The Electrocardiogram and Other Matters of the Heart

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EID 424
Bioengineering Applications in Sports Medicine
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1

Overview

- The heart: an introduction
  - Anatomy
  - Physiology
- EKG historical background
- The 12-lead EKG
  - Easy detection of bad heart mojo
  - Verrrrry clinical
    - Interpretation

2

The Cardiovascular System

- The heart
  - Pumps the blood
- The lungs
  - Oxygenate the blood
- Arteries
  - Carry blood away from heart
  - Deliver oxygen-rich blood (almost always)
- Capillaries
  - Gas exchange
  - Huge surface area
- Veins
  - Carry blood back to heart
  - Return of blood carrying CO_2 (almost always)
- Pulmonary artery/vein are exceptions

3

The Heart

- 4 chambers
  - Right/left atria (upper chambers)
  - Right/left ventricles (lower chambers)
- Valves
  - Tricuspid, mitral, pulmonary, aortic
  - Keep blood from backing up
- Special conduction system
  - SA, AV nodes
  - Purkinje fibers

4

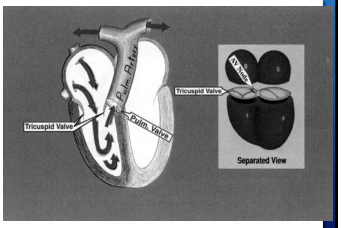
Flow of Blood Through the Heart

- From body circulation, enters right atrium
- Through tricuspid valve into right ventricle
- Through pulmonary valve into pulmonary artery
  - To lungs
- From lungs, enter left atrium
- Through mitral valve into left ventricle
- Ejected through aortic valve into aorta and body circulation

5

Follow the Blood Through the Heart

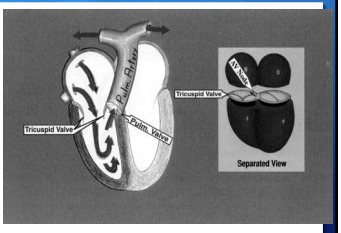
- Enters right atrium from general circulation
  - Flows gradually through tricuspid valve into right ventricle
- Atrium contracts
  - Forces more blood into right ventricle
- Right ventricle now filled with oxygen-poor blood



6

Follow the Blood Through the Heart

- Ventricle contracts
  - Pressure builds, tricuspid valve closes
    - Blood cannot flow back into right atrium
- Blood forced out of right ventricle into pulmonary artery
  - Carries blood to lungs for gas exchange
  - Oxygen-rich blood returns to heart via pulmonary vein



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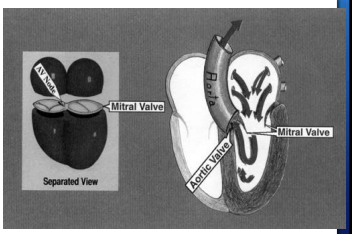
Follow the Blood Through the Heart

- Oxygen-rich blood enters left atrium
  - Flows gradually through mitral valve into left ventricle
- Atrium contracts
  - Forces more blood into left ventricle
- Left ventricle now filled with oxygen-rich blood



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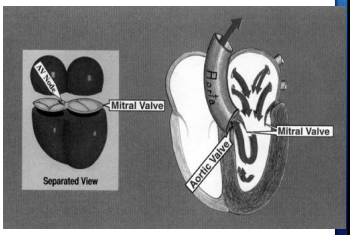
Follow the Blood Through the Heart

- Ventricle contracts
  - Pressure builds, mitral valve closes
    - Blood cannot flow back into left atrium
- Blood forced out of left ventricle into aorta
  - Distributed to general circulation



9

Circulation Notes

- Right/left atrium contract simultaneously
- Right/left ventricle contract simultaneously
- Contraction of ventricle: systole
- Relaxation of ventricle: diastole
- Opening and closing of valves creates heart sounds heard with stethoscope

10

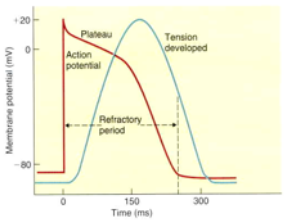
? ? ?

