Feel the rhythm of the beat!
Imaging the left atrium:
What the electrophysiologist wants to know

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Disclosure

• Linda B Haramati—Family member:
  – Board Member and Shareholder
  • Kryon, LTD

• Anna Shmukler, Anna Bader, Narmadan Kumarasamy, Eric Bader—Nothing to disclose
Outline

• Atrial fibrillation (AF) – most common sustained arrhythmia, with significant morbidity and mortality including stroke, heart failure and death
• Limited efficacy of rhythm control medications and risks of anticoagulation have led to development of procedures such as catheter ablation and left atrial appendage occlusion and exclusion
• Pre-procedure image-based planning can increase the likelihood of safety and success, providing imaging of the left atrium (LA), left atrial appendage (LAA), and the pulmonary veins (PV)
• Proper protocolling, choice of effective imaging modality, and comparison with prior exams is crucial
Introduction

- AF- characterized by ineffective atrial contractions and rapid ventricular response rates
- Decreased flow and stagnation of blood in LA and LAA predisposes to thromboembolism formation
- AF itself may represent an inflammatory and procoagulable state
- AF prevention largely relies on the recognition of the risk factors for its development
- Imaging in AF helps identify potential risk factors, patients at higher risk for adverse outcomes and is essential in guiding therapy
- AF is associated with an increased risk of cardiac morbidity and mortality
Pathophysiology of AF

- Requires a trigger as well as a substrate to become chronic
- Triggers—arrhythmogenic zones around the ostia of the pulmonary veins (PV), superior vena cava (SVC) or the coronary sinus
- AF results in electric and structural endomyocardial remodeling
- Remodeling and fibrosis lead to re-entry circuits
- Destruction of electric or anatomical abnormalities by isolation of the PV or LAA and ablation of the left atrial substrate can eliminate arrhythmia
Types of AF

- **Paroxysmal** – may last for seconds, minutes, hours, or even several days; often symptomatic; may resolve spontaneously
- **Persistent** – lasts for more than 7 days
- **Longstanding persistent** – lasts more than one year
- **Permanent** – normal heart rhythm cannot be restored. Medications, procedures, and controlled electrical shocks do not help return the heart to a normal rhythm
Risk Factors for AF

- Age older than 65
- Hypertension
- Diabetes
- Body Mass Index
- Structural heart disease
- Family History of AF
- Structural heart disease
- Alcohol and stimulant use
- Thyroid Disease
- Pulmonary disease
- Sleep Apnea
- Heart failure
- Structural heart disease
- Hypertension
- Diabetes
Complications from AF

• Thromboembolism
• Cerebrovascular accident (CVA)
• Heart failure
• Dementia
• Death
Thromboembolism

- Complex pathophysiological process, result of LA remodeling and mechanical dysfunction
- LAA most common source of thrombus
- Increased interest in closing the LAA to prevent thrombus
- Imaging used before and during the procedure to define patient suitability for LAA closure and to guide the procedure
- LAA closure is therapeutic alternative to anticoagulation

65-year-old man with atrial fibrillation. CTA delayed post-contrast image demonstrates a nonenhancing thrombus in the left atrial appendage (arrow)
Indications for LAA Percutaneous Device Closure

• Contraindications to anticoagulation:
  – Major bleeding or at risk of bleeding
  – Coronary stenting
  – Drug interactions
  – Stroke on anticoagulation
  – Renal or hepatic disease
  – Risk of fall
LA Anatomy

63 year old man with AF. Non-gated CTA for pulmonary vein mapping. A, Axial, B, Coronal and C, 3D images demonstrating anatomy of left atrium (LA), including pulmonary veins (PV), and left atrial appendage (LAA), septal portion (S), vestibule (V)

- Most posterior cardiac chamber
- Pulmonary veins enter the posterior part of the left atrium
- Consists of 4 parts:
  - pulmonary venous portion
  - septal portion
  - vestibule, which is the outlet part of the atrial chamber surrounding the mitral orifice
  - LAA
LA remodeling in AF

- Alterations of extracellular matrix and myocytes lead to myofibroblastic proliferation, fibrosis and zones of slow conduction and conduction disturbances
- Electrical remodeling
- Structural remodeling:
  - Dilatation of LA
  - Tissue fibrosis
- Autonomic nervous system changes
- Ca^{2+} handling abnormalities
- LA dilatation, as a marker of remodeling
- Controversial whether AF causes LA dilatation, or is its consequence

55-year-old woman with AF. CTA demonstrates marked left atrial dilatation (arrows)
LAA Anatomy

