The effect of electrode density on the interpretation of atrial activation patterns in epicardial mapping of human persistent atrial fibrillation

Tomos E. Walters, MBBS, PhD,[*†] Geoffrey Lee, MBChB, PhD,[*†] Steven Spence, ACCT,[*] Jonathan M. Kalman, MBBS, PhD, FHRS[*†]

From the [*]Department of Cardiology, Royal Melbourne Hospital, Melbourne, Australia, and [†]Department of Medicine, University of Melbourne, Melbourne, Australia.

BACKGROUND Mechanisms sustaining human persistent atrial fibrillation (AF) remain debated, with significant differences between high-density epicardial and global endocardial mapping studies. A key difference is the density of recording electrodes.

OBJECTIVE We aimed to determine the differences in the prevalence of different atrial activation patterns, and specifically in the prevalence of rotational activations, with varying densities of bipolar electrodes.

METHODS Epicardial mapping was performed in 10 patients undergoing cardiac surgery, with bipolar electrograms recorded using a triangular plaque (6.75 cm^2 area; 117 bipoles; 2.5-mm inter-bipole spacing) applied to the left atrial posterior wall or right atrial free wall. Dynamic wavefront mapping based on the timing of atrial electrograms was applied to 2 discrete 10-second AF segments. The spacing between bipolar electrode locations was increased from 2.5 × 3.5 mm in the horizontal and oblique directions to 5.0 × 3.5, 5.0 × 7.1, and 7.5 × 10.6 mm, with wavefront mapping repeated at each density.

RESULTS As density reduced, there was a significant change in relative proportions of the various activation patterns ($F=3.69$; $P < .001$). Simple broad wavefront activations became more prevalent (20% ± 8% to 54% ± 8%; $P < .05$) and complex patterns became less prevalent (48% ± 8% to 9% ± 8%; $P < .05$) with reducing density. The prevalence of rotational activity declined with bipole density, from median 5.0% (range 0.9%–12.1%) to 0% (range 0%–1.5%) ($P = .03$). The largest change occurred between inter-bipole spacings of 5.0 × 3.5 and 5.0 × 7.1 mm.

CONCLUSION Apparent activation patterns in persistent AF vary significantly with electrode density. Low density underestimates the prevalence of complex and rotational patterns. The largest difference occurs between an inter-bipole spacing of 5.0 × 3.5 and a spacing of 5.0 × 7.1 mm. This may have important implications for mapping technology design.

KEYWORDS Atrial fibrillation; Mapping; Bipolar electrode; Density; Rotor

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Introduction

The mechanisms by which human atrial fibrillation (AF) is maintained continue to be debated,[1,2] with particular focus on the prevalence of rotational activation and its mechanistic significance as a focal driver of fibrillation. A range of high-density epicardial mapping studies,[3–8] with an inter-electrode spacing of 1.2–2.5 mm and the use of activation mapping based on the timing of discrete bipolar or unipolar atrial electrograms (EGMs), have reported no more than infrequent and transient rotational activity. Conversely, studies of human AF using lower-density endocardial mapping baskets,[9,10] with 64 unipolar electrodes aiming to cover the entire atrial endocardial surface and subsequent phase analysis of the unipolar atrial EGMs, have suggested that human AF may be driven by a small number of rotors with a high degree of temporal stability.[11]

A key difference between these 2 groups of mapping studies is the density of recording electrodes, and it remains unclear what electrode density is required to accurately discern atrial activation patterns and to identify the presence of any rotors. In this epicardial mapping study of human persistent AF, we therefore aimed to determine the differences in the distribution of atrial activation patterns and in the prevalence of rotational activations with progressive reduction in the density of recording electrodes.

Methods

Ten patients with long-standing persistent AF undergoing a first elective cardiac surgical procedure were studied (Table 1). Participants were undergoing coronary artery

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Table 1 Participant characteristics

Characteristic	Value
Age (y)	69 ± 17
Sex: male	6 (60)
AF duration (y)	4.5 (2–6)
BMI (kg/m^2)	29.6 ± 4.3
Hypertension	9 (90)
Smoking	3 (30)
Diabetes	5 (50)
Vascular disease	7 (70)
Aspirin	3 (30)
Warfarin	9 (90)
RAS inhibitor	5 (50)
β-Blocker	0
Calcium channel blocker	6 (60)
Digoxin	6 (60)
Class I antiarrhythmic medication	0
Sotalol	2 (20)
Amiodarone	0
LA area (cm^2)	32.3 ± 5.4
LVEF (%)	52.3 ± 5.8

Values are presented as mean ± SD, as n (%), or as median (interquartile range).

AF = atrial fibrillation; BMI = body mass index; LA = left atrium; LVEF = left ventricular ejection fraction; RAS = renin-angiotensin system.

bypass graft surgery (CABGS; n = 3 (30%)), aortic valve replacement (AVR; n = 2 (20%)), mitral valve replacement (MVR; n = 2 (20%)), CABGS/AVR (n = 2 (20%)), and CABGS/MVR/AVR (n = 1 (10%)). Antiarrhythmic medications were discontinued ≥5 half-lives before surgery. All participants gave written informed consent, with the protocol approved by the Melbourne Health Human Research and Ethics Committee.