- The wall of the left ventricle is significantly thicker than that of the right ventricle
- Why?

11

Cardiac Action Potential

- Longer (100x) than skeletal muscle
  - After entry of Na+, opening of K+ channels is delayed
  - Before opening, exit of K+ offset by influx of Ca++
    - Plateau
- Long refractory period
  - Always twitches
    - No tetanic contractions
  - Allows relaxation so heart can fill with blood



12

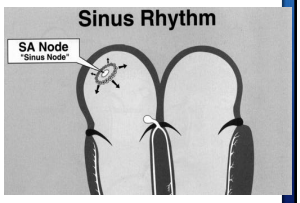
Electrical Properties of Cardiac Tissue

- Similar to skeletal muscle
- Unlike skeletal muscle, parts are self-exciting
  - Automaticity foci
  - Pacemakers
- Atria and ventricles insulated from each other
  - Contract in sequence
  - Except at *AV node*

13

AP Propagation Through the Heart

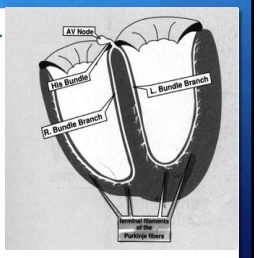
- Starts at sinus node (SA node)
  - Pacemaker for the heart
- Propagates along atrium
  - Atrium contracts
- Arrives at atrio-ventricular node (AV node)
  - Depolarization slows
    - .04 sec from SA node to AV node
    - .11 sec to leave AV node
    - Time for atria to finish contracting before ventricles



14

AP Propagation Through the Heart

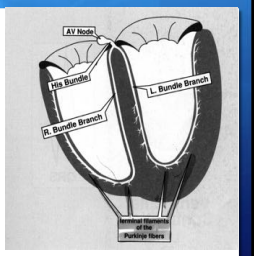
- Special conduction network allows for fast propagation of AP from AV node through ventricles
  - His bundle
  - Left/right bundle branches
    - Purkinje fibers
- Fast conduction system allows coordinated ventricular contraction



15

Pacemaker Backups

- Multiple automaticity foci can act as pacemakers
  - SA node
  - Several locations in atria
  - AV junction
    - Middle and distal parts of AV node
  - Purkinje fibers
    - Ventricular automaticity foci



16

Pacemaker Backups

- Faster pacemaker suppresses slower pacemakers
  - *Overdrive suppression*
- Each potential pacemaker has preferred (*inherent*) rate
  - SA node: 60-100 bpm
  - Atrial: 60-80 bpm
  - AV junction: 40-60 bpm
  - Ventricular: 20-40 bpm
    - Watch for syncope (passing out)!
    - Monitor and maintain airway!

17

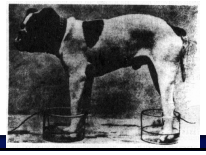
EKG Prehistory

- Kolliker and Mueller, 1856
  - Rheoscopic frog
  - Lay motor nerve of frog leg over ventricle of beating heart
  - Leg twitched
    - Stimulated by de-/repolarization of ventricles

18

EKG Prehistory

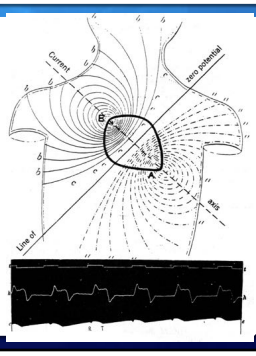
- Waller, 1880's
  - Recorded EKG from "Jimmy" by putting feet in glasses containing saline and metal electrodes
    - His dog
  - Obtained first EKGs from humans in 1887 using capillary electrometer
    - Proposed heart could be represented as a dipole using various recording sites



