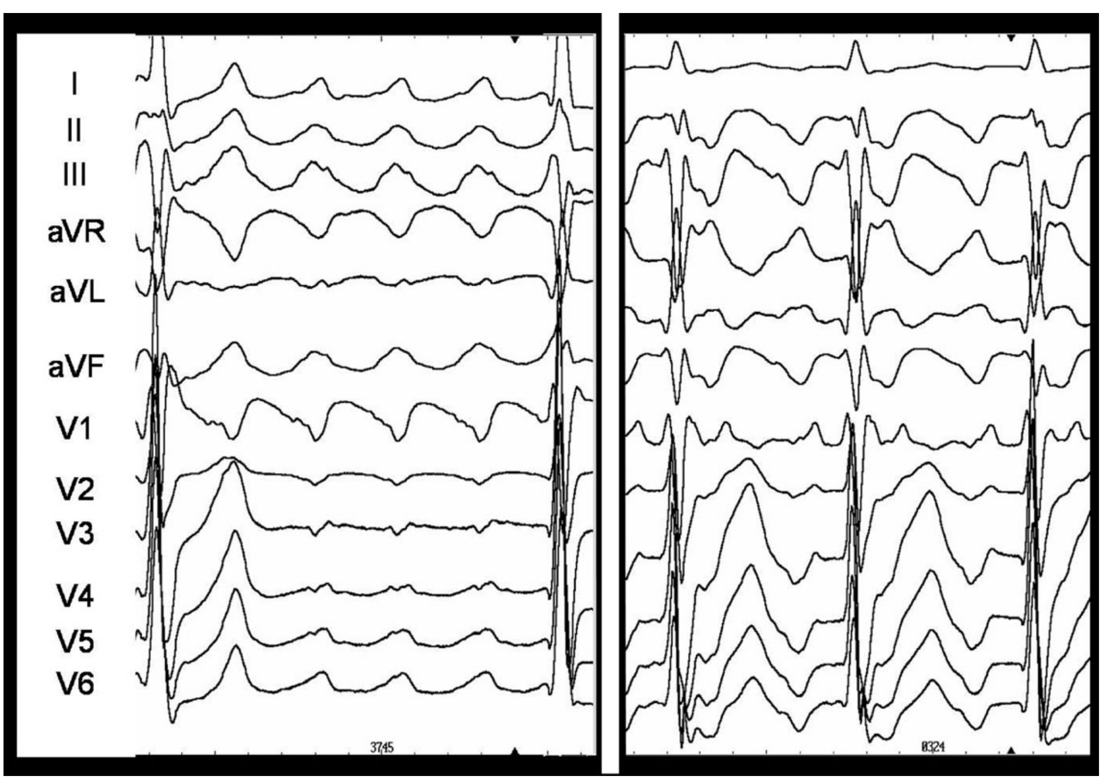

Figure 3 Examples of clockwise (left panel) and counterclockwise (right panel) typical flutter from the same patient. In clockwise atrial flutter, the flutter waves in inferior leads are broad, positive, and commonly notched. Lead V1 is broadly negative and notched, transitioning to upright across the precordium. Lead I is upright and aVL is low amplitude negative.The inferior lead flutter wave in counterclockwise atrial flutter demonstrates an initial gradual negative deflection, followed by a deeply negative component, and low amplitude terminal positive deflection. Lead V1 has an initial inverted component followed by an upright component. With precordial transition, these two flutter wave components become isoelectric/negative. Lead I is low amplitude negative and aVL is upright.

and depends upon the site of breakthrough of the wavefront at the crista terminalis.[7,8] When breakthrough occurs at the low lateral RA, the resulting clockwise ascending wavefront collides with the counterclockwise wavefront propagating from the interatrial septum and roof of RA, thus abolishing the late descending wavefront on the lateral RA wall seen in counterclockwise typical AFL. Abolishing these late inferiorly directed forces is reflected by attenuation in the late positive deflection of the flutter wave compared with that of counterclockwise typical AFL (*Figure 4*). As the LA and septum are activated in a similar sequence to counterclockwise typical AFL, the flutter waves are otherwise comparable. This arrhythmia will also be successfully ablated in the cavo-tricuspid isthmus.

Clockwise or reverse typical atrial flutter

The re-entrant circuit and the anatomical/functional constraints are identical to those in typical AFL, with a clockwise direction of rotation around the tricuspid annulus.[3,9,10] About 10% of the patients with typical counterclockwise AFL also manifest clockwise AFL, although a higher percentage may be induced in the electrophysiology laboratory.[11,12]

The surface ECG appearance is more variable than that of typical counterclockwise AFL (*Figure 5*). In the inferior leads, the flutter waves are usually broadly positive, with characteristic notching.[3] However, there is an inverted component preceding the upright notched component. Depending on the amplitude of this component, the appearance can be of continuous undulation without an obviously predominant upright or inverted component (*Figure 6*). On other occasions, it may appear that the inverted component is dominant, thus superficially mimicking counterclockwise flutter.[3] V1 is characterized by a broad negative and usually notched deflection. There is transition across the precordium to an upright deflection in V6.[3,4,9] Lead I is usually upright and aVL is low amplitude negative and notched. Thus in many respects, clockwise flutter presents an inversion of the appearance in counterclockwise flutter (*Figure 3*).[3]

Atypical atrial flutters: right atrial flutter

Right atrial free wall atypical atrial flutter

Atrial macro-re-entry in the right free wall is the most common form of right atrial atypical flutter. Such macro-re-entrant circuits may propagate around areas of low voltage or scar in the lateral or postero-lateral right atrial wall. Such scarring can arise spontaneously or as a consequence of prior atrial surgery.[8,13] Electroanatomical mapping has identified both single-loop re-entry and dual-loop re-entrant circuits utilizing neighbouring anatomical structures.[14] It may manifest as an isolated arrhythmia, although coexists in the majority with typical and/or reverse typical AFL.[8,13]

The ECG appearance of free wall AFL is highly variable; depending on factors including anatomic location (superior or inferior), direction of rotation, the presence of coexisting conduction block in the atrium, and the presence of a simultaneous peri-tricuspid circuit (*Figure 7*). For example, the

