Classification and Migration Tracking of AF Sources in Human Atrial Fibrillation using Phase Mapping and Multi-Electrode Basket Catheter Recordings

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I. Introduction

Mechanisms of human atrial fibrillation (AF) remain incompletely understood. Phase mapping is an important technique for identifying potential mechanisms of AF as rotor sources (RS) and focal sources (FS). The migration behavior of RS and FS is unknown. Also, the adequacy of a multi- electrode basket catheter (MBC) to identify sources in the left atrium for PM is unknown.

II. Methods

Ten patients underwent left atrial instrumentation with a MBC in persistent AF at the time of their scheduled AF ablation. Simultaneous 60 second bipolar electrograms (filtered 30-500 Hz) were recorded twice in each patient from all potential bipoles of the MBC. Phase mapping was performed using custom software. RS were defined by phase singularities. FS were defined by centrifugal propagation. Migration of RS and FS locations were measured over time. An edge sources (ES) was defined by sequential propagation from the proximal or distal electrodes of the MBC splines. ES were characterized if they migrated into the MBC array of electrodes as a RS or FS.

III. Results

There was a mean of 3.5 +/- 0.9 potential sources of AF identified at each time epoch. The number of sources varied little within an individual over time and between recordings (standard deviation 0.3 over 60 seconds, mean absolute difference 0.1 on sequential recordings). Source locations and types were highly conserved on sequential recordings in individual patients, but varied between patients. The overall proportions of sources were 46% RS, 11% FS, and 43% ES. Among sources with ¿ 3 cycles duration, there were 54% RS, 10% FS, and 36% ES. ES migrated into the MBC array of electrodes 14% of the time. The migrating ES were 69% RS and 31% FS. Migration of greater than 2 cm occurred with 96% of RS and 12% of FS.

IV. Conclusion

Rotor sources were the most common identified mechanism of human atrial fibrillation using phase mapping and a MBC. Rotor sources nearly always displayed migration, whereas focal sources did not. Edge sources outside the MBC array of electrodes were common. New catheter designs and/or computational techniques may be needed for more complete identification of AF sources.

Appendix A
Result Attachments

A. Patient 1 Map 1

0.00 - 60.00 s time interval. 218.58 ms mean cycle length. 2.82 simultaneous sources in every 10 ms: 42.56 % rotor source; 13.47 % focal source; 43.97 % edge source. 37.75 % edge source $->$ focal source. 62.25 % edge source $->$ rotor source. 8.15 % rotor source migrated more than 2 cm. 0.90 % focal source migrated more than 2 cm. 2.77 % edge source migrated more than 2 cm. 2.09 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 7.69 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 92.31 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

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B. Patient 1 Map 2

0.00 - 60.00 s time interval. 220.30 ms mean cycle length. 2.77 simultaneous sources in every 10 ms: 45.21 % rotor source; 13.81 % focal source; 40.97 % edge source. 34.04 % edge source $->$ focal source. 65.96 % edge source $->$ rotor source. 8.55 % rotor source migrated more than 2 cm. 0.69 % focal source migrated more than 2 cm. 2.81 % edge source migrated more than 2 cm. 2.18 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 18.18 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 81.82 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

C. Patient 2 Map 1

0.00 - 60.00 s time interval. 166.33 ms mean cycle length. 3.27 simultaneous sources in every 10 ms: 58.87 % rotor source; 17.39 % focal source; 23.74 % edge source. 46.84 % edge source $->$ focal source. 53.16 % edge source $->$ rotor source. 8.25 % rotor source migrated more than 2 cm. 0.61 % focal source migrated more than 2 cm. 3.79 % edge source migrated more than 2 cm. 3.48 % edge source migrated into MBC field. 16.67 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 16.67 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 66.67 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

D. Patient 2 Map 2

0.00 - 60.00 s time interval. 165.48 ms mean cycle length. 3.22 simultaneous sources in every 10 ms: 53.97 % rotor source; 19.34 % focal source; 26.69 % edge source. 37.96 % edge source $->$ focal source. 62.04 % edge source $->$ rotor source. 8.42 % rotor source migrated more than 2 cm. 0.33 % focal source migrated more than 2 cm. 3.26 % edge source migrated more than 2 cm. 2.86 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 66.67 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 33.33 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

E. Patient 3

0.00 - 60.00 s time interval. 164.72 ms mean cycle length. 4.71 simultaneous sources in every 10 ms: 67.22 % rotor source; 7.02 % focal source; 25.76 % edge source. 27.46 % edge source $->$ focal source. 72.54 % edge source $->$ rotor source. 10.15 % rotor source migrated more than 2 cm. 0.22 % focal source migrated more than 2 cm. 2.61 % edge source migrated more than 2 cm. 2.04 % edge source migrated into MBC field. 12.50 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 6.25 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 81.25 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