19

EKG Prehistory

- Waller's recordings, potential maps



20

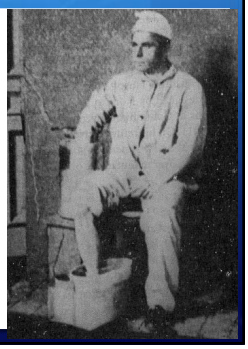
Willem Einthoven

- First proper EKG
  - Dutch, hence *electrokardiogram*
- Connected silvered wire though holes in poles of permanent magnet
- Two electrodes placed on skin attached to either end of wire
  - Wire twitched with heartbeat
- Recorded by projecting light beam across wire onto scroll of moving photographic paper

21

Einthoven's EKG

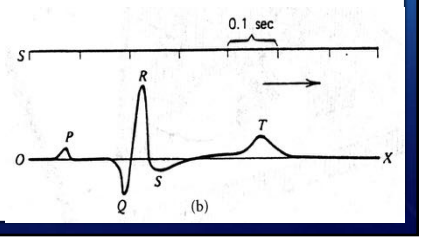
- Electrodes on each limb
  - Saline-filled buckets
- Only negligibly-altered if right foot not used
  - Why?



22

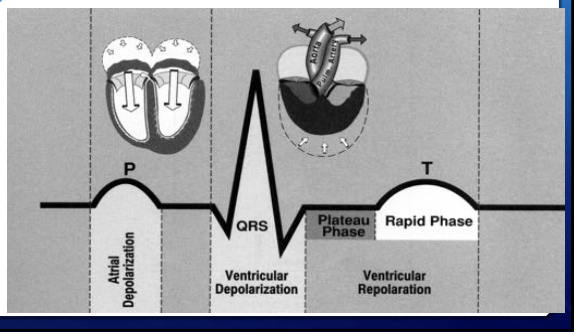
Einthoven's EKG

- Labeled each deflection with a letter
  - P wave
  - QRS complex
  - T wave



23

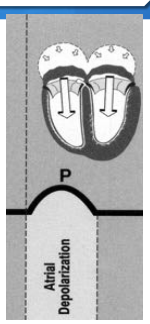
Elements of the Heartbeat Seen on EKG



24

Atrial Depolarization

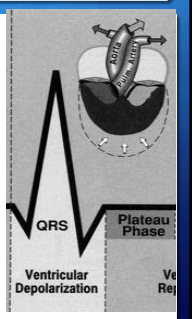
- P wave
- Contraction of atria
  - In reality, longer than P wave
  - Close enough
- Time between P and QRS because depolarization slows in AV node



25

Ventricular Depolarization

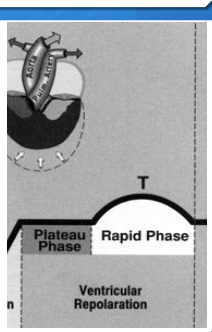
- QRS complex
  - R is always *first positive deflection after P*
  - Q often not there
- Large voltages
  - Lots of ventricular tissue



26

Ventricular Repolarization

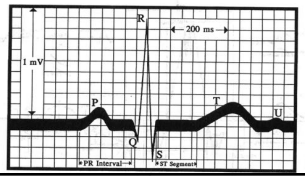
- T wave
- ST segment plateau very important
- Ventricular contraction starts with QRS and ends at end of T
  - QT interval



27

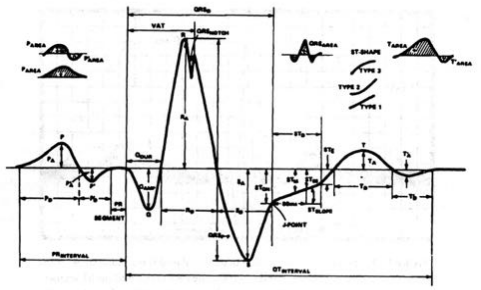
The Occasional U Wave

- U comes after T
  - Duh
- Seen sometimes
- Repolarization of Purkinje fibers
  - Delayed for some reason
  - Hypokalemia
  - Hypercalcemia



28

How Many Measurements Can You Come Up With?