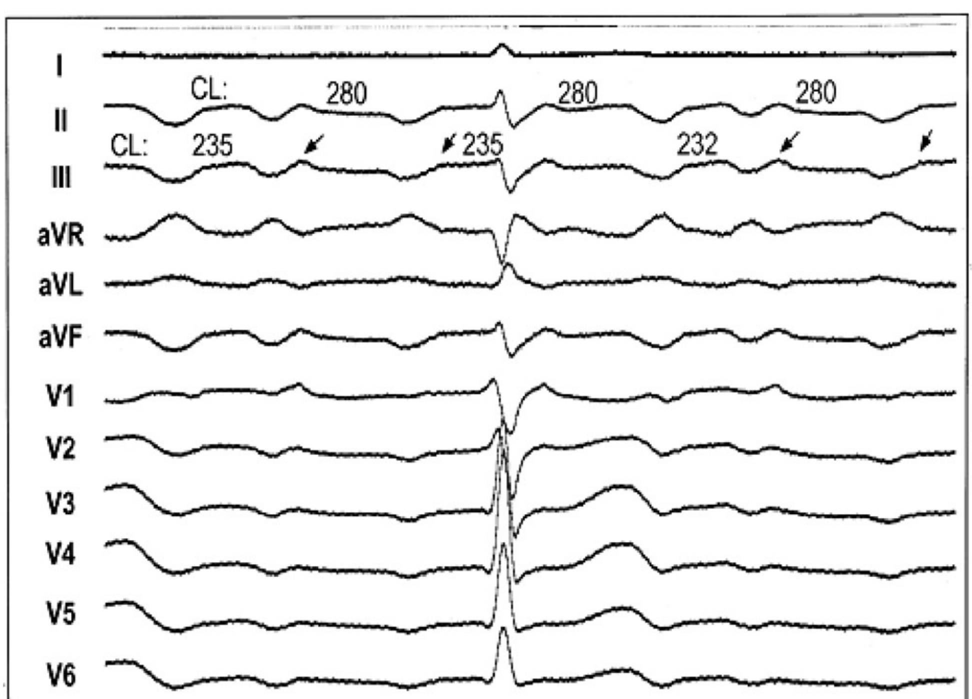

Figure 4 Lower loop re-entry. Typical counterclockwise flutter is alternating with lower loop re-entry. The loss of the late terminal positive component is a very subtle change and demonstrates the difficulties inherent in using the flutter wave for circuit localization. In addition, it can be seen that unless you are looking for this arrhythmia specifically and depending on the level of crista terminalis breakthrough, this will look very much like typical flutter. And like typical flutter these circuits were all successful ablated in the CTI. (Figure from Cheng *et al.*,[5] reproduced with kind permission).

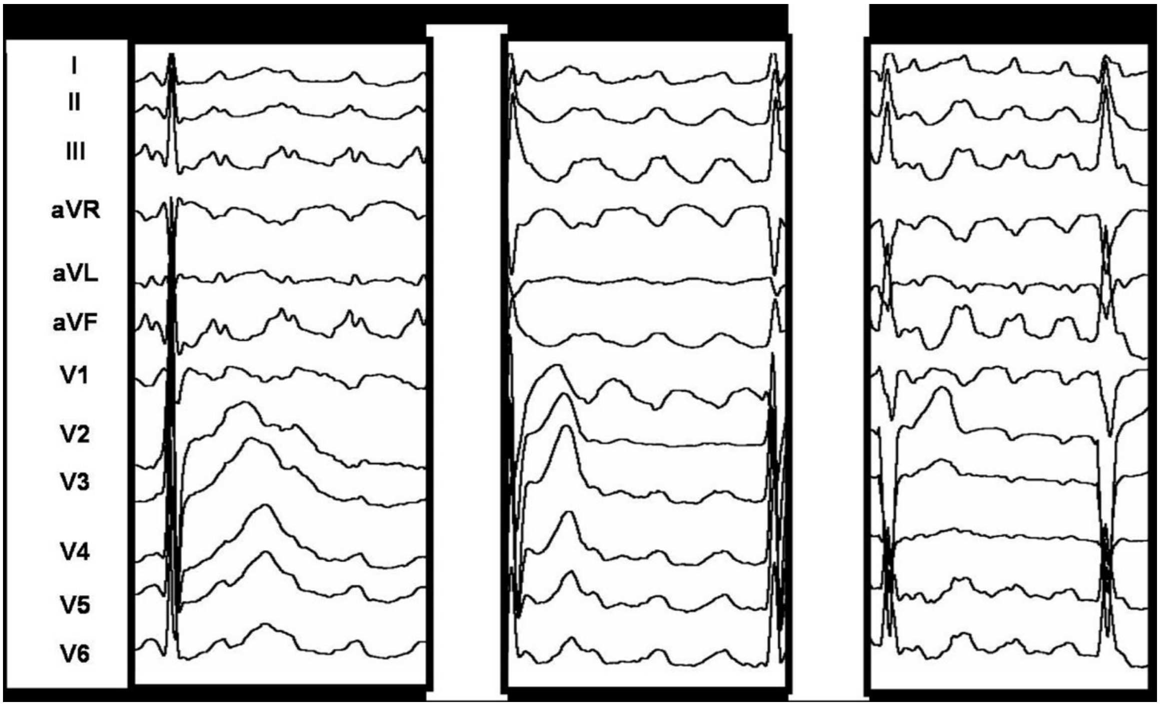

Figure 5 Three examples of clockwise typical atrial flutter showing the characteristic overall pattern but considerable variation in flutter wave amplitude and extent of notching.

