Spikes and Dips: CMR Imaging Manifestations of the ECG

Lea Azour MD
Javier Sanz MD
Matthew D. Cham MD
Adam H. Jacobi MD

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Learning Objectives

1. Review basic ECG interpretation
2. Discuss the MR imaging correlates of arrhythmias and conduction abnormalities
   a. Atrial fibrillation
   b. Bundle branch block
   c. Ectopy
3. Compare the electrocardiographic and MR findings of ischemic disease (anterior, lateral, and inferior wall infarctions)
4. Correlate the electrocardiographic and MR features of various cardiomyopathies
   a. Hypertrophic
   b. Dilated
   c. Takotsubo
   d. ARVD
   e. Amyloidosis
   f. Sarcoidosis
   g. Fabry Disease
5. Explore how to optimize image acquisition in the setting of abnormal ECG
1: Basic ECG Interpretation

The Rhythm Strip: Horizontal boxes = Time

- Each small box = 0.04 seconds
- Each large box (5 small boxes) = 0.2 seconds
1: Basic ECG Interpretation

The Rhythm Strip: Vertical boxes = Voltage

- Each small box = 0.1 mV
- Each large box (5 small boxes) = 0.5 mV
1: Basic ECG Interpretation

Each Lead Corresponds to a Myocardial Territory

- Inferior
- Septal
- Lateral
- Anterior
1: Basic ECG Interpretation

The Spikes and Dips

P: atrial depolarization
QRS: ventricular depolarization
T: ventricular repolarization

*PR Interval: 0.12-0.20s (3-5 boxes wide)
*QRS interval: 0.04-0.12s (up to 3 boxes wide)
1: Basic ECG Interpretation

The Spikes and Dips

No P Wave
- Atrial fibrillation

Peaked P Wave
- Atrial enlargement

Short PR Interval (normally 0.12-0.20s)
- Wolf Parkinson-White

Inverted T Wave:
- Ischemia (symmetric)
- Ventricular Hypertrophy (asymmetric)
- Electrolyte abnormalities

Pathologic Q Wave
- Prior MI

Wide QRS (normally < 0.12s)
- Bundle branch block

High Voltage QRS
- Ventricular hypertrophy
2: Arrhythmias and Conduction Abnormalities

a. Atrial fibrillation
b. Bundle branch block
c. Ectopy
Atrial Fibrillation (AF)

- Two-chamber cine demonstrates left atrial (LA) enlargement and poor atrial contraction
- Other findings in AF may include LA thrombus, as well as mitral valve disease
- On ECG, there are no discrete \( \text{p} \) waves (circled), with irregularly irregular QRS complexes
2: Conduction Abnormalities

Bundle Branch Block (BBB)

- Short axis cine shows paradoxical motion of the interventricular septum, compatible with left BBB
- ECG demonstrates wide QRS complexes, with duration >120 ms (3 horizontal boxes)
2: Conduction Abnormalities

Ectopy (PVCs, Bigeminy, Trigeminy)

Frequent and consecutive PVCs (circled)

Ectopic beats (arrows) are seen after each sinus beat, compatible with bigeminy

- Short axis cine shows extensive motion artifact due to ectopic beats, compatible with PVCs and bigeminy in this 36 year old patient
3: Myocardial Infarction

a. Left Main (LM)
b. Left Anterior Descending (LAD)
c. Left Circumflex (LCx)
d. Right Coronary Artery (RCA)
3: Ischemic Disease

LAD

RCA

LCx

Basal

Inferior

Anterior

Septal

Lateral

Mid

Apical

Lateral
3: Ischemic Disease

Left Main—Anterolateral Wall MI

LGE images demonstrate transmural enhancement in the septum, and near transmural enhancement in the anterolateral walls.

Widespread ST depression (arrows), with ST elevation in aVR (circle), is suggestive of left main coronary occlusion. The patient was found to have multivessel disease with subtotal left main stenosis.
3: Ischemic Disease

LAD—Anterior Wall MI

LGE images demonstrate subendocardial enhancement in the anteroseptum (arrows). Short axis cine (top right) shows corresponding absence of myocardial thickening in these segments.

Q waves in V1 and V2 (arrows) are consistent with infarction in this territory.
3: Ischemic Disease

LCx—Lateral Wall MI

LGE image (left) shows subendocardial enhancement in the anterolateral wall (arrow).

