Localizing circuits of atrial macroreentry using electrocardiographic planes of coherent atrial activation

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BACKGROUND The complexity of ablation for atrial macroreentry atrial flutter (AFL) varies significantly depending on the circuit location. Presently, surface electrocardiogram (ECG) analysis poorly separates left from right atypical AFL and from some cases of typical AFL, which delays diagnosis until invasive study.

OBJECTIVE The purpose of this study was to differentiate and localize the intra-atrial circuits of left atypical AFL, right atypical, and typical AFL using quantitative ECG analysis.

METHODS We studied 66 patients (54 men, age 59 ± 14 years) with typical (n = 35), reverse typical (n = 4), and atypical (n = 27) AFL. For each, we generated filtered atrial waveforms from ECG leads V5 (X-axis), aVF (Y-axis), and V1 (Z-axis) by correlating a 120-ms F-wave sample to successive ECG regions. Atrial spatial loops were plotted for three orthogonal planes (frontal, XY = V5/aVF; sagittal, YZ = aVF/V1; axial, XZ = V5/V1) and then cross-correlated to measure spatial regularity (i.e., coherence; range −1 to 1).

RESULTS Mean coherence was greatest in the XY plane ($P < 10^{-3}$ vs. XZ or YZ). Atypical AFL showed lower coherence than typical AFL in the XY ($P < 10^{-3}$), YZ ($P < 10^{-6}$), and XZ ($P < 10^{-5}$) planes. Atypical left AFL could be separated from atypical right AFL by lower XY coherence (P = .02); for this plane, coherence <0.69 detected atypical left AFL with 84% specificity and 75% sensitivity. F-wave amplitude alone did not separate typical, atypical right, or atypical left AFL (P = NS).

CONCLUSIONS Atypical AFL shows lower spatial coherence than typical AFL, particularly in the sagittal and axial planes. Coherence in the Cartesian frontal plane separated left and right atypical AFL. Such analyses may be used to plan ablation strategy from the bedside.

KEYWORDS Atrial flutter; Mapping; Vectorcardiography; Electrocardiogram; Electrophysiologic study; Signal processing

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Introduction

Many approaches can be used to localize the circuits of typical and atypical (non-subeustachian-isthmus-dependent) atrial flutter (AFL) at invasive electrophysiology study (EPS).[1] Diagnosing atypical AFL from the surface electrocardiogram (ECG) could potentially identify the need for high-resolution mapping, and identifying left AFL circuits a priori could help plan the need for transseptal cannulation. However, the characteristic F waves of typical and reverse typical AFL[1] are altered with left atrial (LA) enlargement, heart failure,[2] or prior ablation.[3] Moreover, in the absence of typical F waves, AFL localization is imprecise,[4,5] and many atypical AFL circuits can mimic "typical" F waves.[4] Even features such as F-wave polarity may be misleading since, for example, positive F waves in V1 occur both in typical AFL in the right atrium (RA)[1] and in atypical AFL in the LA.[6,7] For left-sided atypical AFL, F waves may have lower amplitude,[5] but this has not been tested as a means of localizing the circuit from the ECG.

We hypothesized that identifying planes of reproducible atrial activation might separate atypical left AFL, atypical right AFL, and typical AFL. Although macroreentry in AFL is precisely timed,[8] we[9,10] and others[11] have quantified subtle timing variability with distance from the circuit. We reasoned that it should be possible to construct functional ECG loops to locate an AFL circuit based on the plane of greatest spatiotemporal regularity as opposed to planes of greater variability irrespective of F-wave shape.[12]

We tested our hypothesis by analyzing planes of greatest atrial spatiotemporal regularity (quantified as coherence) for 66 patients referred for AFL ablation compared with the actual AFL circuit location from precise intra-atrial mapping before successful ablation.

Methods

We studied 66 consecutive patients (54 males, average age 59 ± 14) who were referred for catheter ablation at the University of California San Diego (UCSD) and Veterans' Affairs (VAMC) Medical Centers in San Diego. The study was approved by the joint UCSD/VAMC Institutional Review Board. For this pilot study, we excluded patients with prior ablation for atrial fibrillation

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Table 1 Clinical characteristics

	Typical (n = 39)	Atypical (n = 27)	*P*
Age, years	59 ± 14	58 ± 15	NS
AFL cycle length, ms	247 ± 31	284 ± 48	<.01
Ventricular cycle length, ms	618 ± 201	655 ± 220	NS
Atrioventricular ratio	2.5 ± 0.8	2.3 ± 0.7	NS
LA diameter, mm	39 ± 9	44 ± 7	NS
Left ventricular ejection fraction, %	58 ± 17	55 ± 12	NS
New York Heart Association Class > II	0	3	NS
Prior cardiac surgery	6	12	<.01
Medications:			
Antiarrhythmic*	22	9	NS
Rate slowing†	25	12	NS
Hypertension	18	8	NS
Diabetes mellitus	7	4	NS

*Therapy with class I or class III agents.
†Therapy with beta-blocker or calcium antagonists.