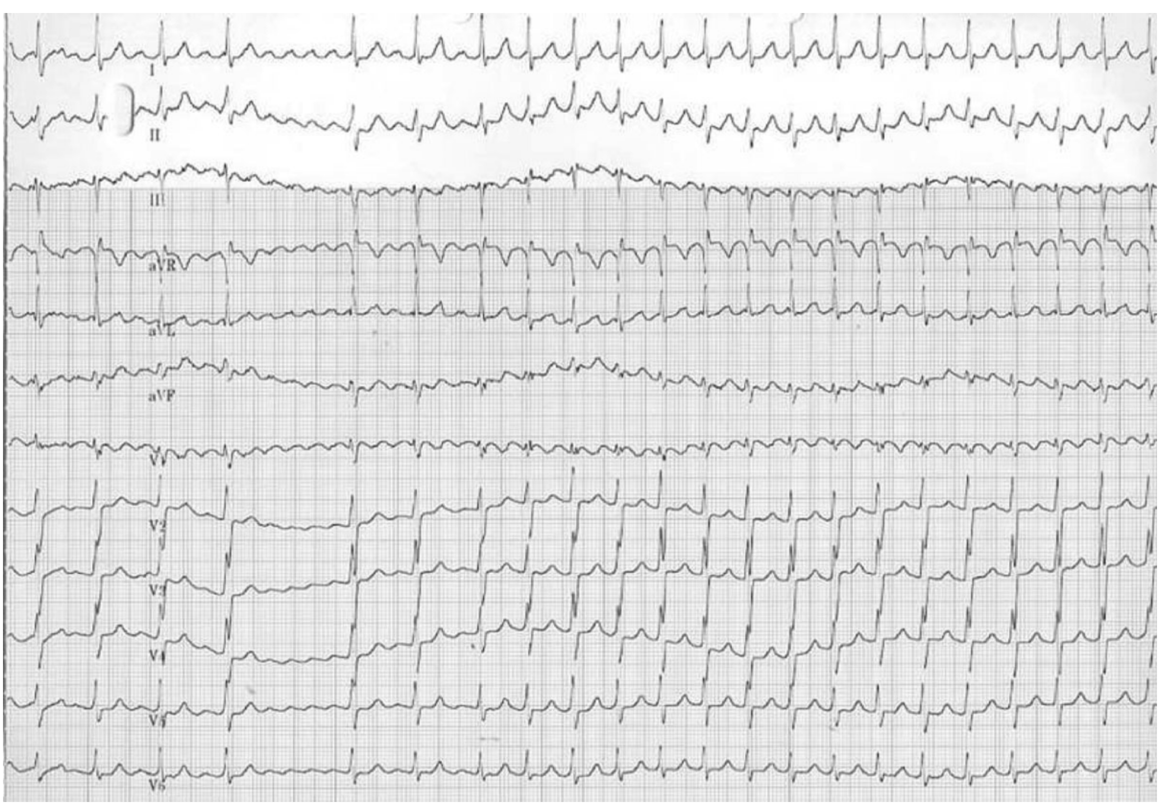

Figure 6 Another example of typical clockwise CTI-dependent flutter. In this patient, the amplitude of the upright and inverted components in both inferior and precordial leads is similar rendering localization of the circuit impossible.

flutter morphology of a free wall circuit will be markedly altered by the presence of pre-existing cavo-tricuspid isthmus block (*Figure 8*). If there is a hallmark for a right atrial free wall flutter, it shows the presence of an inverted flutter wave in V1. Depending on the predominant direction of septal activation, right atrial free wall flutter can mimic either clockwise or counterclockwise flutter (*Figure 8*).[13]

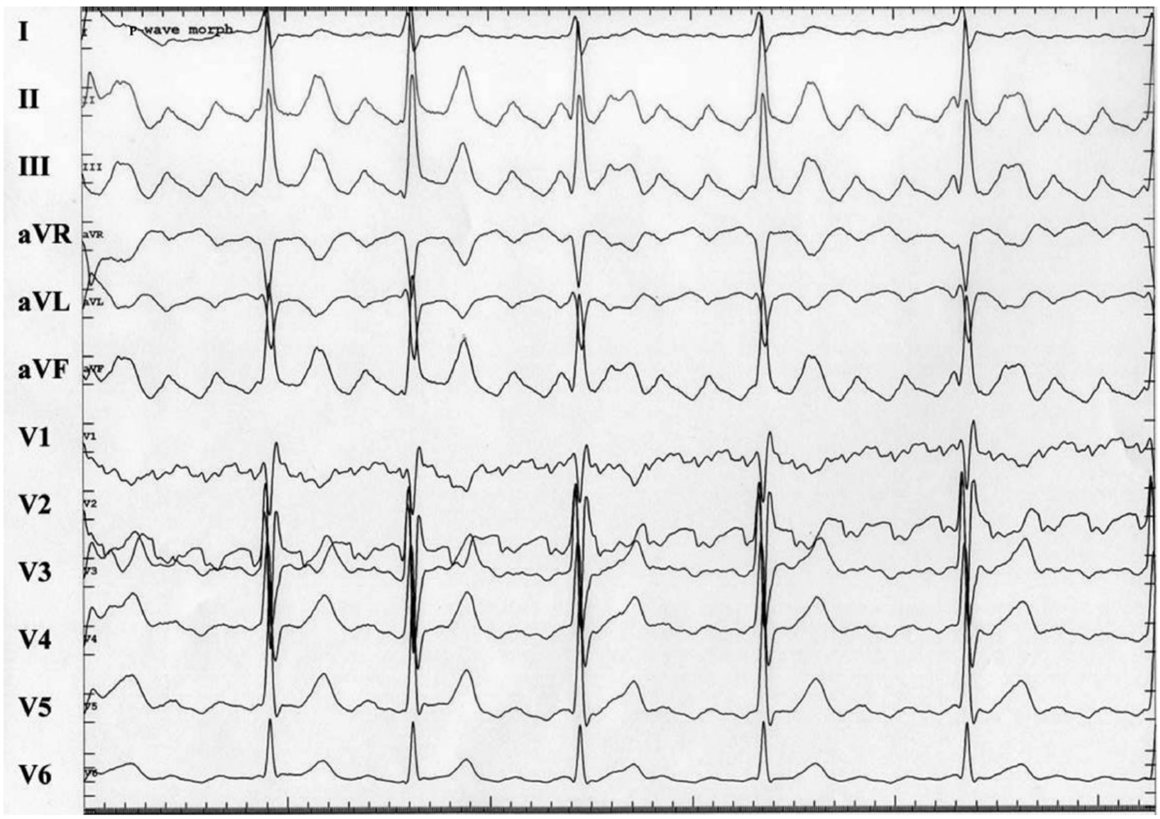

Figure 7 Electrocardiogram from patients with dual-loop right atrial flutter and past history of atrial septal defect repair. The circuit around the tricuspid annulus is clockwise with a simultaneous counterclockwise circuit around the free wall scar. The inferior leads show similar amplitude upright and inverted components. V1 shows unusual notching.

