How to perform electrogram-guided atrial fibrillation ablation

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Over the past decade, several mapping studies of human atrial fibrillation (AF) have made the following important observations: (1) Atrial electrograms during sustained atrial fibrillation have three distinct patterns: single potential, double potential, and complex fractionated potential(s) (CFAEs).[1–3] (2) The distribution of these atrial electrograms during AF localizes to specific atrial sites, and these electrograms exhibit remarkable temporal and spatial stability.[1,2] (3) The CFAE areas represent AF substrate sites and are important targets for AF ablation.[1–5] By ablating such areas that have persistent CFAEs, one eliminates AF and usually renders AF noninducible. With this observation, CFAE mapping has become a novel approach for guiding successful AF substrate ablation with excellent long-term outcomes.

What are CFAEs?

CFAEs are defined as (1) atrial electrograms that are fractionated and composed of two deflections or more and/or have a perturbation of the baseline with continuous deflections from a prolonged activation complex as shown in the atrial septum in Figure 1; or (2) atrial electrograms with a very short cycle length (≤120 ms) with or without multiple potentials when compared with the atrial cycle length recorded from other parts of the atria (Figure 2).

CFAEs are usually low-voltage multiple potential signals between 0.06–0.25 mV. The distribution of CFAEs in the right and left atria is markedly different in one area compared with another.[1,2] In spite of regional differences in the distribution of these atrial electrograms, CFAEs are surprisingly stationary, exhibiting relative spatial and temporal stability. Thus one can perform point-to-point mapping of these CFAE areas and display them with an electroanatomical map.

AF substrate mapping guided by point mapping of CFAEs

Mapping is always done during AF. For recording and stimulation, a multipolar electrode catheter is positioned in the coronary sinus (CS) or right atrium. AF is induced in patients who present to the laboratory in sinus rhythm. The AF induction protocol is discussed in detail elsewhere.[1] Once AF is sustained for over 5 minutes, the patients undergo nonfluoroscopic electroanatomic mapping with the CARTO (Biosense Webster, Diamond Bar, California) navigation and mapping system, as do patients with chronic AF. Intracardiac recordings are simultaneously recorded from the CARTO computerized mapping system and a multichannel computerized recording system.

During AF, the local activation time of the arrhythmia is not of value in guiding ablation. However, CARTO allows the construction of an endocardial shell and enables the operator to tag areas of CFAEs with the anatomy in both atria. We use bipolar recordings filtered from 30 to 500 Hz.

To improve the accuracy of CFAEs mapping, custom software with algorithms that enable tagging of areas of CFAE with the anatomical shell of both atria is used. The CFAE complex could be identified using an algorithm that quantifies the CFAE phenomena in two parameters:

1. Interval confidence level (ICL): The number of intervals identified between consecutive complexes identified as CFAE. The assumption is that the more complex intervals recorded during the signal recording time (2.5 ms), that is, the more repetitions in a given time duration, the more confident the categorization of CFAE.
2. Shortest complex interval (SCL): The shortest interval found in milliseconds, out of all intervals identified between consecutive CFAE complexes.

We then display the data for each point in the whole chamber map. CFAE areas are displayed in a color-coded manner according to the degree of fractionated signals and their cycle lengths for easier identification.

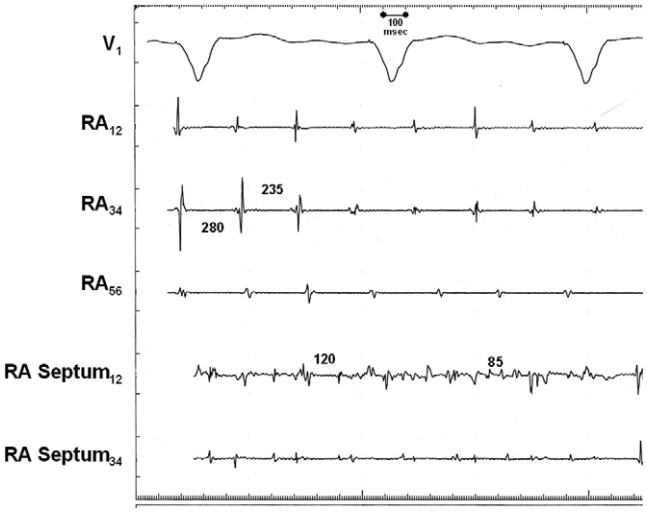

Figure 1 Examples of CFAEs. Fractionated electrograms with continuous prolonged activation complexes were recorded from the right atrial septum (RA septum12).