T2 Cine images show edema in the basal to mid anterolateral segments.

ECG reveals Q waves (arrows) in the lateral leads, leads I and aVL. Lateral wall infarcts may be occult on ECG.
Cine LGE images show subendocardial enhancement in the basal to mid inferoseptum, and transmural enhancement in the mid to apical inferior walls. Short axis cine confirms corresponding wall motion abnormality.

Q waves (arrows) are seen in the inferior leads (II, III, avF), compatible with prior MI.
4: Cardiomyopathies

a. Hypertrophic  
b. Dilated  
c. Takotsubo  
d. ARVD  
e. Amyloid  
f. Sarcoid  
g. Fabry Disease
4: Cardiomyopathies: HCM

Hypertrophic Cardiomyopathy

Four chamber cine shows asymmetric hypertrophy, with the mid septum measuring 2.7 cm, compatible with severe HCM. LGE images show enhancement in the mid septal and inferior segments, as well as the apical segments.

The tall R waves in aVL (boxed) meet Cornell criteria for LVH. Negative asymmetric T waves (circled) are seen in the low lateral leads. “Dagger like” Q waves in the lateral leads may also be seen as a result of apical hypertrophy.
29 year old woman with postpartum DCM. 3-chamber LGE image shows linear intramyocardial enhancement in the basal ateroseptum. Four-chamber cine shows moderate to severe LV dilatation, and accompanying severe LV dysfunction (LVEF 24%).

While many abnormal ECG findings may be seen in the setting of DCM, high voltage V6 (circled) has been described as a characteristic finding. LVH is also commonly seen, as in this patient, with the S (V1) + R (V5) > 35, via the Sokolow-Lyon Criteria.
4: Cardiomyopathies:  

Takotsubo Cardiomyopathy

- A middle aged woman presented with chest pain after a home explosion, and was found to have non-obstructive CAD.
- There is left ventricular apical dyskinesis on the 2 chamber and 4 chamber cine views.

At presentation, diffuse negative T waves (arrows) were identified, deepest in leads V4-V5.

4 months later (right), the T wave abnormality had resolved.
• **Epsilon waves (arrows)**, small positive deflections at the end of the QRS complex, are seen in leads V2 and V3. They are highly specific for ARVD. Deep T-wave inversions may also be found in ARVD.

• Short axis cine (center) shows a **severely dilated right ventricle** with akinesia/dyskinesia of the basal to mid inferior RV segments, and **reduced RVEF (29%)**.

• LGE image (right) shows **diffuse enhancement** in the RV free wall.
Cardiac Amyloidosis

LGE PSIR image (left) shows diffuse ventricular and left atrial enhancement. Short axis cine (right) shows severe concentric LV wall thickening with normal ejection fraction.

Low voltage EKG, when the QRS complex is < 5 mm in height in limb leads and < 10 mm in precordial leads, is commonly seen in amyloidosis. (rectangle height 10 mm)
55 year old man with pulmonary sarcoid, found to have myocardial enhancement at the RV aspect of the basal anteroseptum, as well as in the basal inferoseptal and inferolateral segments.

The patient has 1st degree AV block, demonstrated by the prolonged PR interval (286ms, circled), which corresponds to the finding of scar at the RV aspect of the septum.
In two separate patients, on short axis and 3-chamber LGE images, hypertrophy and enhancement are seen in the basal inferolateral segment, compatible with Fabry disease.

ECG from Patient B shows evidence of LVH, with the S (V1) + R (V6) > 35, via the Sokolow-Lyon Criteria. A short PR interval may also be seen in Fabry disease.
5: Optimizing Image Acquisition in the setting of an abnormal ECG

a. Setting up the ECG

b. Gating
   - Prospective Triggering
   - Retrospective Gating
   - Pulse Gating

c. Acquisition Technique
   - Segmented (Cine, LGE)
   - Non-Segmented (“Real Time” Cine, Single Shot LGE)
5: Optimizing Images

Setting up the ECG

• Synchronizing the MRI pulse to the R-wave allows us to acquire images without motion
  \[ \Rightarrow NEED A STRONG WAVEFORM \]