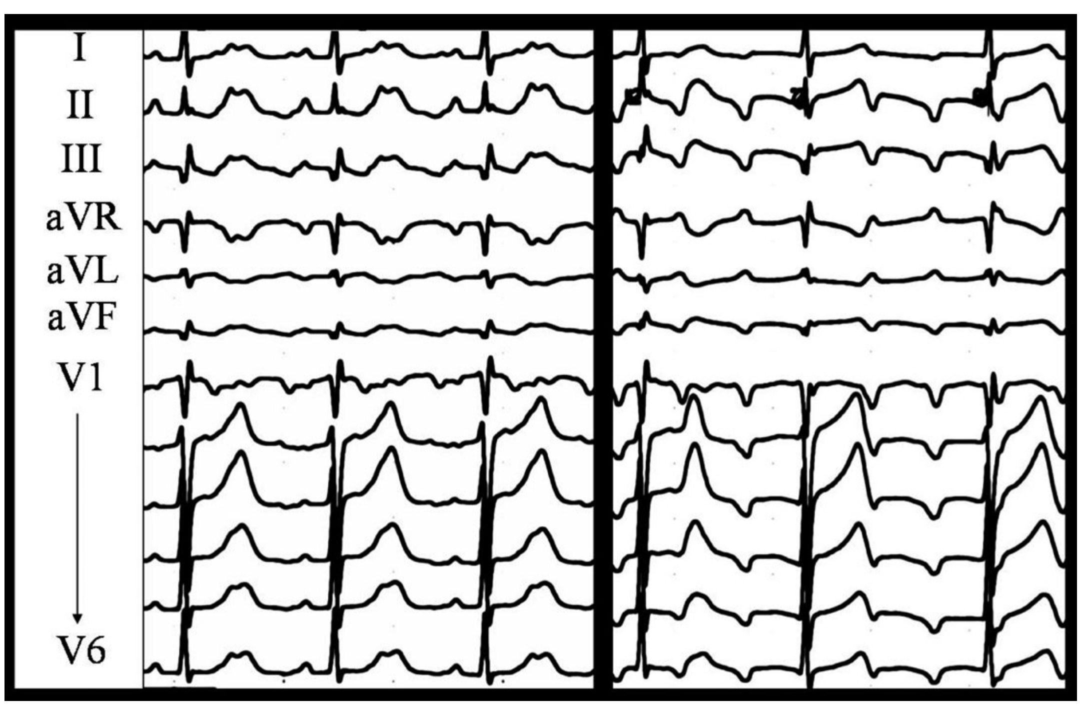

Figure 8 This slide is from a patient with a right atrial free wall flutter (no prior surgery but mapping demonstrated spontaneous free wall scar). Cavo-tricuspid isthmus entrainment and three-dimensional electroanatomic mapping confirmed that the CTI was not part of the circuit. The right panel shows the flutter wave morphology prior to CTI ablation, which was performed first. The flutter wave is deeply inverted in V1 (right atrium free wall) and in inferior leads because of predominant passive activation of the septum and left atrium from inferior to superior. In the left panel, following CTI ablation there is a dramatic change in the flutter wave morphology due to change in the activation pattern of the septum and left atrium. This example emphasizes the dependence of flutter wave morphology on propagation patterns distant to the circuit. Prior surgery or ablation can thus markedly influence the flutter appearance.

Upper loop re-entry

Upper loop re-entry (ULR) defines an atypical AFL involving the upper portion of the RA and is not cavo-tricuspid isthmus-dependent.[8,14,15] Although this macro-re-entrant circuit may exist in isolation, episodes often arise after transition from typical clockwise AFL, LLR, or atrial fibrillation.[8] Three-dimensional non-contact mapping has delineated the re-entrant circuit around the superior vena cava and the upper crista terminalis, which serves as the zone of functional block.[14] Most commonly, ULR closely resembles the appearance of clockwise or reverse typical AFL on the surface ECG, with positive P-waves in the inferior leads, as in the majority of cases, activation of the septum and LA occurs via inferiorly directed forces.[7,8,14,16] The cycle length of ULR circuit is shorter in comparison with CTI-dependent flutters, because of the shorter circuit length.[8,14,17] An algorithm to help distinguish ULR from reverse typical AFL has been proposed, based on the polarity and amplitude of the P-wave in lead I.[17] Negative or isoelectric/flat P waves in lead I were associated with ULR, and when P waves were positive in lead 1, ULR was probable when P wave amplitude was $\leq$0.07 mV, and reverse typical AFL was probable when P wave amplitude was $>$0.07 mV. In this study, the algorithm was found to have an accuracy of 90–97%, a sensitivity from 82 to 100%, and specificity of 95%. Distinguishing ULR from reverse typical AFL from the ECG prior to electrophysiological study is potentially valuable, as the two arrhythmias require different mapping and ablation techniques. However, definitive diagnosis of ULR requires detailed intracardiac mapping.

Other unusual forms of atypical right AFL have been described. Circuits involving the septum have been demonstrated, particularly after prior surgery involving this area but are relatively uncommon. They are usually characterized by a biphasic or isoelectric flutter morphology in V1.

Left atrial flutter

Left AFLs are less common than typical AFL and most usually occur in association with SHD including hypertension, mitral valve disease, left atrial dilation, and cardiac failure. These circuits occur around regions of spontaneous scarring frequently located in the posterior LA. The macro-re-entrant circuits show considerable anatomic variability and frequently involve multiple simultaneous loops.[18,19] Circuits may propagate around the mitral valve annulus, around regions of scarring, and the ostia of the pulmonary veins or infrequently may involve the septum rotating around the fossa ovalis.[7,18]

Left AFL circuits are less well-described than typical and atypical right AFLs; however, the most common form involves a perimitral circuit.[20] Jais *et al.*[20] described a