29

EKG Signal Characteristics

- ±2 mV
- 0.05-150 Hz
  - Low frequency response of instrumentation *vital*
    - ST segment
- Instruments must be able to withstand defibrillator
- Can time-average multiple signals to reduce noise, find low-level signals

30

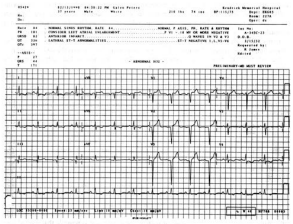
Traditional EKG

- Printed on graph paper
  - 1-mm squares
  - 10 mm = 1 mV (vertical scale)
    - People often refer to mm rather than mV
  - 25 mm = 1 sec (horizontal scale)
  - Every medical resident has a pair of dividers
- DON'T MESS WITH THE PAPER

31

The 12-Lead EKG

- 12 signals, not 12 electrodes
- Historically-based
  - Same since 1930s
- Redundant
- Maybe not optimal
- *Huge* database, great deal of experience
  - MIT-BIH databases
    - http://ecg.mit.edu
    - Normal rhythms
    - Arrhythmia
    - More!



32

The 12-Lead EKG

- 12 leads provide different viewpoints of depolarization of the heart
  - Viewing object from different angles
- Some pathology clearly seen in certain leads and not in others
- Redundancy can aid in confirming diagnosis

33

Note

- 12 leads contain lots of redundancy
  - Some of us are gEEks
  - This *begs for signal processing*

34

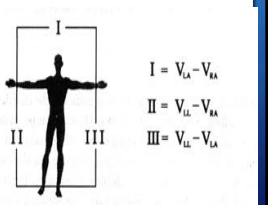
Skin Prep

- Just like EMG
  - Shave if necessary
  - Abrade skin
  - Clean with alcohol

35

Limb Leads

- Described by Einthoven
- Electrodes on
  - Right arm
  - Left arm
  - Left leg
- I = $V_{LA} - V_{RA}$
- II = $V_{LL} - V_{RA}$
- III = $V_{LL} - V_{LA}$
  - Note: II = I + III



$I = V_{LA} - V_{RA}$

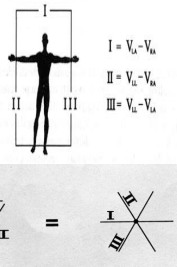
$II = V_{LL} - V_{RA}$

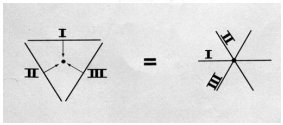
$III = V_{LL} - V_{LA}$

36

Limb Leads

- Form *Einthoven's Triangle*
  - Equally-spaced lines joining electrodes
  - Keep track of which end is positive
  - This becomes interesting and useful shortly

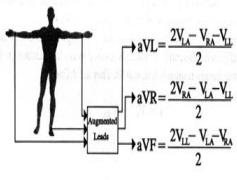




37

Augmented Limb Leads

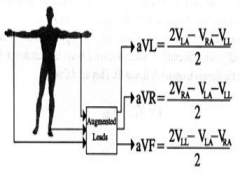
- Introduced by Goldberger
- Uses pair of electrodes as common ground
- Each is a mix of two other leads
- Had to be amplified to be comparable voltage to traditional limb leads



38

Augmented Limb Leads

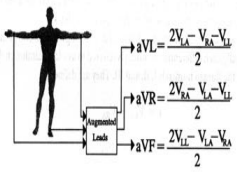
- aVL
  - *A*ugmented *V*oltage, *L*eft arm
  - Uses right arm, left foot as common ground
  - Combination of I and III