F. Patient 4 Map 1

0.00 - 60.00 s time interval. 177.20 ms mean cycle length. 2.88 simultaneous sources in every 10 ms: 46.09 % rotor source; 23.63 % focal source; 30.27 % edge source. 43.55 % edge source $->$ focal source. 56.45 % edge source $->$ rotor source. 8.85 % rotor source migrated more than 2 cm. 0.59 % focal source migrated more than 2 cm. 1.51 % edge source migrated more than 2 cm. 1.25 % edge source migrated into MBC field. 3.70 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 51.85 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 44.44 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

G. Patient 4 Map 2

0.00 - 60.00 s time interval. 176.83 ms mean cycle length. 2.67 simultaneous sources in every 10 ms: 51.21 % rotor source; 19.44 % focal source; 29.35 % edge source. 43.08 % edge source $->$ focal source. 56.92 % edge source $->$ rotor source. 8.43 % rotor source migrated more than 2 cm. 0.53 % focal source migrated more than 2 cm. 1.88 % edge source migrated more than 2 cm. 1.42 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 42.86 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 57.14 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

H. Patient 5

0.00 - 60.00 s time interval. 180.79 ms mean cycle length. 4.29 simultaneous sources in every 10 ms: 57.78 % rotor source; 12.05 % focal source; 30.18 % edge source. 21.74 % edge source $->$ focal source. 78.26 % edge source $->$ rotor source. 10.06 % rotor source migrated more than 2 cm. 1.01 % focal source migrated more than 2 cm. 3.95 % edge source migrated more than 2 cm. 3.11 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 0.00 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 100.00 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

I. Patient 6 Map 1

0.00 - 60.00 s time interval. 178.67 ms mean cycle length. 4.67 simultaneous sources in every 10 ms: 61.76 % rotor source; 9.11 % focal source; 29.13 % edge source. 20.67 % edge source $->$ focal source. 79.33 % edge source $->$ rotor source. 10.83 % rotor source migrated more than 2 cm. 0.44 % focal source migrated more than 2 cm. 3.27 % edge source migrated more than 2 cm. 2.68 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 12.50 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 87.50 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

J. Patient 6 Map 2

0.00 - 60.00 s time interval. 172.48 ms mean cycle length. 4.66 simultaneous sources in every 10 ms: 63.97 % rotor source; 8.82 % focal source; 27.21 % edge source. 19.28 % edge source $->$ focal source. 80.72 % edge source $->$ rotor source. 11.00 % rotor source migrated more than 2 cm. 0.82 % focal source migrated more than 2 cm. 3.99 % edge source migrated more than 2 cm. 3.09 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 0.00 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 100.00 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

K. Patient 6 Map 3

0.00 - 60.00 s time interval. 168.29 ms mean cycle length. 4.54 simultaneous sources in every 10 ms: 62.14 % rotor source; 9.51 % focal source; 28.35 % edge source. 17.35 % edge source $->$ focal source. 82.65 % edge source $->$ rotor source. 10.62 % rotor source migrated more than 2 cm. 0.54 % focal source migrated more than 2 cm. 3.90 % edge source migrated more than 2 cm. 2.98 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 14.29 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 85.71 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

L. Patient 6 Map 4

0.00 - 60.00 s time interval. 167.81 ms mean cycle length. 4.48 simultaneous sources in every 10 ms: 63.28 % rotor source; 9.06 % focal source; 27.65 % edge source. 25.70 % edge source $->$ focal source. 74.30 % edge source $->$ rotor source. 10.70 % rotor source migrated more than 2 cm. 0.89 % focal source migrated more than 2 cm. 3.92 % edge source migrated more than 2 cm. 3.00 % edge source migrated into MBC field. 14.29 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 0.00 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 85.71 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

M. Patient 7 Map 1

0.00 - 60.00 s time interval. 161.03 ms mean cycle length. 4.19 simultaneous sources in every 10 ms: 50.98 % rotor source; 11.45 % focal source; 37.57 % edge source. 29.32 % edge source $->$ focal source. 70.68 % edge source $->$ rotor source. 9.33 % rotor source migrated more than 2 cm. 0.97 % focal source migrated more than 2 cm. 3.23 % edge source migrated more than 2 cm. 2.12 % edge source migrated into MBC field. 4.76 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 4.76 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 90.48 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

N. Patient 7 Map 2

0.00 - 60.00 s time interval. 160.53 ms mean cycle length. 4.30 simultaneous sources in every 10 ms: 52.70 % rotor source; 9.14 % focal source; 38.16 % edge source. 27.18 % edge source $->$ focal source. 72.82 % edge source $->$ rotor source. 9.77 % rotor source migrated more than 2 cm. 0.76 % focal source migrated more than 2 cm. 3.13 % edge source migrated more than 2 cm. 2.18 % edge source migrated into MBC field. 3.13 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 9.38 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 87.50 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