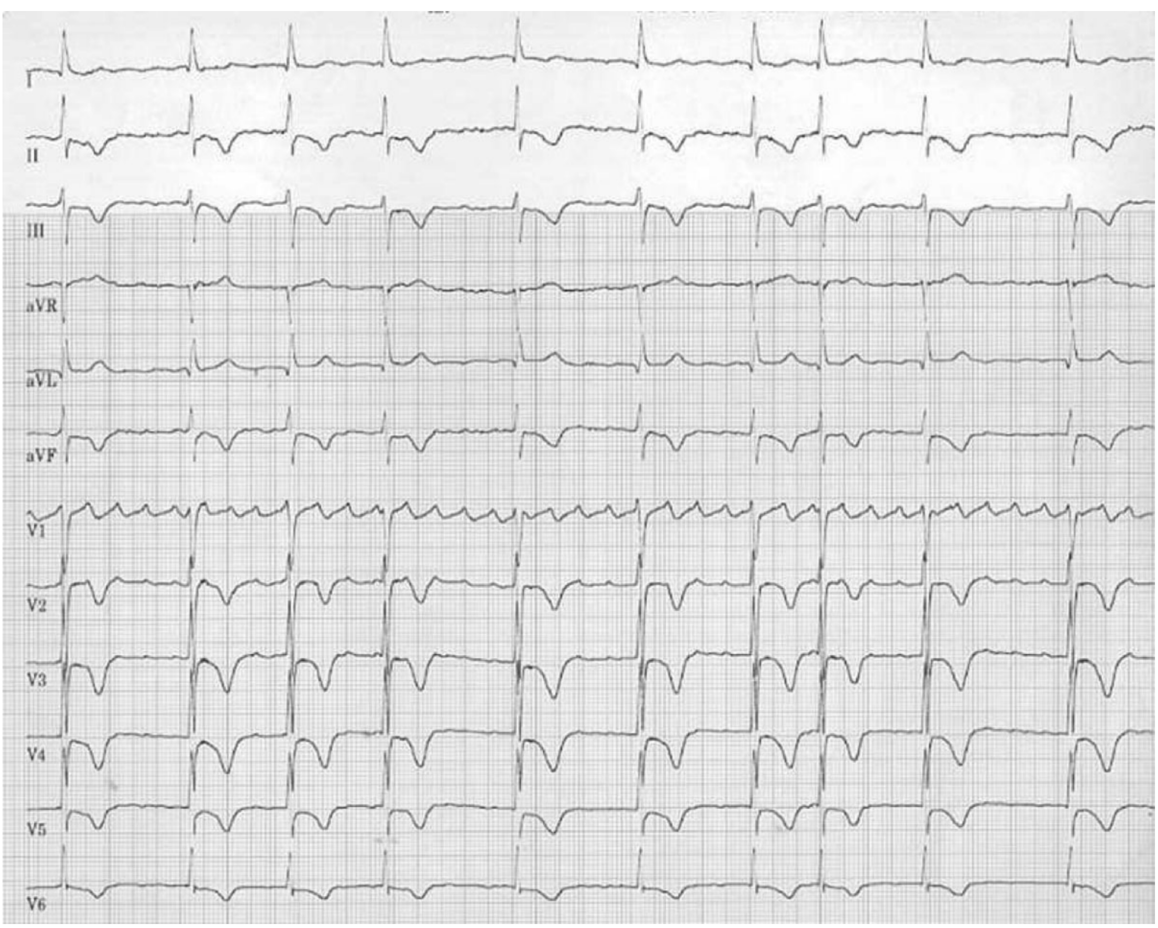

Figure 9 Electrocardiogram from a patient with a left atrial flutter. The circuit was rotating around the left pulmonary veins. The patient had a history of congestive heart failure but no prior atrial surgery or ablation. Mapping demonstrated extensive left atrial regions of electrical silence. Note that the flutter wave is upright in V1 with constant morphology and cycle length. All other leads are virtually isoelectric and thereby mimicking atrial fibrillation.

series of patients with spontaneous LA flutter and frequently found rotation around the mitral annulus, a zone of block including the pulmonary veins or an electrically silent area. Electrically silent areas are a relatively common finding in LA flutters, most likely representing atrial fibrosis in association with SHD, may also act as a lateral barrier allowing circuit stabilization.[20]

The surface ECG findings are often similar for different underlying substrates, making the localization within the LA based on the ECG difficult (*Figures 9*, *10*, and *11*). The flutter wave usually shows a prominent positive deflection in lead V1 and uncommonly is flat or isoelectric. The flutter waves in leads II, III, and aVF may be upright but are frequently of low amplitude. However, in a minority of patients, the morphology resembles typical flutter (*Figure 1*).[7,18] The two most commonly observed patterns in the left AFL would include: a broad upright flutter wave in V1 with upright waves in inferior leads; or broad upright flutter wave in V1 with low amplitude; or isoelectric waves in all other leads (*Figures 9*, *10*, and *11*). Owing to a high prevalence of generalized atrial disease and slower conduction, longer cycle lengths with a greater isoelectric interval between flutter waves have been observed.[7] Left AFL may thus mimic a focal atrial tachycardia (*Figure 12*).

Distinguishing right-sided vs. left-sided macro-re-entrant circuits from the electrocardiogram

The most useful lead to evaluate right from left AFL is V1. A broad-based upright V1 is highly predictive of a left-sided flutter. However, when V1 has an initial isoelectric (or inverted) component (followed by an upright component), this is consistent with a right AFL. Conversely, when V1 is deeply inverted, this is highly suggestive of a right-sided flutter. However, when V1 is biphasic or isoelectric, it is not helpful in predicting the chamber of origin.

Distinguishing macro-re-entrant atrial tachycardia vs. focal atrial tachycardia

The pattern and behaviour of the tachycardia can indicate the likely underlying substrate. Focal atrial tachycardias classically exhibit alterations in cycle length with speeding ('warm up') and slowing ('cool down') at the onset and termination of tachycardia. Focal atrial tachycardias often manifest as bursts of tachycardia with spontaneous onset and termination, although can be incessant, and may accelerate in response to sympathetic stimulus.

The tachycardia cycle length is less helpful in differentiating between focal and macro-re-entrant mechanisms. Although the cycle length is usually ≥250 ms in focal atrial tachycardia, shorter cycle lengths are now well described. In this situation, particularly in the presence of intra-atrial conduction delay, there may be no observable isoelectric interval between P-waves, and an undulating baseline resembling AFL may be seen (*Figure 13*). Conversely, macro-re-entrant circuits may have long cycle length in the presence of SHD and anti-arrhythmic agents.[2] Furthermore, in the presence of significant atrial scarring, there may be a long isoelectric interval between flutter waves, incorrectly suggesting a focal mechanism (*Figure 12*). This

