Mapping techniques in AFib

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... critical zone

Microreentrant circuits

LOM

PV foci

Sueda
Ann Thorac Surg 1997

Haissaguerre
NEJM 1998

Hwang
Circulation 2000
LA mechanisms of AFib

- PV triggers/drivers
- Rotors
- Ganglionated Plexi (GP)
- Triggers/drivers from other thoracic veins
Ablation strategy

- Focal (within PV)
- Segmental ostial
- Circumferential atrial
- Additional lines
- Substrate mapping (CAFE, DF)
- Ganglionated plexus (GP)
Ablation strategy

• Focal (within PV)
• Segmental ostial
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• Ganglionated plexus (GP)
Ablation Strategy for Atrial Fibrillation

1. Identification of arrhythmogenic PV
2. Perimetric distribution of PV potentials
3. Ostial ablation of PVP
   End point = PV-LA block

Hospital Haut-Leveque, Bordeaux
PV-Mapping

Gap electrogram
LSPV and LAA Electrograms

Figure 1  Electrograms at the left superior pulmonary vein (LSPV) and left atrial appendage (LAA) during sinus rhythm (A) and pacing at the LAA (B). During sinus rhythm, wavefronts reach the LSPV and LAA at the same time (C). During pacing at the LAA, LSPV is activated following the LAA (D), thereby distinguishing PV potentials from far-field LAA potentials.
Fig. 1 Shown is the response to pacing from the left atrial appendage (LAA). The ring catheter in the left superior pulmonary vein records a potential (arrow) in the right portion of figure. It is not clear whether the potential represents activation of the pulmonary vein, appendage, or fusion of both. Pacing from the appendage as shown in the left portion of the figure, results in advancement of the potential (dashed arrow). This response is consistent with an origin from the appendage and therefore no ablation is required. Note that there is a marked delay of the coronary sinus electrograms due to ablation of the mitral isthmus. Also shown are electrocardiographic leads I, V5, bipolar electrograms recorded by the LA, Lasso and the coronary sinus (CS) catheters.
Fig. 2 A virtual endoscopic view of the LA in a patient with paroxysmal atrial fibrillation. Note the narrow rim of tissue (arrows) between the left sided pulmonary veins (LSPV, LIPV) and the appendage (LAA).
**Figure 2**  Lasso catheter recordings in the right superior pulmonary vein (PV). (A) The lasso catheter is deployed at the ostium of the PV. No potential is recorded. (B) The lasso catheter is deployed at >1 cm distal to the ostium of the PV. Far-field potentials from the right atrium are recorded at the beginning of the P-wave on bipolar 7/8, 8/9, 9/10, and 10/1, which are located at the anterior part of the PV.
Figure 3 A CT-derived virtual endoscopic view of the junction of right sided pulmonary veins (PV) and LA. The ostium of the anomalous right middle PV is encircled by the yellow solid line. If the lasso catheter is located inside the right superior or inferior PV (red broken circles), far-field potentials from the right middle PV may be recorded on the lasso catheter.
LSPV/LAA Electrogram in AFib

Figure 4  Lasso catheter recordings during atrial fibrillation (AF) in the left superior pulmonary vein (PV). Disorganized and organized PV potentials are recorded. During organized PV activation, the earliest activity (asterisk) indicates the LA–PV connection, and far-field potentials from the left atrial appendage (arrow) are recorded on bipolar 1/2, 2/3, 3/4 and 4/5, which are located at the anterior part of the ostium of the PV.
LSPV and LAA electrogram during ablation

Figure 5  (A) Lasso recordings in the left superior pulmonary vein (PV) during ablation. Two activities are recorded on the lasso catheter. Potentials indicated by an asterisk show sudden prolongation of cycle length. This indicates that ablation has an effect on the LA–PV connection and that the activity demonstrating a change in cycle length is a PV potential. (B) Lasso recording in the same PV after disconnection. The remaining activity in the PV is synchronized to the activity in the LA appendage (LAA), demonstrating that the remaining activity is far-field from the LAA.
Ablation strategy