- Narrow, blind-ending structure arising from the LA free wall, protruding superiorly and leftward
- Multi-lobed in 80%, contains pectinate muscles
- Close proximity to the ostium of the left superior pulmonary vein, separated by a ridge
- Close proximity to the left atrioventricular groove containing circumflex coronary artery

63-year-old man with AF. A, CTA vertical long axis and B, axial images demonstrate the left atrial appendage (arrows)
LAA imaging

- Transesophageal echocardiography (TEE) -- main diagnostic modality for LAA morphology, function, and thrombus
- CT offers novel noninvasive insights into LAA morphology
- However, CT has limitations in evaluating LAA thrombus due to slow flow, and non-uniform opacification of the LAA, which may resemble thrombus
- Delayed post-contrast images are useful for LAA thrombus evaluation
- MRI is occasionally used for anatomy and LAA thrombus evaluation, but more studies are needed to access MRI utility

60-year-old man with persistent AF. A, CTA demonstrate incomplete contrast filling of the distal tip of the LAA (arrow), which has a concave margin (arrow). In contrast, B, CTA of another patient shows LAA thrombus with convex margins and contrast surrounding the filling defect (arrow).
CT Protocol

- Contrast enhanced—CT angiogram (CTA)
- May be ECG gated
- Prospective triggering—less radiation, limited information on cardiac function and motion
- Retrospective gating—much higher radiation, permits evaluation of function, wall and valvular motion
- Injection rate: 4cc/sec or 5cc/sec triggered by LA enhancement
- Delayed images may be needed for optimal LAA opacification
Pulmonary Vein Anatomy

- Commonly 2 pulmonary veins from each lung drain into the LA
- Common pulmonary vein ostia or extrapulmonary veins are normal variants

A, CTA demonstrates right upper (RU), right lower (RL), left upper (LU) and left lower (LL) pulmonary veins. B, Maximum intensity projection (MIP) image demonstrates an accessory right middle lobe pulmonary vein with a separate orifice in addition to bilateral upper and lower pulmonary veins.
Pulmonary Vein Variants

• Common ostium--common draining of the inferior and superior PV directly into the LA with no intervenous segment
• Late fusion--merging of the venous segments occurs less than 5 mm before the ostium
• Accessory PV--supernumerary PV with a separate ostium

A, B, Axial and sagittal CTA images demonstrate a single common left pulmonary vein draining into the left atrium (arrow). The right upper and right lower pulmonary veins have separate orifices. C, Axial oblique MIP image demonstrate an accessory right middle lobe pulmonary vein.
Partial Anomalous Pulmonary Venous Return

A, B 63-year-old woman with AF. CTA for pulmonary vein mapping. Axial and axial oblique MIP images demonstrate right upper lobe pulmonary veins draining into the SVC (arrows). The right middle, right lower, left upper and left lower pulmonary veins drain separately into the LA.

C, D, 72-year-old. 3D recons and coronal oblique images: incidentally noted PAPVR (arrow) draining the left upper lobe into the vertical vein which drains to the left brachiocephalic vein.

Look for anomalous drainage of the lung into systemic venous system (usually SVC from the right lung or to the vertical vein from the left lung.)
Left Superior Vena Cava (LSVC)

A, B, C Axial, coronal and sagittal CTA images for pre-ablation planning demonstrates un-opacified small persistent left SVC (arrow) in a patient with duplicated SVC. (Right sided injection)

D, Another patient with a large opacified persistent LSVC (arrow) after left sided contrast injection. Note, there is no contrast in LA and contrast is noted in right atrium (RA), as the LSVC is draining into the coronary sinus.

LSVC is a embryological precursor of the ligament of Marshall, which has been implicated in the initiation and maintenance of atrial fibrillation (AF).
AF Ablation

- Radiofrequency catheter ablation
- Evidence from several prospective randomized trials catheter ablation is superior to antiarrhythmic drugs
- Improves quality of life

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<tr>
<th>Indications:</th>
<th>Contra-indications:</th>
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<tr>
<td>– Symptomatic paroxysmal AF not responsive to optimal anti-arrhythmic</td>
<td>– Unstable angina</td>
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<td>medication</td>
<td>– Bacteremia or septicemia</td>
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<td>– Symptomatic persistent AF refractory or intolerant to medical treatment</td>
<td>– Acute decompensated congestive heart failure not caused by the arrhythmia</td>
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<td>– Major bleeding diathesis</td>
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<td>– Acute lower extremity venous thrombosis if femoral vein cannulation is desired</td>
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<td>– Intracardiac mass or thrombus</td>
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Pre AF Ablation Imaging