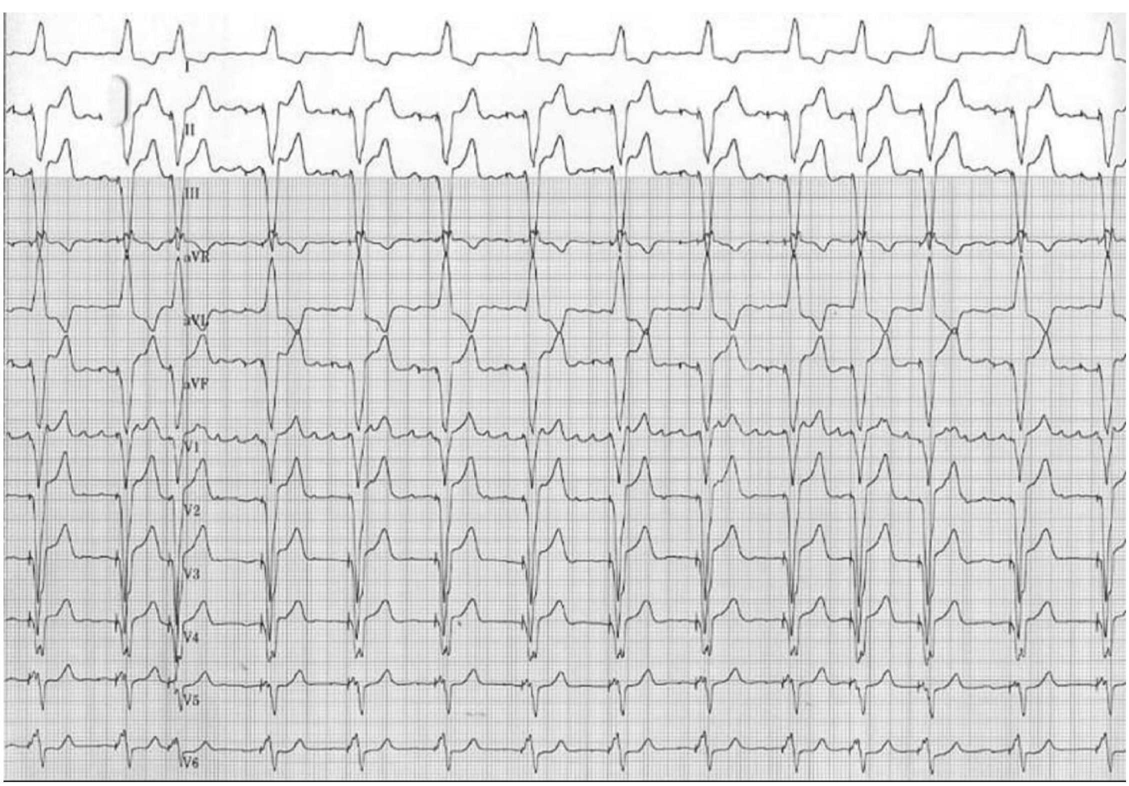

Figure 10 Electrocardiogram from another patient with left atrial flutter and no prior atrial surgery or ablation. This patient has a dual chamber pacemaker, which is failing to sense appropriately in the atrium. Mapping revealed a clockwise circuit around the mitral annulus and posterior regions of electrical silence. Note that the flutter morphology is upright both in V1 and in inferior leads highly suggestive of a left atrial circuit.

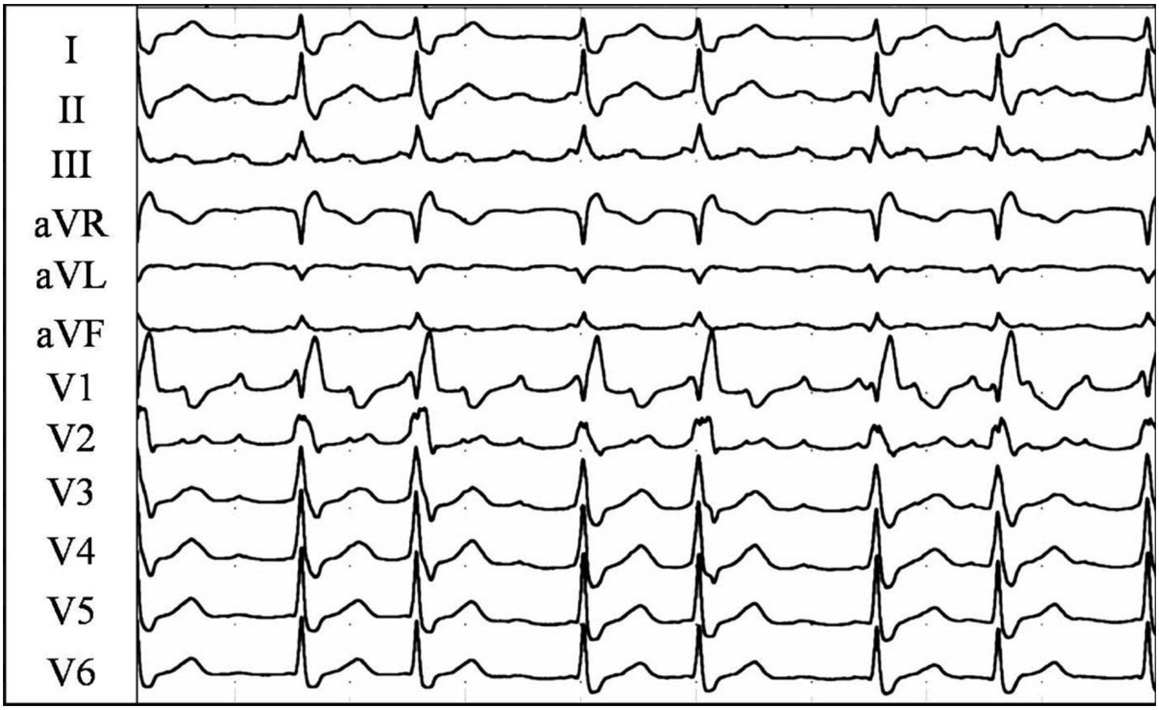

Figure 11 Electrocardiogram from a 42-year-old woman with left atrial flutter and no structural heart disease. The morphology is again upright in inferior leads and in V1 as in the case in *Figure 9*. However, the circuit involved the left-sided pulmonary veins and a posterior region of scarring rather than the mitral annulus.

