Objectives

- Review the basics of interpreting electrocardiograms (ECG)
- Review important ECG abnormalities and their clinical implications
- Identify high risk findings that should prompt further evaluation
- Identify high risk findings that warrant urgent/emergent evaluation
Basic Information

• Always check to make sure this is the right ECG performed at the right time.
• It is helpful to know what the patient’s symptoms were at the time the ECG was done.
• Never trust the computer’s reading of the ECG (but it’s pretty good for intervals, axis, etc.)

31 year old physician without symptoms gets his ECG to use as normal for teaching. Do you agree with the computer’s interpretation? No (hopefully). I have sinus arrhythmia, not AF!

Rate

• Popular method: 300 / BB
• What if RR is variable?
• More accurate method: QRS x 6
• Assuming ECG runs at 25 mm/sec (standard)
• The rate on my ECG could be about 55 to 75 BPM using the 300 / BB method
Rhythm

• Usually...

<table>
<thead>
<tr>
<th>Rhythm</th>
<th>P wave</th>
<th>QRS width</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal sinus</td>
<td>Narrow</td>
<td>Regular</td>
<td>60-100</td>
</tr>
<tr>
<td>Atrial</td>
<td>Irregular/regular</td>
<td>Narrow</td>
<td>60-100</td>
</tr>
<tr>
<td>Junctional</td>
<td>Negative/No/Late</td>
<td>Regular</td>
<td>40-60</td>
</tr>
<tr>
<td>Ventricular</td>
<td>Dissociated</td>
<td>Regular</td>
<td>30-40</td>
</tr>
</tbody>
</table>

... but there are many exceptions

- Sinus arrhythmia: PP interval varies by >10% or >0.16 s
- Sinus bradycardia: HR < 60
  - Causes: vagal tone, IMI, drugs, hypothyroidism, hypothermia
- Sinus tachycardia: HR > 100
  - Causes: pain, caffeine, sympathetic tone, anxiety, pheochromocytoma
- Wandering atrial pacemaker: HR 60-100 and >3 P morphologies
- Multifocal atrial tachycardia: HR > 100 and >3 P morphologies
- Paroxysmal atrial tachycardia: HR > 100, usually due to 1 focus
- Atrial flutter: AR 240-350, inverted F waves in II/III/aVF without isoelectric baseline, small positive F waves in V1 usually with isoelectric baseline
- Atrial fibrillation: P > 350/s, fibrillation most visible in II/III/aVF/V1/V2, irregularly irregular (IR)
- Junctional tachycardia may be due to junctional focus, AV nodal reentrant tachycardia, or AV reentrant tachycardia
- Accelerated idioventricular rhythm: 40-100. Not always associated with poor prognosis (unless VT)

51 year old man has palpitations. What is the rhythm? Sinus rhythm with a PAC.
72 year old man has palpitations. What is the rhythm? Sinus rhythm with a PVC. (Also, inferior and posterior infarct.)

72 year old man has palpitations. What is the rhythm? Atrial fibrillation. (Also, inferior and anterior infarct, IVCD)

63 year old woman has palpitations. Why? Atrial flutter with variable AV conduction. ("Typical" or counterclockwise flutter with negative flutter waves in II and isoelectric in V1.)
56 year old woman has palpitations. What drug was given at the arrow?

Adenosine.

44 year old woman has rapid HR.

What was the rhythm before adenosine was given?

AVNRT

73 year old woman with palpitations. What’s the rhythm?

Wandering atrial pacemaker.

(36 BPM with 3 or more different P waves)
43 year old man with palpitations. What is the rhythm?
Ectopic atrial tachycardia.
(Note the unusual P wave axis.)

18 year old man with palpitations. What is the rhythm? His subsequent ECG:
The first ECG shows ectopic atrial tachycardia. Note the inverted P waves in leads II, III, and AVF and compare to the second ECG, when the patient is in sinus rhythm.