- Focal (within PV)
- Segmental ostial
- Circumferential atrial
- Additional lines
- Substrate mapping (CAFE, DF)
- Ganglionated plexus (GP)
Wide areas circumferential ablation (WACA) (+ left atrial lines± ostial ablation)
• Decrease in local atrial electrogram amplitude >50% or amplitude <0.1 mV (voltage abatement)
• Additional ablation within circumferential lines in 32%
• Lines not specifically verified for conduction block and PV isolation (PVP still present in 30-60% of PVs assessed)
• 8mm tip ablation catheter (55°C, 60 W)
SOI vs WACA
Oral et al, Circulation 2003; 108:2355-60
Proposed mechanisms:

• Elimination of triggers and drivers located in PVs
• Elimination of rotors anchoring at the PV-LA junction
• Debulking effect
• Vagal denervation
Ablation validation (Pappone)

Figure 3. Preablation (A') and postablation (A'') three-dimensional left atrial voltage maps in a patient who had vagal reflexes that were evoked and then abolished by radiofrequency application around left superior PV (arrow). Red represents low voltage and purple high. LIPV = left inferior pulmonary vein; LSPV = left superior pulmonary vein; MV = mitral valve; RIPV = right inferior pulmonary vein; RSPV = right superior pulmonary vein.
Electrophysiologically guided LA ablation: Double Lasso Technique
Double Lasso Technique
Double Lasso Technique: Simultaneous isolation of LSPV and LIPV

before left CCL

during RF #22
Double Lasso Technique: Sequential isolation of RSPV and RIPV
Double Lasso Technique: Dissociated automatic PV activity
Double Lasso Technique: PV tachycardia

Figure 5. Tracings during sinus rhythm are ECG leads I, II, and V₁ and intracardiac electrograms recorded from 2 Lasso catheters within RSPV and RIPV, mapping catheter (Mp) at ostium of RIPV, catheter inside coronary sinus (CS), and catheter at His bundle region (HBE) after isolation of right-sided PVs. Note that (1) tachycardia with CL of 205 ms within RSPV is initiated by 2 different automatic activities (marked by arrow) originating from RIPV; (2) decremental conduction between RSPV and RIPV is observed during these 2 different automatic activities; (3) tachycardia activates around Lasso catheter within RSPV (marked by continual arrows); (4) tachycardia passively activates into RIPV with 2-to-1 conduction; and (5) stable sinus rhythm is dissociated from tachycardia.
Double Lasso Technique: Clinical results

<table>
<thead>
<tr>
<th></th>
<th># of pts (n)</th>
<th>Pts in SR after 1. procedure</th>
<th>Pts in SR after re-ablation</th>
<th>Komplikationen</th>
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<tbody>
<tr>
<td>Paroxysm. AFib</td>
<td>320</td>
<td>70%</td>
<td>95%</td>
<td>30% PV stenosis 1 pt, pericarditis 2 pts, tamponade 3 pts</td>
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<tr>
<td>Persist. AFib</td>
<td>110</td>
<td>70%</td>
<td>92%</td>
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<tr>
<td>Perm. Afib (&gt; 1 year)</td>
<td>91</td>
<td>60%</td>
<td>85%</td>
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Double Lasso Technique: PV reconnection

- Redo procedure in 25% of pts with paroxysmal AFib and in 35% of pts with persistent AFib
- Recovered PV conduction in circumferential lesions in >80% of cases
- Successful elimination by segmental RF ablation
Clinical impact of PV reconnection