(AF). All patients had been anticoagulated or lacked thrombus on transesophageal echocardiography, and most had failed one or more antiarrhythmic medications (Table 1). Separate analyses have been reported elsewhere in a subset of these patients.[9]

Diagnosis at electrophysiologic study

EPS was performed in the fasted state at least 5 half-lives after discontinuing all antiarrhythmic medications. A 6-F decapolar catheter was advanced to the coronary sinus via the right internal jugular vein, and 6-F quadrapolar catheters were advanced to the His bundle and RA via femoral veins. Transseptal cannulation was used to map AFL in the LA.

Typical (subeustachian-isthmus-dependent) AFL[1] was diagnosed by counterclockwise activation around the tricuspid annulus (clockwise in reverse typical) and concealed entrainment during pacing from the cavotricuspid isthmus (CTI). Diagnosis was further confirmed by the inability to reinduce AFL after creating bidirectional block across the CTI by ablation. Atypical (non-subeustachian-dependent) AFL was diagnosed by a distinct activation pattern, concealed entrainment at sites of earliest activation or double potentials, and successful ablation outside the CTI. Mapping and ablation of atypical AFL was assisted by electroanatomic mapping (Carto, Biosense-Webster, Diamond Bar, CA) in 16 cases. AF was excluded by 1:1 capture of all atrial sites and successful ablation without atrial compartmentalization at nonpulmonary venous sites.[1] When multiple AFL circuits were present, the ECGs and simultaneous intracardiac electrograms of the rhythm that was categorically entrained, localized, and ablated were used for this study.

Acquisition of ECG data

Standard surface ECG recordings of 10-second duration of the index arrhythmia were obtained at EPS from a

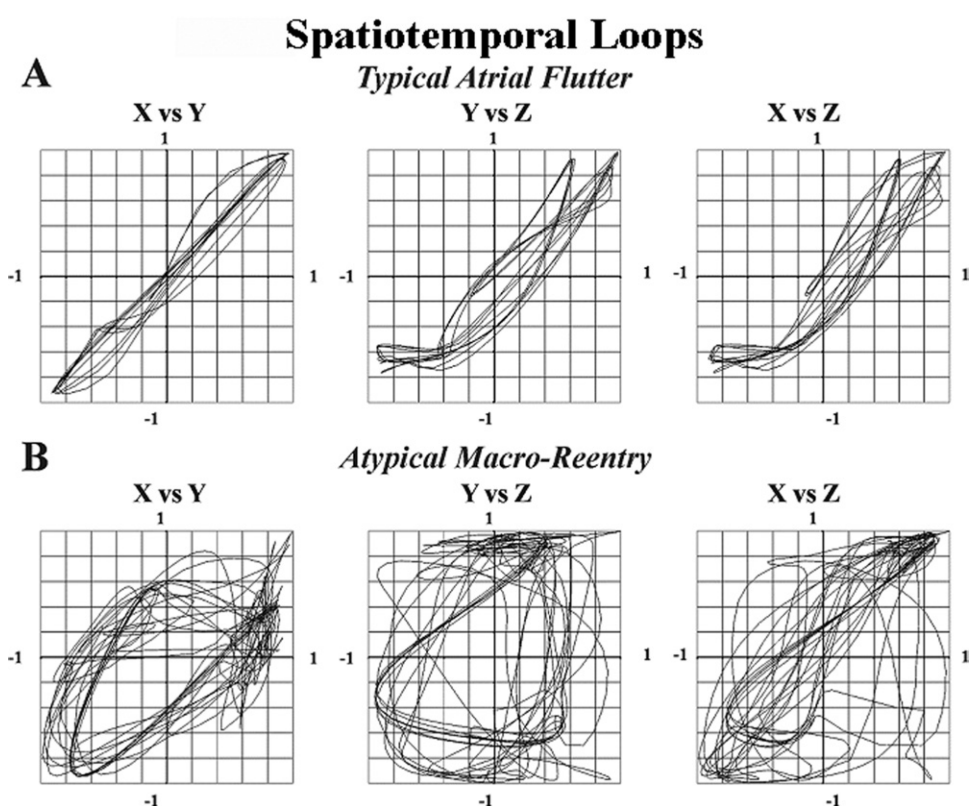

Figure 1 Atrial spatiotemporal loops for (**A**) typical AFL and (**B**) atypical AFL. Coherence values were higher for typical than for atypical AFL.