75 year old man with palpitations. What is the rhythm?
Junctional rhythm.
(Also, retrograde conduction is present.)
77 year old man with palpitations. What is the rhythm? Junctional rhythm, converting to sinus rhythm. Possible isorhythmic dissociation.

73 year old woman suddenly loses consciousness 3 days after a large MI. What is the rhythm? Monomorphic ventricular tachycardia. (Note AV dissociation, very wide QRS, slurred RS line.)

25 year old woman with a history of diuretic abuse was found down. What is the rhythm and what are the appropriate therapies? Polymorphic ventricular tachycardia (torsades de pointes). Treatment includes defibrillation (200J, 300J, 360J), plus IV magnesium if due to long QT secondary to magnesium loss from diuretic use.
A 49-year-old man with chest pain had anterior ST elevations when EMS arrived but then "his eyes rolled up and he started posturing." Does his repeat ECG provide any insight into what has happened?

Yes. Ventricular fibrillation has ensued.

(Defibrillate en route to the cath lab!)

**Axis**

- **P axis:** normal 0 to 75
- **QRS axis:** normal -30 to 105
- **QRS axis**
  - Normal
  - Left
  - Right
  - Indeterminate
- **Some causes of LAD:** LAFB, IMI, LBBB, LVH, primum ASD, COPD, hyperkalemia
- **Some causes of RAD:** RVH, COPD, PE, LPFB, lateral MI, secundum ASD, dextrocardia, lead reversal

**P waves**

- Think of the P wave as a summation wave of RA and LA depolarization. Remember, the SA node depolarizes the RA first.

- **RAE**
  - > 2.5 mm tall in II, III, and aVF ("P pulmonale"), or
  - > 1.5 mm tall in V1 or V2
  - **Causes:** COPD, pulmonary HTN, PE, congenital, or normal variant (thin)
- **LAE**
  - Terminal negative P > 1 mm deep and > 0.04 s wide in V1, or
  - P > 0.12 s wide and notched in II, III, or aVF ("P mitrale")
  - **Causes:** mitral valve valve disease, MI, LVH, heart failure
66 year old man with a murmur.
Left atrial enlargement.
(Also, sinus bradycardia, ?anterior infarct)

50 year old man with shortness of breath.
Right atrial enlargement.
(Also, sinus tachycardia, ?anterior infarct)

35 year old woman with seizure.
Sinus tachycardia with biatrial enlargement.
(BAE was confirmed on echo.)
Ventricular hypertrophy

- LVH voltage criteria – any of the following:
  - R aVL + S V3 (Cornell criteria, most accurate) > 28 mm (males) or 20 mm (females)
  - R V5 + S V1 > 35 mm if age > 40 (>40 if age 30-40)
  - R I + S V6 > 45 mm
  - R V1 > 16 mm
  - R V5 > 26 mm
  - R V6 > 20 mm
  - R I > 14 mm
  - S aVR > 15 mm
  - R aVL (specific unless LAFB present) > 12 mm
  - R aVF > 21 mm
  - Sensitivity decreased by low voltage (COPD, PTX, edema, CAD, sarcoidosis, RVH, LBBB)
  - Specificity decreased by high voltage (thin body, left mastectomy), LBBB, WPW, LAFB

- RVH voltage criteria (less reliable) – RAD > 110° and any of the following:
  - R/S ratio in V1 or V5R > 1
  - R/S ratio in V5 or V6 > 1
  - R V1 > 5 mm
  - R V1 + S V5 > 10.5 mm
  - rSR’ V1 present with R’ being > 10 mm
  - qR present in V1

54 year old man with HTN. Left ventricular hypertrophy (Also, sinus bradycardia, 52 BPM)

69 year old man with shortness of breath. Right ventricular hypertrophy with repolarization abnormalities (RAD, R/S V1, RV12mm, SVT12mm) (Also, NSR 82 BPM, right axis deviation, incomplete RBBB, szrtrr TWV)
First degree AV block:
- PR > 0.20 s, PR constant, and P:QRS 1:1
- Causes include: high vagal tone (athletes), drugs, normal, congenital heart disease, injuries.