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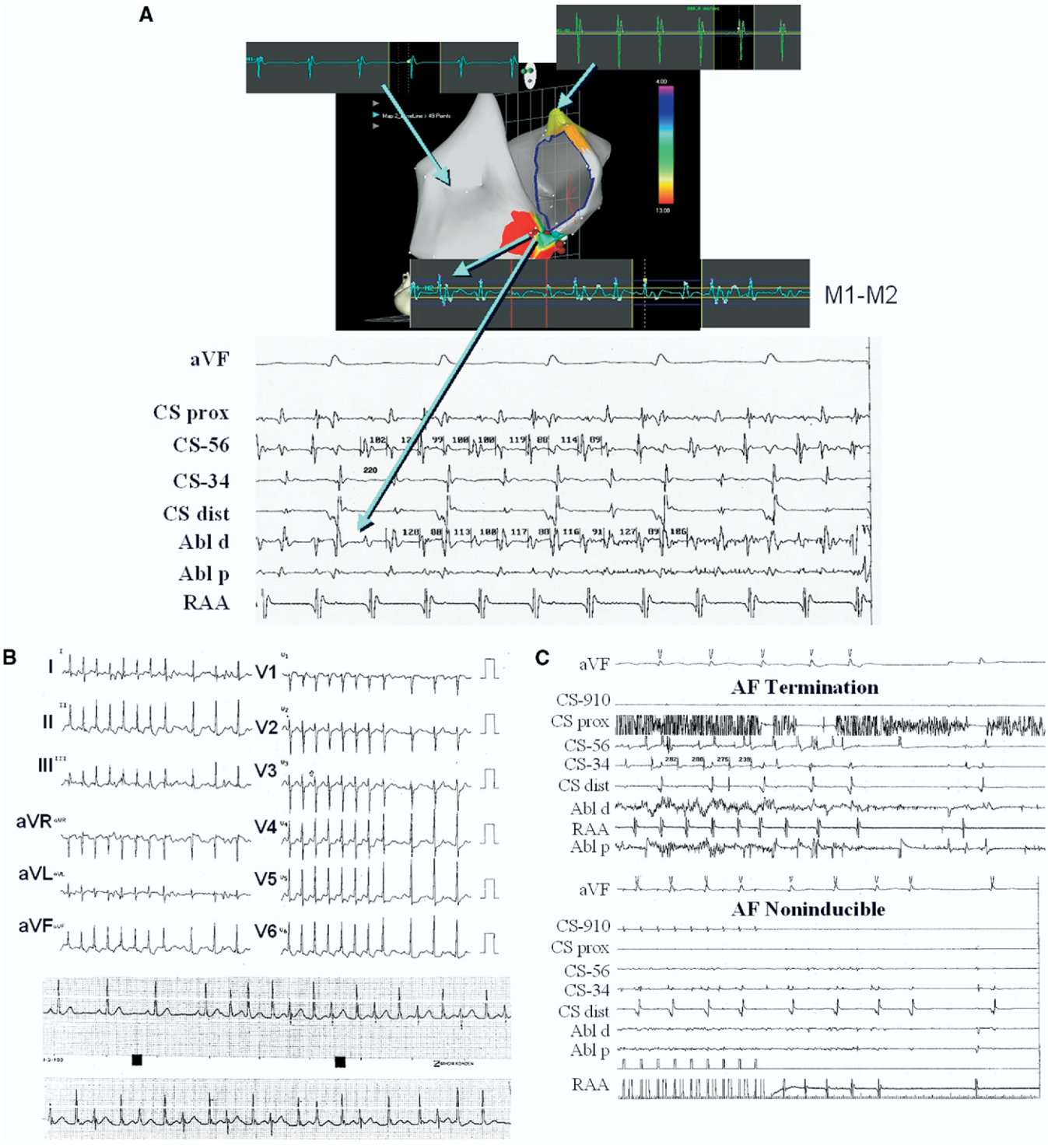