39

Augmented Limb Leads

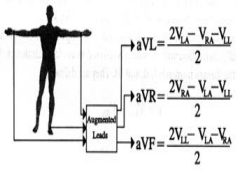
- aVR
  - *A*ugmented *V*oltage, *R*ight arm
  - Uses left arm, left leg as common ground
  - Combination of I and II



40

Augmented Limb Leads

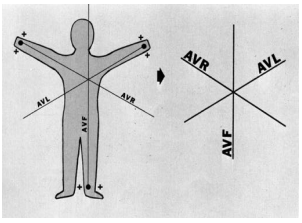
- aVF
  - *A*ugmented *V*oltage, *F*oot
  - Uses arms as common ground
  - Combination of II and III



41

Augmented Limb Leads

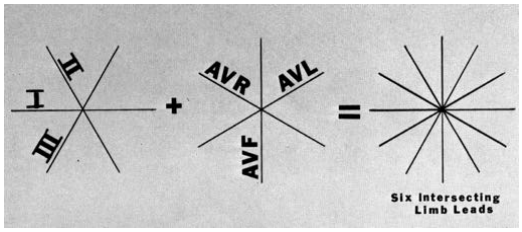
- Form three different equally-spaced vectors than traditional limb leads



42

Limb Lead Vectors

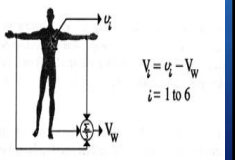
- Form six reference lines in frontal plane



43

Chest Leads

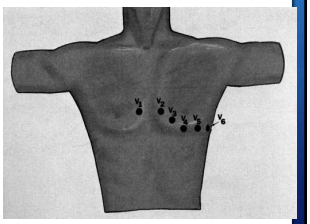
- Introduced by Wilson
  - Dennis wasn't bothering him a lot that day [quiet laughter now is appropriate and polite]
- V1-V6
  - Also known as *precordial leads*
- Use average of limb electrodes as reference
  - *Wilson terminal*



44

Chest Leads

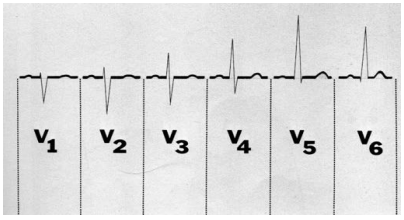
- V1, V2
  - Over right side of heart
- V5, V6
  - Over left side of heart
- V3, V4
  - Over interventricular septum
    - Thick wall dividing left from right ventricles



45

Chest Leads

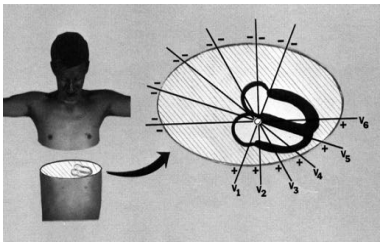
- Progressive changes in chest leads
  - V1: QRS mainly negative
  - V6: QRS mainly positive



46

Chest Leads

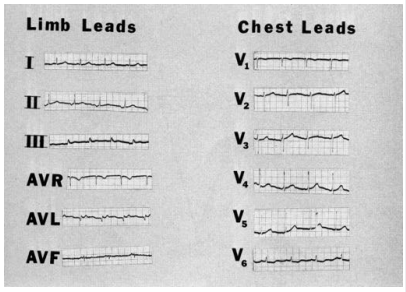
- Form vectors in horizontal plane



47

Diagnostic Stuff

- Heart rate
- Bad rhythms
- Use of axes
- Hypertrophy
- Infarction



48

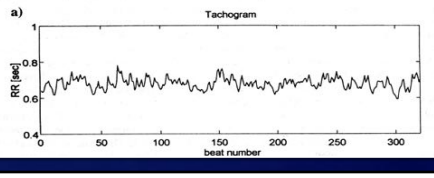
Heart Rate

- Low: *bradycardia*
- High: *tachycardia*
- Sinus rhythm generated by SA node
  - Typically 60-100 bpm
  - Lower in exercise-trained people
  - Higher during exercise
- Figure out using R wave-R wave distance
  - Count squares
  - *R-R interval*