Epicardial mapping protocol

High-density atrial epicardial mapping was performed after median sternotomy and pericardial division, before cardioplegia and cardiopulmonary bypass. Mapping involved a custom-made triangular plaque (UniServices, Auckland, New Zealand) used in previous epicardial AF mapping studies.[6,7] This plaque includes 128 silver-plated copper electrodes 0.7 mm in diameter (117 bipole pairs), with spacing between the location of bipole pairs of 2.5 mm in the horizontal and vertical directions and of 3.5 mm in the oblique direction, and a total mapping area of 6.75 cm^2 (Figure 1). The plaque was positioned by the operating surgeon, and bipolar signals were recorded. Nine recordings from the posterior left atrial wall were made, with 4 from the right atrial free wall. Bipolar EGMs, with a sampling frequency of 1000 Hz and a band-pass filter of 0.05–400 Hz, were recorded using the UnEmap mapping system (UniServices). After the recording was visually scanned, 2 discrete 10-second AF segments with high-quality signals were analyzed.

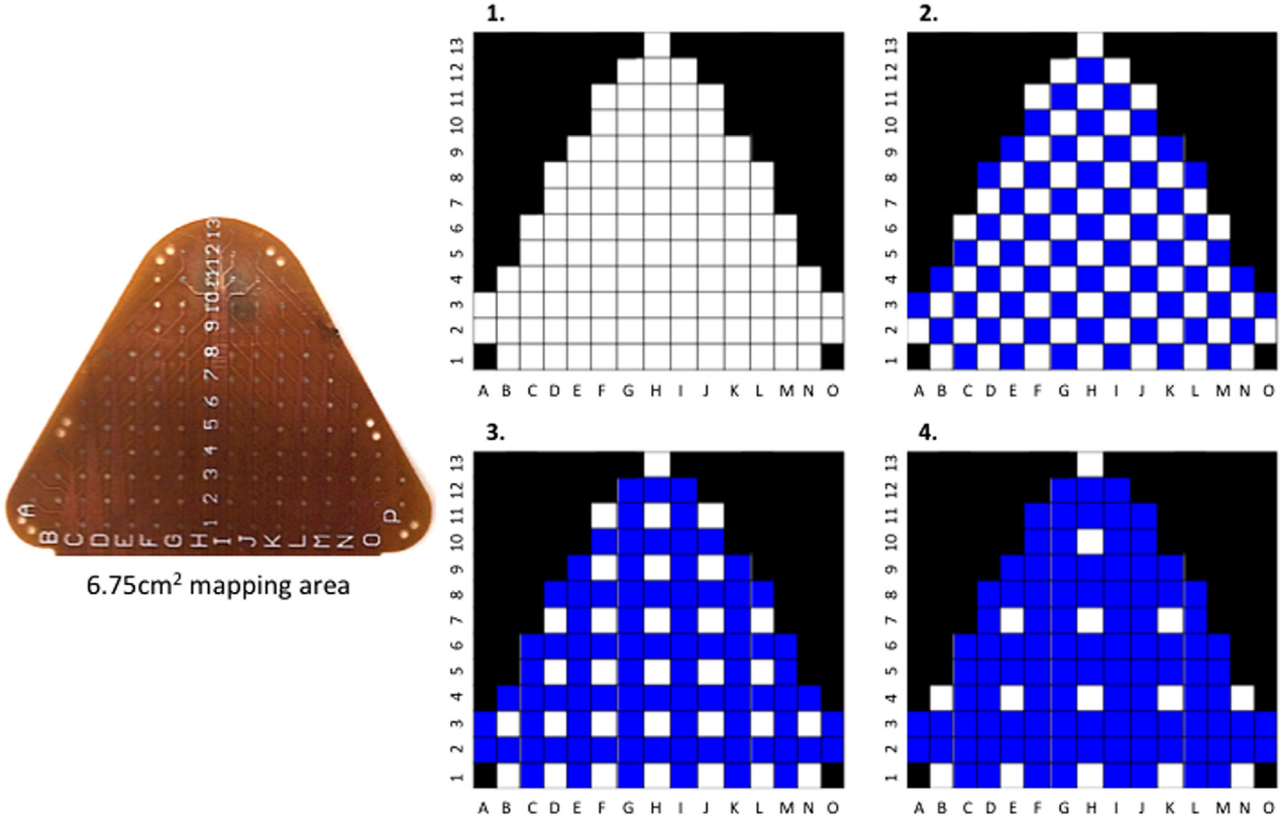

Figure 1 The high-density epicardial mapping plaque used in this study (left). Bipole density schemas 1–4 (right), with the locations of active bipolar recording sites shown in white. The distances between active recording sites in schema 1 are 2.5 mm in the horizontal or vertical direction and 3.5 mm in the oblique direction; in schema 2, the distances are 5.0 and 3.5 mm, respectively; in schema 3, the distances are 5.0 and 7.1 mm, respectively; and in schema 4, the distances are 7.5 and 10.6 mm, respectively.