Role of complete PV isolation

<table>
<thead>
<tr>
<th>No. Recurrent PVA</th>
<th>Group I</th>
<th>Group II</th>
<th>Group III</th>
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<tr>
<td>0</td>
<td>21 (81)</td>
<td>2 (5)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>1</td>
<td>5 (19)</td>
<td>12 (32)</td>
<td>6 (14)</td>
</tr>
<tr>
<td>2</td>
<td>0 (0)</td>
<td>17 (46)</td>
<td>25 (57)</td>
</tr>
<tr>
<td>3</td>
<td>0 (0)</td>
<td>6 (16)</td>
<td>11 (25)</td>
</tr>
<tr>
<td>4</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>2 (4)</td>
</tr>
<tr>
<td>% Δ all PVs</td>
<td>473 ± 71%</td>
<td>267 ± 110%</td>
<td>69 ± 47%</td>
</tr>
</tbody>
</table>

Verma A et al. (Circulation 2005;112:627–635)
Double Lasso technique

Proposed mechanisms

- Ablation including adjacent atrial myocardium
- Delivery of higher power with more reliable PV disconnection
- Debulking effect
- Prevention of focal and macroreentrant atrial arrhythmias
Ablation strategy

- Focal (within PV)
- Segmental ostial
- Circumferential atrial
- Additional lines
- Substrate mapping (CAFE, DF)
- Ganglionated plexus (GP)
Mitral Isthmus ablation
(Jais et al, Circulation 2004;110:2996-3002)

Figure 1. Anteroposterior (AP) and left anterior oblique (LAO) views of catheter placement during mitral isthmus ablation. Ablation was started with the ablation catheter at the ventricular edge of the mitral annulus (1). The catheter was then moved gradually to mid-isthmus (2) and subsequently to the junction with the ostium of the LIPV (3). A long sheath was used to facilitate catheter manipulation.
Mitral isthmus ablation

Figure 2. Progressive changes observed on the timing, amplitude, and morphology of atrial electrograms recorded at the mitral isthmus ablation line (RF 1–2 and 3–4) during CS pacing. Complete block was achieved by using endocardial RF delivery and is visible in D, both endocardially (RF 1–2) and epicardially (CS 1–2).
Mitral isthmus ablation

Figure 3. Persisting epicardial conduction at the mitral isthmus. In A, during CS pacing septal to the ablation line, the endocardial conduction delay recorded with the ablation catheter (RF endo dist) after delivering 5 minutes of RF is 70 ms while the corresponding epicardial delay recorded with the distal bipole of the CS catheter (CS 1–2) is 62 ms (lateral to the ablation line). In B, after 20 minutes of RF delivered endocardially, a maximal delay of 105 ms was observed as compared with 95 ms epicardially. In C, the ablation catheter was then used to map the CS (RF CSd) during CS pacing lateral to the ablation line. A fractionated long-duration, high-amplitude gap potential covering most of the conduction delay recorded endocardially was found. Note significant difference in the amplitude of the endocardial and epicardial potentials recorded on the ablation line. In D, ablation at that site resulted in complete mitral isthmus block with a conduction delay of 150 ms both endocardially and epicardially.
Figure 4. Demonstration of mitral isthmus block during pacing lateral to the line. A, In sinus rhythm, the CS is activated proximally to distally and no conduction delay or double potentials are recorded on the ablation line (RF). B, Pacing performed lateral to the ablation line with the distal pole of the ablation catheter (RF 1-2) results in proximal-to-distal activation in the adjacent CS (as in sinus rhythm) during conduction block while being distal-to-proximal with persistent conduction.
Mitral isthmus block

Figure 5. With continuous pacing from the proximal bipole of the CS catheter (CS 3–4), an abrupt delay is observed on the distal bipole of the RF catheter, suggesting complete linear block (A). To perform differential pacing, the CS catheter is then withdrawn slightly to position the distal bipole (CS 1–2) just septal to the line. During pacing from proximal CS, the delay from the pacing artifact to the atrial potential on the RF catheter is 156 ms and represents perimital activation shown by yellow line (B). Changing the pacing site to distal CS results in a longer perimital activation time (red line) and hence a longer delay (C).
Atypical perimitral left atrial flutter with Incomplete mitral isthmus block