49

Heart Rate Variability

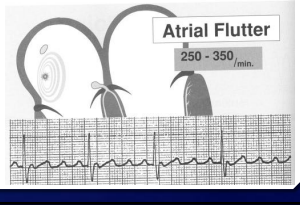
- Necessary!
  - Action of autonomic nervous system
- Lack of variability indicative of pathology
  - Some sports med literature suggests lack related to incomplete recovery/burnout



50

Rhythm

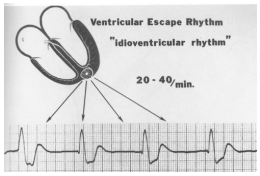
- Normally, constant rhythm
  - Constant, small variation
- Irregular rhythms caused by multiple active pacemakers
  - Atrial flutter
    - Irritable atrial pacemaker
    - Multiple P waves



51

Escape Rhythms

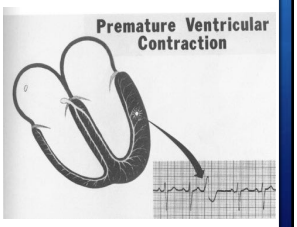
- Pacemaker escapes overdrive suppression and starts to pace
- Look at rate to determine what may be pacing
- Junctional pacemaker may cause retrograde atrial depolarization
  - Inverted P wave



52

Escape Beats

- Pacemaker escapes overdrive suppression for a beat
  - Irritable pacemaker
  - Caffeine, hyperthyroid, adrenaline, digitalis, etc
- *Premature ventricular contraction* (PVC)
  - Ventricle not completely filled
  - Very wide, because conduction system not used effectively
  - Careful if it happens on a T wave!



53

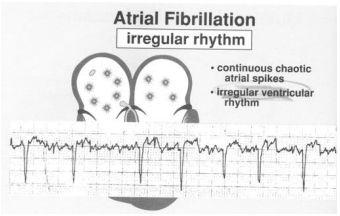
Fibrillation

- Multiple pacemakers discharging rapidly, continuously

54

Atrial Fibrillation

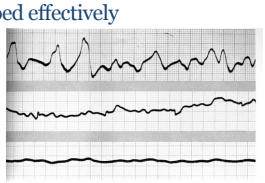
- Many irritable atrial pacemakers firing
- Atria never fully depolarize
- No real P wave
  - "Thick" baseline?
- Irregular ventricular rhythm



55

Ventricular Fibrillation

- Rapid discharge from many ventricular foci
  - Totally erratic EKG
- Ventricle only twitches, never fully contracts
  - "Bag of worms"
- Blood is not pumped effectively
- Nice knowing you



56

External Defibrillators

- 3-10 msec pulse
- Few thousand volts
- Tens of amps
- Not during T wave!
  - May induce VFib

57

External Defibrillators

- TV is bullshit!
  - A flat line cannot be shocked
    - "You can't shock asystole!" –my ex
    - Push the drugs!
  - Defibrillators attempt to *restore [convert]* normal rhythm from abnormal rhythm
  - *Cardioversion*

58

Implantable Defibrillators

- Same principal as external
- Implanted in heart
- Detects abnormal rhythm, immediately tries to convert it
  - *Sucks* if it guesses something normal is abnormal and you're awake
    - Not too great even if it guesses correctly but you're awake

59

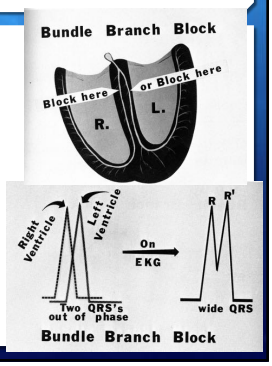
Heart Blocks

- Pacing does not propagate correctly
  - Nodes
  - Bundle branches

60

Bundle Branch Block

- Left or right side blocked
- One ventricle depolarizes later than the other
  - R appears as a doublet



