Introduction to Clinical Electrocardiography

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Electrocardiography

- The heart is an electrical organ, and its activity can be measured non-invasively
- Wealth of information related to:
  - The electrical patterns proper
  - The geometry of the heart tissue
  - The metabolic state of the heart
- Standard tool used in a wide-range of medical evaluations
A heart

- Blood circulates, passing near every cell in the body, driven by this pump
- …actually, two pumps…
- Atria = turbochargers
- Myocardium = muscle
- Mechanical systole
- Electrical systole
To understand the ECG:

- Electrophysiology of a single cell
- How a wave of electrical current propagates through myocardium
- Specific structures of the heart through which the electrical wave travels
- How that leads to a measurable signal on the surface of the body
Part I: A little electrophysiology
Once upon a time, there was a cell:
Intracellular millivoltage

-90

Resting comfortably

- a myocyte

time

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Intracellular millivoltage

Depolarizing trigger

time
Intracellular millivoltage

Na channels open, briefly

<table>
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|                            | time
Intracellular millivoltage

In: Na+

Mystery current

time
Intracellular millivoltage

In: Na+

Ca++ is in balance with K+ out

time
Excitation/Contraction Coupling:
Ca++ causes the Troponin Complex (C, I & T) to release inhibition of Actin & Myosin
Intracellular

In: Na+

Ca++ in; K+ out

More K+ out;
Ca++ flow halts

time

Intracellular millivoltage

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Intracellular millivoltage

- In: Na+; Out: K+
- In: Ca++; Out: K+
- Sodium channels reset

Time
Higher resting potential → Few sodium channels reset → Slower upstroke
Intracellular millivoltage

-55

Slow current of Na+ in; note the resting potential is less negative in a pacemaker cell.
a pacemaker cell

Threshold voltage

-40

Intracellular millivoltage

time
Intracellular millivoltage

Ca++ flows in

time
... and K+ flows out
... and when it is negative again, a few Na+ channels open.
How a wave of electrical current propagates through myocardium

- Typically, an impulse originating anywhere in the myocardium will propagate throughout the heart
- Cells communicate electrically via “gap junctions”
- Behaves as a “syncytium”
- Think of the “wave” at a football game!
The dipole field due to current flow in a myocardial cell at the advancing front of depolarization. 

$V_m$ is the transmembrane potential.

Cardiac Electrical Activity

SA node (Pacemaker)
AV node (delay)
AV bundle & branches (Insulated)
Purkinje fibers (Activation)
Fibro-fatty atroventricular groove (Separates atrial and ventricular tissue)

Contractile
Conductive
Nonconductive

Figure by MIT OpenCourseWare.
Important specific structures

- Sino-atrial node = pacemaker (usually)
- Atria
- After electrical excitation: contraction
- Atrioventricular node (a tactical pause)
- Ventricular conducting fibers (freeways)
- Ventricular myocardium (surface roads)
- After electrical excitation: contraction
The Idealized Spherical Torso with the Centrally Located Cardiac Source (Simple dipole model)

Excitation of the Heart

Figure by MIT OpenCourseWare. After F. Netter.
Excitation of the Heart

Figure by MIT OpenCourseWare. After F. Netter.
The location of these leads is as follows:

V₁: on the fourth intercostal space at the right sternal margin

V₂: on the fourth intercostal space at the left sternal margin

V₃: midway between leads V₂ and V₄

V₄: on the fifth intercostal space at the midclavicular line

V₅: on the anterior axillary line at the horizontal level of lead V₄

V₆: on the midaxillary line at the horizontal level of lead V₄
Figure 4 — Frontal Plane Limb Leads

Figure by MIT OpenCourseWare.
The temporal pattern of the heart vector combined with the geometry of the standard frontal plane limb leads.
Cardiac Electrical Activity

SA node
(Pacemaker)

AV node
(delay)

AV bundle & branches
(Insulated)

Fibro-fatty atrioventricular groove
(Separates atrial and ventricular tissue)

Purkinje fibers
(Activation)

SA node

AV node

Bundle of His

Left and Right Bundle branches

Fibro-fatty atrioventricular groove

Contractile
Conductive
Nonconductive

SA node

Atrial Muscle

AV node

AV Bundle

Purkinje Fibers

SA node (Pacemaker)

AV node (delay)

AV bundle & branches (Insulated)

Fibro-fatty atrioventricular groove (Separates atrial and ventricular tissue)

Purkinje fibers (Activation)

Figure by MIT OpenCourseWare.

Normal features of the electrocardiogram.


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Normal sinus rhythm

Figure 15 - Normal Sinus Rhythm—Rate 85

Figure by MIT OpenCourseWare.
What has changed?