Figure 2 **A**: Biatrial CFAE map of AF that was induced by isoproternol infusion with rapid pacing at the right atrial appendage. The map is a color-coded CFAE map. The colors represent ICL map regarding consistency and stability of CFAEs in these regions: red color has the highest ICL representing the areas that have most persistent CFAEs, whereas the gray areas represent part of the atrium that have no CFAEs. The red area is the prime target for ablations and confined exclusively to the CS ostium. Note also that the tachycardia cycle length is very short at the proximal CS (CS-prox) compared with that from the distal CS (CS-dist) and that from right atrial appendage (RAA). **B**: EKG and rhythm strips of AF induced during exercise treadmill testing. RF applications were delivered to these areas (red dots) resulting in termination of AF (**C**, *upper tracings*) and rendered AF noninducible (*lower tracing*).

Ablation endpoints

The primary endpoints during RF ablation of AF are either a complete elimination of the areas with CFAEs or conversion of AF to sinus rhythm. The ablation typically begins at sites where CFAEs have the shortest interval and preferably also have high ICL. When the areas with CFAEs are completely eliminated, but the arrhythmias organize into atrial flutter or atrial tachycardia, the atrial tachyarrhythmias are

mapped and ablated (occasionally in conjunction with ibutilide, 1 mg infused over 10 minutes). If the arrhythmias are not successfully terminated by ablation or ibutilide, external cardioversion is performed.

CFAEs: Markers for AF substrate and targets for AF ablation

The other important aspect of CFAE mapping is the persistence of the CFAE recording. In other words, the areas where CFAEs are recorded must demonstrate that the CFAES are not fleeting but stationary to be of importance for AF perpetuation. As mentioned above, we also have created an algorithm for recognizing the persistence of CFAEs that can be displayed as ICL and takes into account the number of CFAEs repetitively occurring during the recording period. The higher the ICL, the more CFAEs are detected. Figure 2A demonstrates an example of such a map from a patient who had experienced frequent bouts of exercise induced AF and syncope (Figure 2B). The map (during AF) shows the left anterior oblique (LAO) view of both atria; the electroanatomic map clearly shows that the CFAEs are localized exclusively around the CS ostium (OS). The red areas show the areas that have the highest ICL of CFAEs at the CS ostium. The cycle length of the atrial electrograms at this site is about 100 ms, which is the shortest cycle length when compared with other sites in the atria. Ablation at this site terminated tachycardia and rendered AF noninducible (Figure 2C). As discernable from this map, the CS ostium is the only site that serves as the substrate perpetuating AF. After ablation, the patient was arrhythmia free.

Figure 3A shows the CFAE map of a patient who had persistent AF refractory to antiarrhythmics including amiodarone. The map (during AF) shows the postero-anterior (PA) view of both atria in the color-coded format according to the shortest cycle length of the CFAEs. The red area has the shortest cycle length, and the magenta has the longest