• Potential problems:
  • Inaccurate QRS detection
  • Low voltage ECG

• Tips:
  • Prepare anterior chest for lead placement:
    – Shave if necessary
    – Clean skin with commercially available gel, \textit{not alcohol}
  • May need to deviate from standard lead placement
  • Keep lead cables parallel to the bore of the magnet and on the same side as the aorta
  • Ensure lead cables not looped \( \Rightarrow \) may twist/braid cables to avoid this
  • Try a different lead selection if necessary (i.e. lead I, II or III) \( \Rightarrow \) use the lead with the sharpest R/S waves
5: Optimizing Images

ECG Gating: Prospective v. Retrospective

**Prospective**
- Acquisition is triggered by the R wave, after which there is a pre-set trigger delay
- Acquisition window excludes 10-15% of the cardiac cycle (gray) at end diastole \(\rightarrow\) underestimates EF
- Exclusion of end-diastole often functions as an arrhythmia rejection window, unless a premature contraction occurs even earlier to fall within the acquisition window/trigger acquisition

**Retrospective**
- Continuous acquisition of untriggered data and the ECG through the entire cardiac cycle
- Information is subsequently post-processed, with images reconstructed/sorted into the correct cardiac “phase” (also termed “segment” or “frame”)
- Arrhythmia rejection capability, which will discard the errant heartbeat and reacquire another, thus creating a longer acquisition. *Not as good for large beat-to-beat variations in the R-R interval.*
5: Optimizing Images

Pulse Gating

- Low ECG voltage/weak waveform may preclude triggering, which can occur in multiple scenarios, including:
  - Large pericardial effusion
  - Emphysema/COPD
  - Amyloidosis
  - Myocardial Edema

- **Solution:** Pulse gating

- **Drawback:** unclear delay time between ventricular contraction and the peripheral pulse
Segmented Acquisition

- Multiple k-space lines (echoes) are measured/combined for each cardiac phase over multiple heartbeats
- Typically requires both triggering and multiple patient breath-holds
- More k-space lines = less heartbeats necessary to acquire the image
  - ↑ k-space lines per segment = ↓ ACQUISITION TIME (TA) = ↓ TEMPORAL RESOLUTION
- May adjust parameters to make the breath-hold shorter/longer
  - Bradycardia (long R-R would necessitate long breath hold): Increase number of k-space lines to decrease TA/breath hold
  - Tachycardia: Can decrease number of k-space lines

<table>
<thead>
<tr>
<th>Heart Rate</th>
<th>Bradycardia</th>
<th>Tachycardia</th>
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<tbody>
<tr>
<td>60-99 bpm</td>
<td>&gt; 15 k-space lines</td>
<td>&lt; 9 k-space lines</td>
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<td>9-15 k-space lines</td>
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<td>&lt; 9 k-space lines</td>
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</tbody>
</table>
5: Optimizing Images

K-Space Schematic—Segmented

SEGMENTED – *Cine*

- K-space lines (echoes) are gathered for multiple phases* (numbered) in each heartbeat
- Data from multiple heartbeats is combined by phase to create the images

SEGMENTED – *LGE*

- K-space lines (echoes) are gathered during a diastolic phase
- Data over multiple heartbeats is combined for this phase to create the image

*Phase is synonymous with “segments” or “frames”*
5: Optimizing Images

Non-Segmented Acquisition

“Real Time” Cine and Single Shot LGE

– All k-space lines are gathered in one R-R interval
– May be useful when:
  • Weak ECG signal precludes gating/triggering
  • Irregular ECG signal precludes gating/triggering
  • Patient cannot maintain breath-holds

– Drawbacks:
  • Lower spatial resolution
  • Lower temporal resolution
5: Optimizing Images

K-Space Schematic—Non segmented

non-segmented – “Real Time Cine”

• K-space lines (echoes) are gathered for multiple phases* (numbered) over the course of one heartbeat

non-segmented – Single Shot LGE

• K-space lines (echoes) are gathered during one phase over one heartbeat

*Phase is synonymous with “segments” or “frames”
Conclusions

• Knowledge of the ECG may foreshadow a potentially suboptimal imaging exam:
  ➢ Early trouble-shooting of rhythm abnormalities

• The ECG may broaden differential considerations:
  ➢ Addition of sequences specific to suspected pathology (i.e. T2 for edema, T1 for fat, T1 Scout for amyloid)

• The ECG may aid in distinguishing among conditions that present with similar imaging features
References


Lea Azour, MD Lea.Azour@nyumc.org