Figure 6. Atypical left atrial flutter observed after PV isolation and incomplete mitral isthmus ablation. The 3-dimensional activation map (CARTO) shows counterclockwise perimitral circuit propagating through a recovered mitral isthmus (A). Reablation of the isthmus resulted in conversion to sinus rhythm, but complete block was not achieved initially, as demonstrated by the CARTO map (B) during CS pacing. Further ablation resulted in complete block (C), with purely counterclockwise perimitral activation reaching the lateral flank of the line. Note posterior ascending front breaking through the roof and colliding with the perimitral front at the anterior left atrium. The left pulmonary veins (LPV) and completely blocked mitral isthmus are displayed in gray, as no local potentials are recordable.
Left atrial activation after mitral isthmus block

Figure 7. CARTO map of LA activation during sinus rhythm in LAO and PA views. Activation fronts (dashed line) collide at the lateral part of the LA at the mitral isthmus (dotted line).
### Clinical results

**Mitral Isthmus Ablation**

<table>
<thead>
<tr>
<th></th>
<th>PVI Only (n=100)</th>
<th>PVI + Mitral isthmus ablation (n=100)</th>
</tr>
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<tbody>
<tr>
<td>Woman</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Age</td>
<td>52 ± 10</td>
<td>55±10</td>
</tr>
<tr>
<td>RF</td>
<td>37±5 min</td>
<td>65±26 min</td>
</tr>
<tr>
<td>CS ablation</td>
<td>0%</td>
<td>68% (≤ 25 W)</td>
</tr>
<tr>
<td>MI Block</td>
<td>-</td>
<td>92%</td>
</tr>
<tr>
<td>Success</td>
<td>69%</td>
<td>88%*</td>
</tr>
<tr>
<td>Recurrence</td>
<td>49%</td>
<td>32%*</td>
</tr>
<tr>
<td>Tamponade</td>
<td>0%</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1% if &lt;40W)</td>
</tr>
</tbody>
</table>

*Jais, Circulation 2004*
Atypical left atrial flutter circuits following PV isolation
LA roofline
(Hocini et al, Circulation 2005;112:3668-3696)

Figure 1. NavX images demonstrate the ablation sites for PVI and the roofline. The PV ablation is shown in red tags, and that of the roofline is in brown. The ablation tags have been postprocessed to remove multiple tags at the same location and demonstrate joining with the ablation around the 2 superior PVs. The right panel demonstrates the potentials locally both on the line and anterior and posterior to the line during pacing at the LA appendage (LAA) in some cases in which potentials cannot be recorded on the line. Validation of the line requires mapping of either side to determine the activation delay. LSPV indicates left superior PV; RSPV, right superior PV; LIPV, left inferior PV; RIPv, right inferior PV; and MA, mitral annulus.
LA roofline

Figure 2. This series of radiographs shows the motion utilized to move the ablation catheter along the LA roof from the left to right PV. Note that the sheath assembly is advanced to offer support as clockwise torque is applied to the catheter sheath assembly to move from the left to the right PVs. The anterior-posterior (AP) and left anterior oblique (LAO) projections are presented.
LA roofline validation

Figure 3. Schematic representation of the roofline ablation joining the 2 superior PVs. Also presented is the activation pattern during LA appendage pacing to evaluate the line that results in an activation detour around the PVs to activate the posterior LA. The electrogram in the right panel shows the corridor of double potentials recorded at various sites on the line recorded with an octopolar catheter. Abbreviations are as defined in Figure 1 legend.
Figure 4. A, Electroanatomic activation map during LA appendage pacing to demonstrate the activation detour to the posterior LA wall. The PVs are marked in this case with orange tags, and the ablation line is seen as areas of electric silence marked in gray as scar. Abbreviations are as defined in Figure 1 legend. B, Propagation map of the same patient. The wave front commences at the LA appendage (LAA) and propagates rapidly around the left PV and later around the right PVs to collide in the posterior LA near the septum.
Atypical left atrial flutter following PV isolation