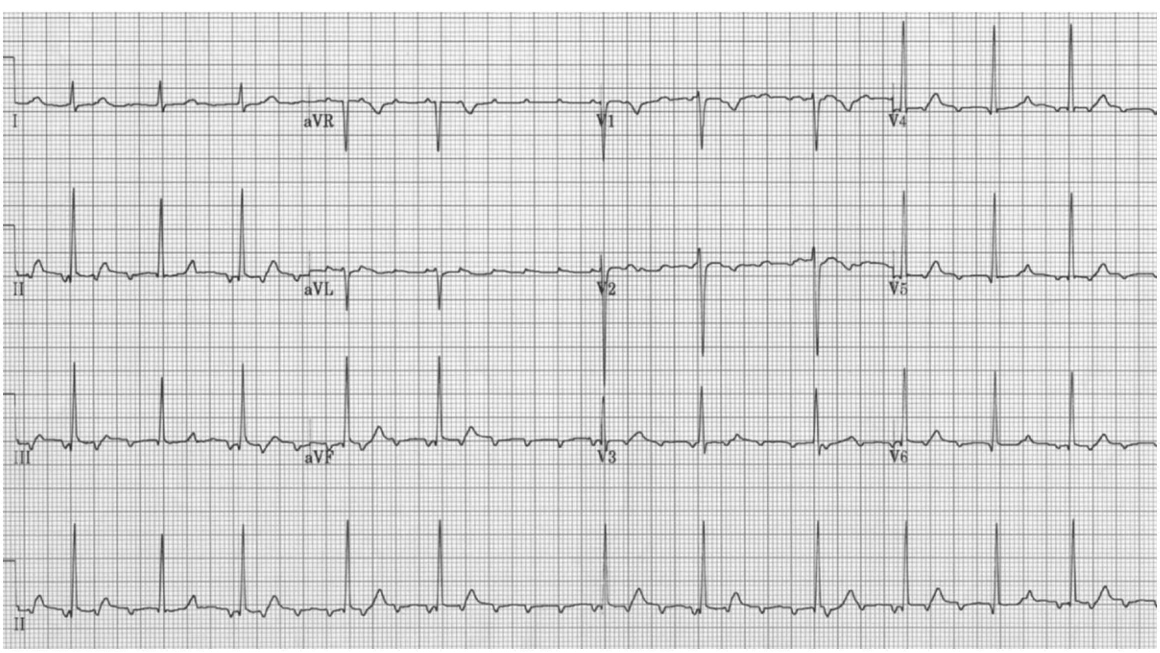

Figure 12 Electrocardiogram from a patient with prior mitral valve replacement via a superior trans-septal incision. The circuit was around the septal scar. V1 is very low amplitude or isoelectric. There is a long isoelectric interval between the flutter waves, incorrectly suggesting a focal mechanism.

is particularly observed for left AFL in the presence of large areas of electrical silence.

Limitations of the surface electrocardiogram

Analysis of the flutter wave is difficult when conduction is 1:1 or 2:1, as the flutter wave is wholly or partially concealed within the QRS complex or T-wave. This is compounded at times when the flutter wave amplitude is low. When making any assessment of flutter wave morphology, it is always important to visualize the complete unencumbered 12-lead ECG.

In many patients, macro-re-entry occurs in the presence of significant atrial SHD, which may play an important role

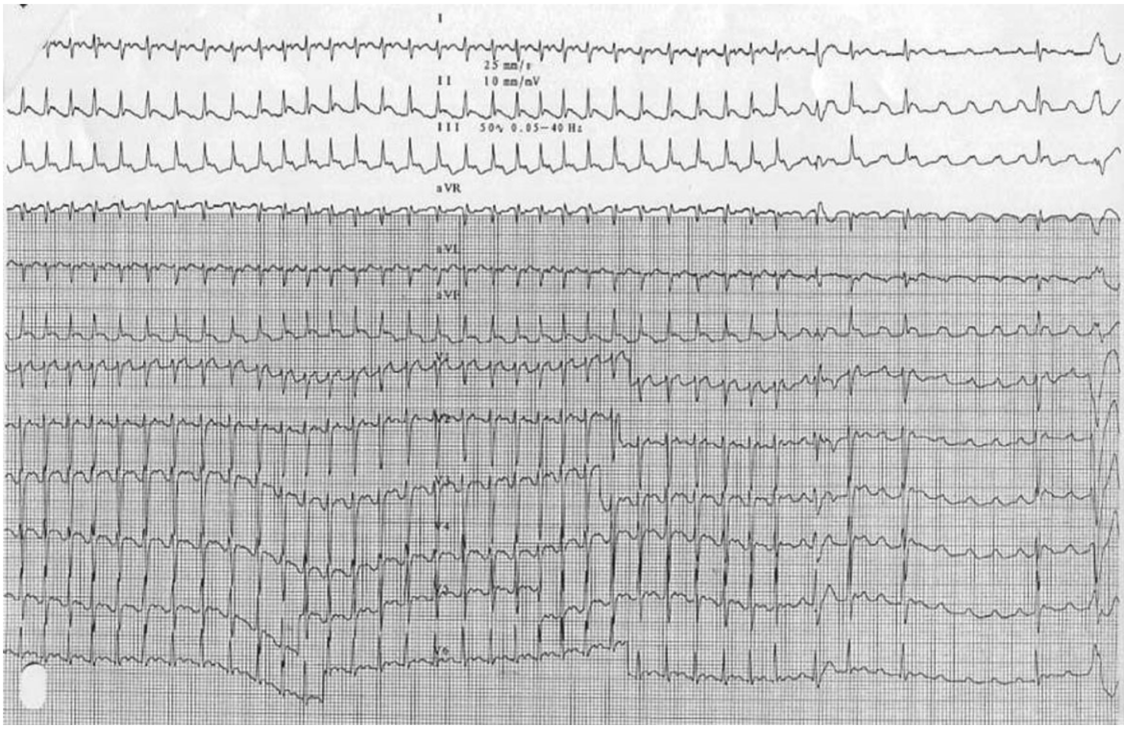

Figure 13 Focal atrial tachycardia originating from the right superior pulmonary vein. Adenosine creates transient block to allow the analysis of the P-wave. The short cycle length and lack of an isoelectric interval between P-waves gives an appearance similar to macro-re-entry.

in modifying the direction of wavefront propagation in a non-uniform manner. Thus, there are only a limited number of macro-re-entrant circuits where the P-wave morphology provides a signature for anatomic location. This effect is most marked in the presence of prior atrial surgery or extensive atrial ablation. These patients often have markedly distorted anatomy both due to the original congenital abnormality and also due to (frequently multiple) prior atrial surgeries. In this patient population, the P-wave morphology is not usually helpful in localizing a circuit.[21–23]

Conclusion

The surface ECG is of limited value for precise anatomic localization of macro-re-entrant circuits. It is most characteristic (and hence predictive) for establishing a diagnosis of typical counterclockwise AFL. Although clockwise CTI-dependent flutter also has a characteristic appearance, this is more variable. For both forms of CTI-dependent flutter, atypical patterns can be seen, and occasionally non-CTI-dependent circuits may present a very similar appearance. The flutter wave morphology of a spectrum of right and left atrial atypical or non-CTI-dependent flutters is highly variable. Many patients with atypical flutter will have more than one circuit. Furthermore, flutter waves produced by macro-re-entrant circuits of divergent anatomic locations may appear similar if the direction of activation of the atrial septum and LA is similar.