Second degree AV block, Type I (Wenckebach):
- Progressive lengthening of PR interval until a P wave fails to conduct.
- RR interval with non-conducted P is shorter than 2 PP intervals.
- Grouped beating and block usually occurs at the AV node level (i.e. narrow QRS).
- Causes include: normal (athletes), inferior MI, drugs, myocarditis.

Second degree AV block, Type II:
- Constant PR but intermittent non-conducted P wave.
- RR interval with non-conducted P is equal to 2 PP intervals.
- Block often occurs below the AV node (wide QRS in 80%).
- Causes include: myocardial damage or fibrosis, anterior MI.

Third degree AV block:
- Independent atrial and ventricular rhythms.
- Complete heart block is present when atrial rate < ventricular rate, otherwise AV dissociation is present if ventricular rate > atrial rate.
- Causes include: degenerative conduction defect, infiltration (sarcoid, amyloid), digitalis, endocarditis (usually preceded by prolonged PR), severe hyperkalemia, Lyme disease.

59 year old man has palpitations. Why?
- 2nd degree, type I (Wenkebach) AV block, converting to 2:1 AV block.

77 year old woman with syncope. Why?
- "Mobitz block." (Prolonged PR interval, LAFB, RBBB.)
- The next slide shows her rhythm strip at the time of syncope.
What is her rhythm now?
Complete trifascicular block, or complete heart block. Note the atrioventricular dissociation, with the atrial rate being faster than the ventricular rate.

Bundle branch block
- Look at the latter half of QRS in V1 and V5/V6 for morphology.
- Incomplete if QRS 0.10-0.119 s. Complete if QRS > 0.12 s.

<table>
<thead>
<tr>
<th>Left Bundle Branch Block</th>
<th>Right Bundle Branch Block</th>
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</thead>
<tbody>
<tr>
<td>VR morphology in V1</td>
<td>LS or RS dominant</td>
</tr>
<tr>
<td>VR morphology in V5/V6</td>
<td>Broad monophasic R</td>
</tr>
<tr>
<td>Interferes with diagnosis of LBBB?</td>
<td>Yes</td>
</tr>
<tr>
<td>Causes</td>
<td></td>
</tr>
<tr>
<td>LVH, degenerative conduction disease, coronary heart disease</td>
<td>Cardiomyopathy, pulmonary edema</td>
</tr>
</tbody>
</table>

71 year old man without symptoms. Left bundle branch block.
72 year old man with HTN and previously known ‘1st degree heart block’ presents with acute shortness of breath and orthopnea. Emergent cath?

Yes. A new LBBB with symptoms of an MI is as much of a cardiac emergency as a STEMI.

(This patient’s EF fell from >55% to 15% after the massive MI. He died 2 weeks later.)

81 year old man with shortness of breath. Right bundle branch block.

(Also, inferior ST elevation.)

ST segment

• Strongest predictor of outcomes
• But there are many variants
20 year old man requests a sports physical. Refer to Cardiology for immediate cath?

No, this is early repolarization, not a STEMI.
(Also, sinus arrhythmia.)

58 year old man had "the runs" last week and now has chest pain. Emergent cath?

No.
(He has pericarditis due to an enterovirus.)
77 year old man who had a heart attack 9 years ago, was brought to the ER after feeling faint while visiting a family member in the hospital. He denies chest pain. Should he go straight to the cath lab based on this ECG?

No. These changes are consistent with an old ventricular aneurysm. His ECG 3 years ago...

49 year old man developed sudden chest pain during a colonoscopy. He smokes but denies HTN, DM, high cholesterol, or a family history of heart disease. Emergent cath?