Figure 6. Macroreentry around the right PV. The electroanatomic map is orientated with the right PV en face with activation demonstrated from red to purple with the use of the roof in its propagation. Left, Entrainment from the LA roof with a postspacing interval that is equal to the tachycardia CL. Right, Entrainment was performed at the lateral LA and demonstrated a postspacing interval 50 ms longer than tachycardia CL, confirming the arrhythmia to be around the right PVs. Ablation of the LA roof terminated the tachycardia. CSD indicates coronary sinus distal; CSP, coronary sinus proximal. Other abbreviations are as defined in Figure 1 legend.
AFib termination by roofline ablation

Figure 5. Progressive slowing and termination of AF during roofline ablation (Abl). DCS indicates distal coronary sinus; PCS, proximal coronary sinus.
Mitral isthmus line and roofline validation

Figure 7. Evaluation of the roofline by activation mapping after achieving conduction block at the mitral isthmus (performed for spontaneous perimital macro-reentry). In this case activation during LA appendage (LAA) pacing proceeds rapidly anteriorly to activate the posterior LA from right/inferior to left because of conduction block at the mitral isthmus. This results in a shorter delay to the local potential on the right extremity (142 ms) of the line than the left (159 ms).
Success rates with PVI ± roofline

Figure 8. Kaplan-Meier analysis for the absence of arrhythmia during follow-up.
Proposed mechanisms

- Prolongation of AFib cycle length
- Reduced AFib inducibility
- Elimination of atypical left atrial flutters
Catheter Ablation of long-lasting persistent AFib
Haissaguerre et al, JCE 2005;16:1125-1137

**Atrial ablation targets**

- Fractionation
- Centrifugal Activation
- Activation Gradient
- Short Cycle Length Activity

**Local ablation endpoint**

- Dist
- Prox
Catheter Ablation of long-lasting persistent AFib
Haissaguerre et al, JCE 2005;16:1125-1137

**Figure 5.** The figure demonstrates the number and cumulative percentage of patients terminating with each step of ablation. Of note, the first three steps (PVI, atrial ablation, and CS/SVC ablation) were performed in a randomized order, while the final step was linear ablation in all cases.
Figure 10. The figure demonstrates the impact of ablation within the CS and shows the dramatic slowing of CS activity prior to disconnection of the CS.
Catheter Ablation of long-lasting persistent AFib
Haissaguerre et al, JCE 2005;16:1125-1137

Figure 11. The figure demonstrates a patient with multiple successive macroreentrant or focal AT prior to restoration of sinus rhythm. CTI = cavitricuspid isthmus; FL = flutter.
Figure 12. Location of focal ATs ablated during the index procedure. The two points marked with an arrow were foci (giving centrifugal activation) located at the cavo-tricuspid isthmus.
Catheter Ablation of long-lasting persistent AFib
Haissaguerre et al, JCE 2005;16:1125-1137
Catheter Ablation of long-lasting persistent AFib
Haissaguerre et al, JCE 2005;16:1125-1137

Sites converting AF in AT or Sinus Rhythm (random Abl)

- SVC 2%
- RA 7%
- Septum 10%
- Anterior LA 3%
- Roof line 6%
- PV 13%
- Post LA 5%
- LAA 17%
- Mitral isthmus 13%
- Inf LA 12%
- CS 13%
Termination

From AT to SR: mapping results

170 ATs were identified:

- macro-reentry 88 (52%)
  - around the mitral annulus 46 (52%)
  - common AFL (CTI dependent) 25 (28%)
  - through the LA roof 17 (20%)

- focal AT 82 (48%)
Follow-Up of 135 Patients (56% SHD)

- Redo procedures in 40%, most for AT
- Clinical outcome after 11 ± 10 months:
  - 3 patients in persistent AF (2% !)
  - 10 pts in paroxysmal AT/AF (single episode in 4)
  - 122 patients in sinus rhythm (90%)
Ablation strategy