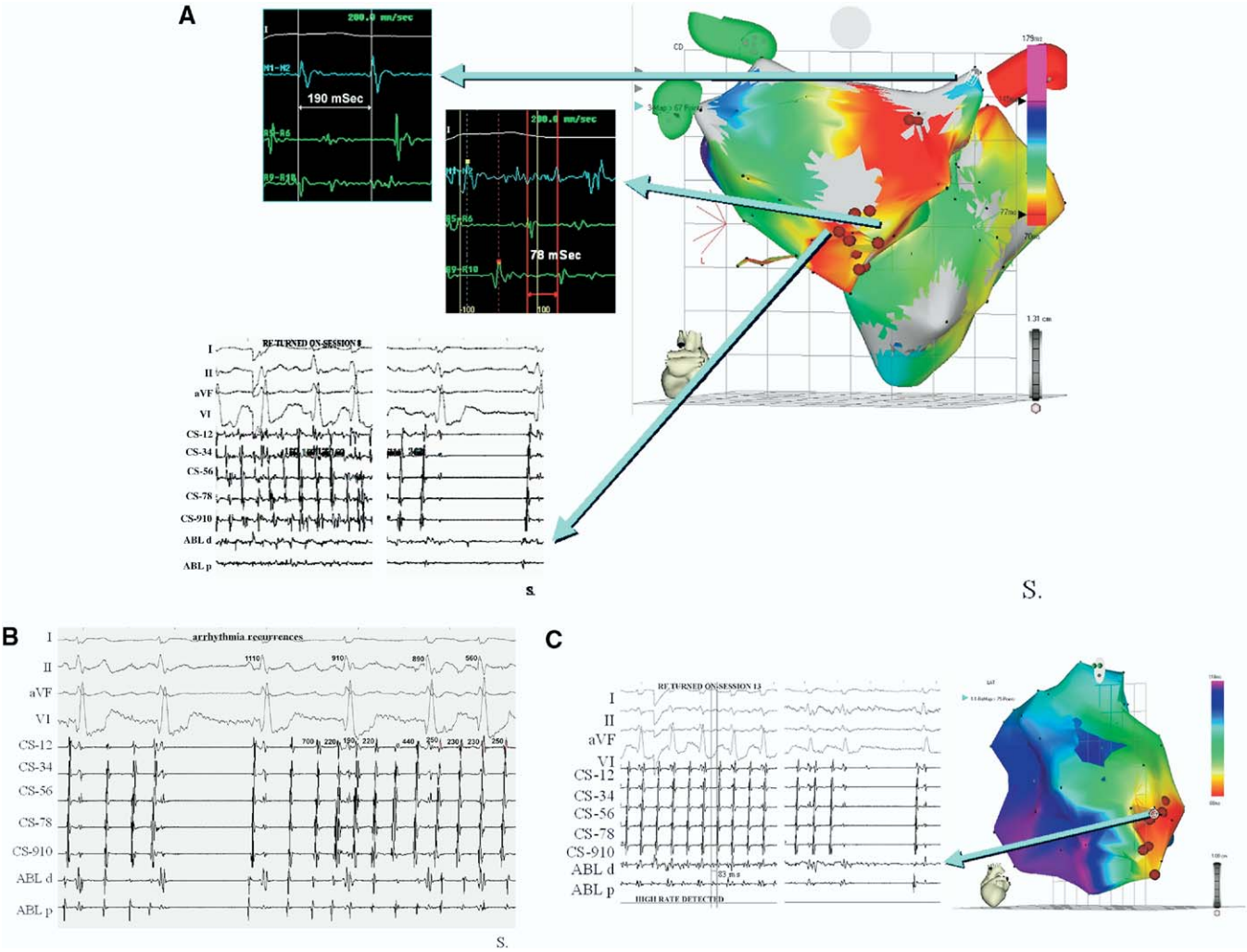

Figure 3 **A**: CFAE map displays the PA view of both atria. The map displays CFAEs areas with respect to the shortest cycle length of the CFAEs. Red areas have the shortest cycle length; in this patient the left posteroseptal area had the shortest cycle length (78 ms). The electrograms from this area are shown in the bipolar recording from the distal pair electrode of the map recording, M1-2 (*arrow to the close inset*). RF applications at this area (*lower left tracing*) terminate the tachycardia. The red dots are the RF application points (see text for more details). **B**: Atrial tachycardia recurrence. **C**: Right atrial CARTO map of the atrial tachycardia. The map is displayed in the activation sequence map of the tachycardia focus, which was located in the right atrial posteroseptum. Ablations at this site terminated the tachycardia and rendered it noninducible.

cycle length; the gray area is the area where there are no CFAE recorded. This map clearly shows that the CFAEs that had the shortest cycle length were localized almost exclusively in the posteroseptum of the left atrium. Ablations at these areas (red dots) terminated atrial fibrillation. However, the patient experienced short runs of PACs triggering atrial tachycardia (Figure 3B). The tachycardia now does not degenerate into AF, indicating that the atria could no longer fibrillate because the substrate that perpetuated AF in the left atrium had been eliminated. The remaining atrial tachycardia was mapped and found to originate from the posteroseptal area of the right atrium (Figure 3C). RF applications at this site terminated the tachycardia and rendered it noninducible.

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