Yes, this is an anterolateral ST elevation MI. (He "smokes" crack cocaine. At cath, he had a 100% occlusive thrombus in the proximal LAD.)
74 year old woman with chest pain. Do you agree with the interpretation?

No, this is an anteroseptal STEMI. Cardiac catheterization revealed a 95% mid-LAD lesion that was successfully stented.

62 year old man with chest pain. What abnormalities do you see?

Inferior ST elevation MI.
(Also, prolonged PR and lateral reciprocal STD.)

54 year old man with chest pain. Why is he worse off than the last patient?

Inferior ST elevation MI with posterior involvement.
(Also, sinus bradycardia, 48 BPM.)
52 year old man with chest pain. What is the diagnosis? Any other helpful tests?

Acute inferior ST elevation MI (leads II, III, aVF) with reciprocal ST depressions in V2-V3.
ST elevation in V1 relative to V2-V3 suggests possible RV involvement, so obtain a right-sided ECG.

Same patient, but right-sided ECG. Is there RV involvement?

Yes. ST elevation in V4R suggests proximal right coronary artery involvement.

52 year old man with chest pain. Acute inferolateral STEMI with possible posterior involvement.
You should obtain a posterior ECG (V7-V9) in the setting of inferior MI with marked ST depressions in V1 and V2.
73 year old man with chest pain and dyspnea.

Acute anterolateral ST elevation MI (remember, you can read ST changes in a RBBB setting!!) (Also, sinus tachycardia, LAFB, RBBB.)

63 year old woman with nausea and vomiting.

Atrial fibrillation.

ST depressions consistent with digoxin toxicity (the patient had digoxin level of 2.1)

Ischemia Pearls

- **ECG findings in acute MI**
  - 51% abnormal ECG but 8% only in posterior (V7-V9) or RV (V3R-V6R) leads
  - 15-18% normal ECG
  - 25% non-specific ECG changes

- **ST depressions can be as important as ST elevations**

- **Left main or triple vessel disease**
  - Sum of ST changes ≥ 18 mm (90% sensitivity)

Am Heart J 2001;141:507-17
... follow-up ECG after resolution of CP.

Urgent cath showed critical 3-vessel disease.
IABP was placed and the patient underwent CABG.

72 year old man with chest pain. NTG SL was given ...

... follow-up ECG after resolution of CP.

Urgent cath showed critical 3-vessel disease.
IABP was placed and the patient underwent CABG.

66 year old man with sudden CP followed by syncope. What is the diagnosis?

Sinus tachycardia with P pulmonale and inferior injury pattern.
However, with the widespread ST depressions (> 7 leads), LM or 3 vessel disease is possible.
Cath revealed severe 3-vessel disease.

66 year old man with sudden CP followed by syncope. What is the diagnosis?

Sinus tachycardia with P pulmonale and inferior injury pattern.
However, with the widespread ST depressions (> 7 leads), LM or 3 vessel disease is possible.
Cath revealed severe 3-vessel disease.

63 year old woman with chest pain. Is there cause for concern?

Sinus rhythm with LVH and ST depressions suggestive of ischemia. The patient was found to have 75% distal left main and 90% ostial LAD disease.
59 year old woman h/o CABG with N/V and diaphoresis. Cath emergently?

Sinus tachycardia and LVH with secondary repolarization abnormality.
Emergent cath was deferred. Serial cardiac biomarkers were negative. Elective cath revealed no culprit CAD.