- Focal (within PV)
- Segmental ostial
- Circumferential atrial
- Additional lines
- Substrate mapping (CAFE, DF)
- Ganglionated plexus (GP)
Ideal approach for tailored AFib ablation
(Haissaguerre et al)

Ideal Approach to Tailoring AF Ablation Should
Guided by Individuals AF Mechanism

- Migrating wavelets/sources
- Extensive linear ablation
- Tissue mass reduction
- Stable "source(s)" (focus/circuit/rot)
- Adequate mapping for local ablation
- Macroreentry
- Identify the isthmus & achieve linear block
CAFE

- Areas of fractionated electrograms
- Areas with extremely short cycle lengths (<120ms)
- Endpoint: Elimination of all areas of fractionation, conversion to SR (including ibutilide), noninducibility in pts with paroxysmal AFib
Complex fractionated electrograms (CAFE)
Nademane et al, JACC 2004;43:2044-2053
AFib Termination
Substrate mapping and ablation: Clinical results

121 pts
- RFA of CAFE’s
- Re-do in 24%
- 83% success at 1 yr off drugs

Nademanee et al, JACC, 6/04
Optical and electrogram fractionation
Kalifa et al, Circulation 2006;113:626-633

- Isolated sheep heart preparation (n=8)
- AF induced by acetylcholine
- Experimental and computer models of AF to explore mechanism underlying signal fractionation during AF (using endocardial videoimaging and electric mapping)
- Characterization of DF and a regularity index (ratio of DF to total power)
Figure 2. Optical and electrogram fractionation. A, Representative pixel recordings at locations 1, 2, and 3 (right to left). B, DF (left) and RI (right) maps for the same movie. C, Simultaneous bipolar electrograms obtained 20 minutes after optical recording at sites 1, 2, and 3. Note a similar increase in fractionation (ie, a decrease in RI) in both optical and electric signals from locations 1 to 3.
Clinical implications:

• Relationship between fastest and most fractionated sites

• Fastest activity is in fact the most regular

• Most fractionated electrograms recorded in adjacent locations surrounding the AF sources

• Electrogram fractionation is the result of increased variability in propagation velocity and direction of waves emanating from AF sources

• Targeting CAFEs may result in isolation of areas harbouring AF sources
CAFE

Future role:

• Alternative/adjunct to linear ablation in pts requiring substrate modification

• No studies formally comparing CAFE with other ablation techniques to date
Ablation strategy

- Focal (within PV)
- Segmental ostial
- Circumferential atrial
- Additional lines
- Substrate mapping (CAFE, DF)
- Ganglionated plexus (GP)
Programmed electrical nerve stimulation (PENS) and GP ablation

- Requires high rates and strengths of stimulation (appr. 10-15 times more than PES)
- Distal tip of map/ablation catheter delivering typically 1200 bpm (20Hz) with a pulse width of 10ms at 5 to 15 V
- High frequency stimulation (HFS) during SR at GP areas induces AFib (by local release of Acetylcholine) and CAFEs
- HFS during AFib induces vagal response (AV block and hypotension) within 10 sec
- Ablation directly over GP area infrequently causes symptoms
- HFS after ablation fails to reinduce vagal response (eliminates afferent response)
Figure 2  Response to high-frequency stimulation in the antral region of the right upper pulmonary vein, revealing transient AV block. Delivery of 10 V caused a positive afferent vagal response. Paper speed is 25 mm/s. Shown are recordings from surface ECG leads I, V₃, V₄, and V₆, intracardiac electrograms from the distal and proximal bipolar pairs of the mapping and ablation catheter also used to perform high-frequency stimulation, bipolar recordings from the catheter positioned in the coronary sinus (distal electrodes 1-2 to 7-8), and recordings from the high right atrium and distal pair of the His bundle, recording ventricular activation at this position.
GP mapping
GP ablation
Nakagawa et al, Heart Rhythm 2006
GP ablation
GP ablation

- Future role: unclear
- Adjunct to conventional ablation strategies?