• Evaluate PV anatomy
  – Identify anatomic variants that require procedural attention such as common ostium or supernumerary PV
• Measurement of LA dimensions
• Identification of LA or LAA thrombus
• Identification of anomalous pulmonary veins and LSVC
• Demonstrate anatomy of the interatrial septum which may help guide trans-septal puncture
• Evaluate for potential risks:
  – Pre-existing PV stenosis in patients with prior ablation
  – Atypical position of the esophagus
Post Ablation Imaging

- Efficacy of catheter ablation crucially dependent on the extent of left atrial (LA) structural remodeling
- Look for potential complications:
  - Pulmonary vein stenosis
  - Cardiac tamponade
  - Atrial-esophageal fistula
  - Perforation of the LA

70 year old man with AF who underwent PV ablation. Non-contrast CT of the chest demonstrates hyperdense pericardial effusion (arrow) consistent with clinically suspected LA perforation and hemopericardium
Post Ablation Complications

A, Frontal C T scout demonstrating median sternotomy and both hemidiaphragms at the same levels. B, Frontal chest xray post pulmonary vein ablation demonstrates elevation of the right hemidiaphragm (arrow) due to right phrenic nerve injury, as the nerve runs in close proximity to the right pulmonary veins (dashed line).

C, D, MIP oblique and axial CTA in a patient who underwent pulmonary vein ablation demonstrating posterior mediastinal hematoma (arrows) posterior to the left atrium, not present pre-ablation, which causes mass effect and compression of the posterior wall of the LA and left lower pulmonary vein (LLPV).

E, 71 year old woman with AF. Axial CTA post PV ablation demonstrating right lower pulmonary vein stenosis at the ostium (arrow).
Percutaneous Device Closure of LAA

- Patients with contraindications to oral anticoagulation at high risk for stroke
- Patients non-compliant with anticoagulation
- Usually performed under general anesthesia and with TEE and fluoroscopic guidance
- Important to assess the technical feasibility of percutaneous LAA closure using pre-procedural TEE and/or CT imaging
- Specific aspects of the LAA should be assessed, as this may influence device/size selection and implantation success: such the size of the LAA ostium, LAA thrombus, LAA morphology and lobulations
- LAA thrombus and valvular disease are contraindication for device implantation

Vertical long axis of the left atrium and ventricle images from a CTA demonstrating LAA. Double-sided arrow indicates measurements of the LAA orifice for device sizing.
Percutaneous Device Closure of LAA

- **AMPLATZER**--self-expanding mesh forming a lobe and disk, connected by a central articulating waist, implanted at the LAA neck

- **WATCHMAN**--self-expanding device covered with permeable polyethylene membrane with fixation anchors, which engage LAA tissue for device stability. The membrane blocks thrombus embolization and promotes healing and endothelialization

Lateral chest radiograph in a patient with AF post implantation of the Watchman device
LAA Morphology

• Four major morphological groups:

  • A, Chicken wing-- obvious bend in the proximal or middle part of the dominant lobe, or folding back of the LAA anatomy on itself at some distance from the perceived LAA ostium. May be associated with a lower stroke risk
  • B, Cactus-- a dominant central lobe with secondary lobes extending from the central lobe in both superior and inferior directions
  • C, Windsock--one dominant lobe of sufficient length
  • D, Cauliflower--limited overall length with variable number of lobes with lack of a dominant lobe

• Studies have shown that non-chicken wing morphology is at higher risk for thromboembolism formation
Lariat Procedure

67-year-old woman with AF undergoing the Lariat procedure. Sequential fluoroscopic static images demonstrating A, catheter in the LAA (outlined), with B, subsequent insertion of the transvenous (TV) and percutaneous wires magnet (M) tipped guide-wires, C, advancement of a snare (arrow) with pre-tied suture over the LAA.

- Complex hybrid procedure that requires endocardial and epicardial approach
- Pre-operative CTA to exclude large (>40 mm) appendages and other anatomic variants
- Consists of a snare with a pre-tied suture that is magnetically guided epicardially over the LAA
- Fluoroscopic LAA closure confirmation after suture release
Conclusion

• AF most common arrhythmia with significant resultant morbidity and mortality, including significant risks of anticoagulation therapy
• Advancements in alternative treatment options such as catheter ablation, left atrial appendage occlusion and exclusion lead to improved quality of life
• Pre-procedural imaging is essential to evaluate for LA, LAA thrombus and LA anatomy
• Proper protocolling, choice of effective imaging modality before and after procedure, and comparison with prior exams is crucial
References

- D.P. Leong, V. Delgado, J.J. Bax  Imaging for atrial fibrillation Curr Probl Cardiol, 37 (2012), pp. 7–33