V1 is the most useful lead for distinguishing left from right atrial origin but much overlap exists. Ultimately, these circuits will require detailed endocardial mapping for precise anatomic delineation.

Conflict of interest: none declared.

References

1. Saoudi N, Cosio F, Waldo A, Chen SA, Iesaka Y, Lesh M *et al*. A classification of atrial flutter and regular atrial tachycardia according to electrophysiological mechanisms and anatomical bases. A Statement from a Joint Expert Group form the Working Group of Arrhythmias of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. *Eur Heart J* 2001;**22**:1162–82.
2. SippensGroenewegen A, Lesh MD, Roithinger FX, Ellis WS, Steiner PR, Saxon LA *et al*. Body surface mapping of counterclockwise and clockwise typical atrial flutter: a comparative analysis with endocardial activation sequence mapping. *J Am Coll Cardiol* 2000;**35**:1276–87.
3. Saoudi N, Nair M, Abdelazziz A. Electrocardiographic patterns and results of radiofrequency catheter ablation of clockwise type 1 atrial flutter. *J Cardiovasc Electrophysiol* 1996;**7**:931–42.
4. Cosio FG, Arribas F, Lopez-Gil M, Gonzalez HD. Radiofrequency ablation of atrial flutter. *J Cardiovasc Electrophysiol* 1996;**7**:60–70.
5. Cheng J, Cabeen WR, Scheinman MM. Right atrial flutter due to lower loop reentry: mechanism and anatomic substrates. *Circulation* 1999; **99**:1700–5.
6. Zhang S, Younis G, Hariharan R, Ho J, Yang Y, Ip J *et al*. Lower loop reentry as a mechanism of clockwise right atrial flutter. *Circulation* 2004;**109**:1630–5.
7. Bochoeyer A, Yang Y, Cheng J, Lee RJ, Keung EC, Marrouche NF *et al*. Surface electrocardiographic characteristics of right and left atrial flutter. *Circulation* 2003;**108**:60–6.
8. Yang Y, Cheng J, Bochoeyer A, Hamdan MH, Kowal RC, Page R *et al*. Atypical right atrial flutter patterns. *Circulation* 2001;**103**:3092–8.
9. Kalman JM, Olgin JE, Saxon LA. Electrocardiographic and electrophysiologic characterization of atypical flutter in man. Use of activation and entrainment mapping and implications for catheter ablation. *J Cardiovasc Electrophysiol* 1997;**8**:121–4.
10. Tai CT, Shen SA, Chiang CE. Electrophysiologic characteristics and radiofrequency catheter ablation in patients with clockwise atrial flutter. *J Cardiovasc Electrophysiol* 1996;**8**:24–34.
11. Olgin JE, Kalman JM, Saxon LA, Lee RJ. Mechanism of initiation of atrial flutter in humans: site of unidirectional block and direction of rotation. *J Am Coll Cardiol* 1997;**29**:376–84.

12. Cosio FG, Lopez Gil M, Arribas F, Gonzalez HD. Mechanisms of induction of typical and reversed atrial flutter. *J Cardiovasc Electrophysiol* 1998;**9**: 281–91.
13. Kall JG, Rubenstein DS, Kopp DE, Burke MC, Verdino RJ, Lin AC *et al*. Atypical atrial flutter originating in the right atrial free wall. *Circulation* 2000;**101**:270–9.
14. Tai CT, Liu TY, Lee PC, Lin YJ, Chang MS, Chen SA. Non-contact mapping to guide radiofrequency ablation of atypical right atrial flutter. *J Am Coll Cardiol* 2004;**44**:1080–6.
15. Ricard P, Imianitoff M, Yaici K, Coutelour JM, Bergonzi M, Rinaldi JP *et al*. Atypical atrial flutters. *Europace*. 2002;**4**:229–39.
16. Inama G, Pedrinazzi C, Durin O, Agricola P, Romagnoli G, Gazzaniga P. Usefulness and limitations of the surface electrocardiogram in the classification of right atrial and left atrial flutter. *J Cardiovasc Med* 2006;**7**: 381–7.
17. Yuniadi Y, Tai CT, Lee KT, Huang BH, Lin YJ, Higa S *et al*. A new electrocardiographic algorithm to differentiate upper loop re-entry from reverse typical atrial flutter. *J Am Coll Cardiol* 2005;**46**:524–8.
18. Jais P, Hocini M, Weerasoryia R, Macle L, Scavee C, Raybaud F *et al*. Atypical left atrial flutters. *Cardiac Electrophysiol Rev* 2002;**6**: 371–7.
19. Ouyang F, Ernst S, Vogtmann T, Goya M, Volkmer M, Schaumann A *et al*. Characterization of reentrant circuits in left atrial macroreentrant tachycardia: critical isthmus block can prevent atrial tachycardia recurrence. *Circulation* 2002;**105**:1934–42.
20. Jais P, Shah D, Haissaguerre M, Hocini M, Peng JT, Takahashi A *et al*. Mapping and ablation of left atrial flutters. *Circulation* 2000;**101**: 2928–34.
21. Walsh E. Interventional electrophysiology in patients with congenital heart disease. *Circulation* 2007;**115**:3224–34.
22. Wong T, Davlouros PA, Li W, Millington-Sanders C, Francis DP, Gatzoulis MA. Mechano-electrical interaction late after Fontan operation: relation between P-wave duration and dispersion, right atrial size and atrial arrhythmias. *Circulation* 2004;**109**:2319–25.
23. Li W, Somerville J. Atrial flutter in grown-up congenital heart (GUCH) patients: clinical characteristics of affected population. *Int J Cardiol* 2000;**75**:129–37.