Ischemia

- **LAD distribution (V2-V5, aVL, V1, V6)**
  - Proximal LAD
    - ST elevation in aVL
    - ST depression in II, III, and aVF
    - Isolated ST depression in aVF (85% sensitivity)
  - Distal LAD
    - ST elevation in V2 < 3.2 mm
    - Slight/moderate ST elevation in V3
    - Tall R wave in V2
    - New Q waves in V4-V6
  - 1st Septal Perforator
    - ST elevation in aVR (43% sensitivity, 95% specificity)
    - Loss of lateral Q waves (50% sensitivity, 84% specificity)
    - ST depression in V5 (17% sensitivity, 99% specificity)
    - RBBB (14% sensitivity, 100% specificity)
    - ST elevation in V3-V4 (correlates with septal hypokinesis)
  - D1
    - ST elevation in I and aVL
    - ST elevation in anterior leads and aVL
    - ST elevation in V2 and aVL + ST depression in III, aVF, and V4

- **LCX distribution (II, III, aVF, VS, V6, aVL)**
  - ST elevation is present in < 50% of LCX occlusions
  - ST depression in V1-V2 (without this, less than 10% LCX disease)
  - Maximal ST depression in V2-V3 (85% sensitivity, 70% specificity)
  - ST elevation in V7-V9 (80% sensitivity, 84% specificity)
  - ST depression in V4R

- **OM distribution**
  - ST depression in V2

Am Heart J 2001;141:507-17
Ischemia

- RCA distribution (II, III, aVF)
  - ST elevation in III more than II
  - ST depression in aVL (94% sensitivity, 71% specificity)
  - Ratio of ST depression in V3 to ST elevation III < 0.5

- RV infarction
  - ST elevation in V4R (93% sensitivity, 93% specificity)
  - ST elevation in V1
  - ST elevation in II, III, aVF, and V1 with ST depression in V2
  - Support hypotension with volume
  - Monitor for high risk of high-grade AV block
  - Avoid nitrates if possible

LBBB – scoring system for detecting ischemia in LBBB

<table>
<thead>
<tr>
<th>Condition</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST elevation ≥ 1 mm in leads with positive QRS</td>
<td>5</td>
</tr>
<tr>
<td>ST elevation ≥ 5 mm in leads with negative QRS</td>
<td>2</td>
</tr>
<tr>
<td>ST depression ≥ 1 mm in V1-V3</td>
<td>3</td>
</tr>
</tbody>
</table>

Score ≥ 2 = 80% specificity
Score ≥ 3 = 90% specificity

29 year old man with cough.

Sinus bradycardia with early repolarization (not acute MI).
### T waves

- **Normal**
  - Upright: I, II, V3-6
  - Inverted: aVR, V1

- **Tall T waves**
  - Acute MI, hyperkalemia, LVH, anemia, CNS disorder, or normal

- **Ischemic T waves**
  - Biphasic T in V1-4 without symptoms suggests proximal LAD lesion
  - Deep symmetrically inverted T in V1-6 suggests LAD lesion (Wellens)

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**55 year old man with stuttering chest pain.**

Anterior lead T wave inversions (Wellens waves), consistent with recent ischemic event.

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**43 year old man on HIV medications with progressive fatigue, including when he walked from the parking lot to your office.**

His symptoms resolved while waiting and he feels fine right now. Urgent cath?

Yes. Biphasic TWI in anterior leads (Wellens waves), often appearing between episodes of chest pain, suggest proximal LAD disease. (He had a 95% proximal LAD lesion at cath.)
38 year old man with fatigue, swelling, and decreased urine output. **Hyperkalemia (6.4)**

A 62 year old woman with chest pain. What is the differential diagnosis?

Although a recent ischemic event jumps to mind, other causes of T wave abnormalities include cerebral injury. This patient’s ECG is the result of familial apical ventricular hypertrophy. Note the exaggerated QRS voltage.

A 42 year old woman who skipped dialysis for a week.

Severe hyperkalemia with QRS widening, QT prolongation, and markedly peaked T waves. Her potassium was 7.4.
QT interval

• QTc = QT divided by the square root of RR
  – Normal QTc = 0.30 to 0.44
  – (in general, less than ½ between RR interval)
• Long QT: hypocalcemia, hypomagnesemia, hypothermia, drugs, CVA, hypothyroidism, bradycardia
  – Hypocalcemia causes prolonged ST segment with normal T
• Short QT: hypercalcemia, hyperkalemia, digitalis, acidosis, hyperthyroidism, hyperthermia

44 year old woman with diabetic ketoacidosis, started on an insulin drip.