O. Patient 7 Map 3

0.00 - 60.00 s time interval. 163.94 ms mean cycle length. 4.44 simultaneous sources in every 10 ms: 54.70 % rotor source; 8.45 % focal source; 36.85 % edge source. 23.81 % edge source $->$ focal source. 76.19 % edge source $->$ rotor source. 9.25 % rotor source migrated more than 2 cm. 0.39 % focal source migrated more than 2 cm. 3.09 % edge source migrated more than 2 cm. 2.03 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 0.00 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 100.00 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

P. Patient 7 Map 4

0.00 - 60.00 s time interval. 162.42 ms mean cycle length. 4.13 simultaneous sources in every 10 ms: 55.82 % rotor source; 10.45 % focal source; 33.73 % edge source. 27.49 % edge source $->$ focal source. 72.51 % edge source $->$ rotor source. 9.51 % rotor source migrated more than 2 cm. 0.51 % focal source migrated more than 2 cm. 3.81 % edge source migrated more than 2 cm. 2.66 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 13.33 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 86.67 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

Q. Patient 8 Map 1

0.00 - 60.00 s time interval. 206.88 ms mean cycle length. 2.69 simultaneous sources in every 10 ms: 28.40 % rotor source; 7.65 % focal source; 63.94 % edge source. 38.60 % edge source $->$ focal source. 61.40 % edge source $->$ rotor source. 4.75 % rotor source migrated more than 2 cm. 0.70 % focal source migrated more than 2 cm. 0.91 % edge source migrated more than 2 cm. 0.57 % edge source migrated into MBC field. 5.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 5.00 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 90.00 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

R. Patient 8 Map 2

0.00 - 60.00 s time interval. 209.92 ms mean cycle length. 2.90 simultaneous sources in every 10 ms: 21.88 % rotor source; 8.73 % focal source; 69.39 % edge source. 39.68 % edge source $->$ focal source. 60.32 % edge source $->$ rotor source. 4.40 % rotor source migrated more than 2 cm. 0.43 % focal source migrated more than 2 cm. 0.55 % edge source migrated more than 2 cm. 0.53 % edge source migrated into MBC field. 4.76 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 4.76 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 90.48 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

S. Patient 9 Map 1

0.00 - 60.00 s time interval. 228.37 ms mean cycle length. 1.94 simultaneous sources in every 10 ms: 7.83 % rotor source; 3.51 % focal source; 88.65 % edge source. 30.77 % edge source $->$ focal source. 69.23 % edge source $->$ rotor source. 5.95 % rotor source migrated more than 2 cm. 0.00 % focal source migrated more than 2 cm. 0.45 % edge source migrated more than 2 cm. 0.25 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 3.45 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 96.55 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

T. Patient 9 Map 2

0.00 - 60.00 s time interval. 234.41 ms mean cycle length. 2.05 simultaneous sources in every 10 ms: 0.94 % rotor source; 0.45 % focal source; 98.61 % edge source. 21.74 % edge source $->$ focal source. 78.26 % edge source $->$ rotor source. 4.30 % rotor source migrated more than 2 cm. 0.00 % focal source migrated more than 2 cm. 0.20 % edge source migrated more than 2 cm. 0.19 % edge source migrated into MBC field. 0.00 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 0.00 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 100.00 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

U. Patient 10 Map 1

0.00 - 60.00 s time interval. 179.12 ms mean cycle length. 2.93 simultaneous sources in every 10 ms: 29.04 % rotor source; 14.57 % focal source; 56.39 % edge source. 29.41 % edge source $->$ focal source. 70.59 % edge source $->$ rotor source. 6.11 % rotor source migrated more than 2 cm. 0.28 % focal source migrated more than 2 cm. 1.76 % edge source migrated more than 2 cm. 1.04 % edge source migrated into MBC field. 3.64 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 14.55 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 81.82 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.

V. Patient 10 Map 2

0.00 - 60.00 s time interval. 178.06 ms mean cycle length. 2.50 simultaneous sources in every 10 ms: 32.45 % rotor source; 15.15 % focal source; 52.40 % edge source. 40.91 % edge source $->$ focal source. 59.09 % edge source $->$ rotor source. 4.98 % rotor source migrated more than 2 cm. 0.39 % focal source migrated more than 2 cm. 2.11 % edge source migrated more than 2 cm. 1.17 % edge source migrated into MBC field. 3.03 % rotor source $>=$ 3 CL among all sources $>=$ 3 CL. 15.15 % focal source $>=$ 3 CL among all sources $>=$ 3 CL. 81.82 % edge source $>=$ 3 CL among all sources $>=$ 3 CL.