Figure 16 - Sinus Tachycardia—Rate 122

Figure by MIT OpenCourseWare.
Sinus bradycardia

Figure 17 - Sinus Bradycardia—Rate 48

Figure by MIT OpenCourseWare.
Neurohumeral factors

Vagal stimulation makes the resting potential MORE NEGATIVE...
Intracellular millivoltage

Neurohumeral factors

... and the pacemaker current SLOWER...
... and raise the **THRESHOLD**
Catecholamines make the resting potential MORE EXCITED...
Intracellular millivoltage

... and speed the PACEMAKER CURRENT...
... and lower the THRESHOLD FOR DISCHARGE...
Vagal Stimulation:

Intracellular millivoltage

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| time |

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Vagal Stimulation: Ricardo Montelban Effect
Intracellular millivoltage

Adrenergic Stim. =
Intracellular millivoltage

Adrenergic Stim. = Potsy Effect

Image removed due to copyright restrictions. Photo of characters from TV show “Happy Days,” including Potsy.
Sinus arrhythmia

Figure 18 - Sinus Arrhythmia

Figure by MIT OpenCourseWare.
Atrial premature contractions
(see arrowheads)

Figure 25 - Atrial Premature Contractions

Figure by MIT OpenCourseWare.
Arrhythmias

- Not firing when you should
- Firing when you shouldn't
- All of the above (Reentrance)
Firing when you shouldn't

- Usually just a spark; rarely sufficient for an explosion
- "Leakiness" leads to pacemaker-like current
- Early after-depolarization
- Late after-depolarization
What’s going on here?

Figure 36 - Ventricular Premature Contractions

Figure by MIT OpenCourseWare.
Wave-front Trajectory in a Ventricular Premature Contraction.
Is this the same thing?

Figure 24 - Ventricular Escape Beat

Figure by MIT OpenCourseWare.
What’s going on here?

Figure 50 - Complete A-V Block with Junctional Escape Rhythm

Figure by MIT OpenCourseWare.
What’s going on here?

Figure 35 - Atrial Fibrillation (2 examples)

Figure by MIT OpenCourseWare.
Non-sustained ventricular tachycardia (3 episodes)

Figure 43 - Short Bursts of Ventricular Tachycardia

Figure by MIT OpenCourseWare.
KeyWords:
Heterogeneous, Circus, Self-Perpetuating
Re-entry

Side “A”  Side “B”

KeyWords:
Heterogeneous, Circus, Self-Perpetuating

No Longer Refractory
Re-entry

KeyWords:
Heterogeneous, Circus, Self-Perpetuating
KeyWords:
Heterogeneous, Circus, Self-Perpetuating

Side “A”

Side “B”

Re-entry
KeyWords:
Heterogeneous, Circus, Self-Perpetuating
KeyWords:
Heterogeneous, Circus, Self-Perpetuating
Timing is Everything

Side “A”

Side “B”

INCREASED Refractory
Timing is Everything

Side “A”

INCREASED Refractory

Side “B”
Timing is Everything

Side “A”

INCREASED Refractory

Side “B”
Timing is Everything

Side “A”

Side “B”

INCREASED Refractory
Timing is Everywhere

INCREASED Refractory

Side “A”  Side “B”
Timing is Everything

INCREASED Refractory

Side “A” Side “B”
Ventricular Fibrillation

Figure 45 - Three Examples of Ventricular Fibrillation

Figure by MIT OpenCourseWare.
Re-Entry-A-Go-Go:

V-Fib

Phase I Undulatory (1-2 sec)
Re-Entry-A-Go-Go:

V-Fib Phase II Convulsive (10-30 sec)
Re-Entry-A-Go-Go:

V-Fib

Phase III Tremulous (minutes)
Re-Entry-A-Go-Go:

V-Fib Phase II Convulsive
(10 - 30 sec)
Heart attack
Frontal Plane Limb Leads

Figure by MIT OpenCourseWare.
The location of these leads is as follows:

$V_1$: on the fourth intercostal space at the right sternal margin

$V_2$: on the fourth intercostal space at the left sternal margin

$V_3$: midway between leads $V_2$ and $V_4$

$V_4$: on the fifth intercostal space at the midclavicular line

$V_5$: on the anterior axillary line at the horizontal level of lead $V_4$

$V_6$: on the midaxillary line at the horizontal level of lead $V_4$
Heart attack
Hyperkalemia

See ECG Wave-Maven (http://ecg.bidmc.harvard.edu/maven/mavenmain.asp) for many other examples of how metabolic conditions can affect the ECG.

Courtesy of Ary Goldberger, M.D. Used with permission.

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Understanding the ECG: A Cautionary Note

- Basic cell electrophysiology, wavefront propagation model, dipole model: Powerful, but incomplete
- There will always be electrophysiologic phenomena which will not conform with these explanatory models
- Examples:
  - metabolic disturbances
  - anti-arrhythmic medications
  - need for 12-lead ECG to record a 3-D phenomenon
Questions?