Sinus tachycardia with prolonged QT interval suggestive of a metabolic disturbance such as hypokalemia.
The patient’s K was 2.9.

Wide complex tachycardia

• Brugada criteria for VT (any one the following is suggestive of VT):
  – Absence of RS in prechordal leads
  – If RS present, R to nadir of S > 100 ms
  – AV dissociation or fusion beat
  – Morphologic features:
    - RBBB pattern: Monophasic R or qR/qR in V1
    - LBBB pattern: Notched S > 60 ms or R > 30 ms in V1
      - qR/qS in V6
• Other things that favor VT:
  – QRS > 0.14 sec (especially in V1-positive tachycardia)
  – Abnormal axis (especially -90 to -180)
  – Capture/fusion beats
  – Concordant preordial pattern (especially negative in V1-6)
28 year old man with palpitations and dyspnea. What is the next step?

Defibrillation (200J, 300J, 360J).

(Ventricular tachycardia in a patient with Emery-Dreifuss muscular dystrophy.)

“ Weird stuff ”

- Reversal of leads
  - Left arm and right arm
    - Menics dehiscence in limb leads (inverted P-QRS-T in I and aVL)
    - Leads II and III transposed
    - Leads aVR and aVL transposed
  - Left arm and left leg
    - Leads I and II transposed
    - Leads aVF and aVL transposed
    - Lead III inverted
  - Right arm and left leg
    - Leads I, II, and III inverted
    - Leads aVR and aVF transposed

- Tremor artifacts
  - Physiologic tremor (e.g. shivering) = 500 per minute
  - Parkinson’s tremor = 300 per minute
39 year old man found down.

Sinus bradycardia (40 BPM) with Osborne waves characteristic of severe hypothermia. The patient’s temperature was 25 degrees Celsius!

39 year old woman with pre-syncope. What is the rhythm?

Isorhythmic dissociation. Note that the QRS complexes are slightly more regular than the P waves.
Electronic atrial and ventricular pacemaker with evidence of sense and capture.

Also, one PVC — can you find it?

17 year old woman without symptoms. What abnormalities do you see?

Short PR interval with a delta wave.

(Wolff-Parkinson-White syndrome)
59 year old man with palpitations. What major abnormality is present?
Ventricular pre-excitation (Wolff-Parkinson-White), Type A pattern.

60 year old man is short of breath and has edema. What is the rhythm and why?
Sinus rhythm, 92 BPM, with a second set of non-conducted P waves from an atrial remnant.
(The patient is status post heart transplantation.)

66 year old woman with chest pressure and abnormal troponin.
Sinus rhythm with S1, QIII, TIII, and anterior T wave inversions.
Cardiac cath revealed no significant CAD.
CT revealed massive PE.
25 year old man struck by lightning. What abnormalities do you see?

Inferior ST elevations suggestive of RCA infarct or spasm. Note the severe T wave inversion, suggestive of pericardial friction versus atrial injury. In addition, there is left posterior fascicular block.

60 year old woman for pre-operative evaluation. What is the diagnosis?

Dextrocardia. A right-sided ECG was performed…

Same patient, right-sided ECG.
A 70-year-old woman had an episode of chest pain. Can you predict the lesion?

99% mid-LAD.

Final thoughts
• ECGs provide valuable information but often require clinical context
• ECG interpretation is challenging but many rules can help guide you
• Recognition of important patterns can provide immediate clinical diagnostic value (esp. rhythms/blocks and ST/T changes)

Objectives
• Review the basics of interpreting electrocardiograms (ECG)
• Review important ECG abnormalities and their clinical implications
• Identify high risk findings that should prompt further evaluation
• Identify high risk findings that warrant urgent/emergent evaluation