61

Myocardial Infarction

- Heart attack
- Blockage of flow in coronary artery
  - Supplies blood (oxygen) to the heart itself
  - Ischemia
  - Take an aspirin
    - Thins blood
- Part of heart muscle dies
  - Less tissue to pump blood
- Can irritate ventricular pacemakers
  - Bad arrhythmia
- Changes easily seen on EKG
- More often refers to left ventricular infarction

62

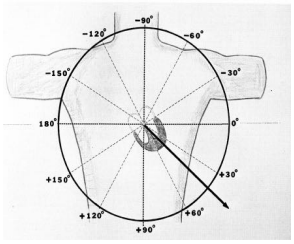
Myocardial Infarction

- Ischemia
  - Indicated by inverted T waves
- Diagnosed by *significant* Q waves
  - At least 1 mm wide (.04 sec)
  - At least one third of entire QRS amplitude

63

Using Axes

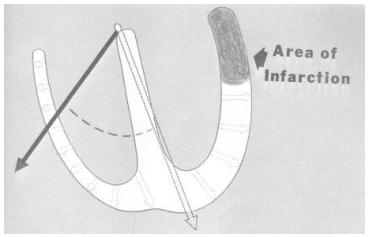
- Mean QRS vector
  - Add up all small vectors of ventricular depolarization
  - Points down and to the patient's left
    - Why?



64

Effect of Infarction

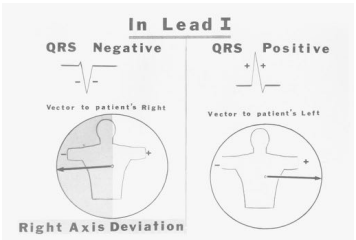
- Dead tissue not electrically active



65

Determination of Mean QRS Vector

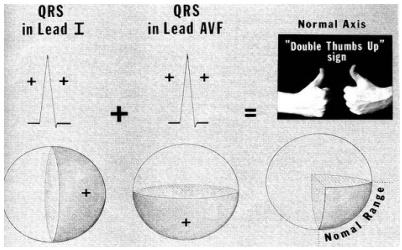
- Use lead I...



66

Determination of Mean QRS Vector

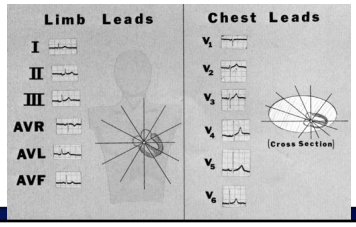
- ...and aVF



67

More with Vectors...

- V1...V6 determine vectors in horizontal plane
- Can also look at T wave vector
  - If T wave vector and QRS vector more than 60° out of phase, there may be a problem



68

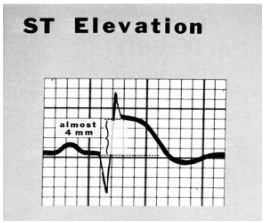
Vector Caveats

- Know your patient!
  - Obese patients may have heart rotated
    - Pushed up by diaphragm
  - Anatomical differences
    - Different orientation
    - Heart on wrong side
      - *Dextrocardia*
    - Mirrored inside (!)
      - *Situs inversus*
      - 1/10,000

69

ST Elevation

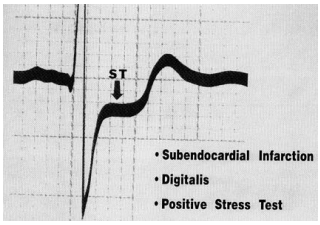
- ST segment higher than baseline
- Indicative of recent infarction



70

ST Depression

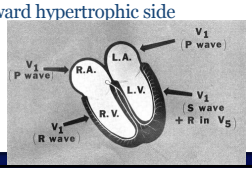
- ST segment below baseline
  - Angina (diminished coronary artery flow)
  - Often detected via stress test



71

Hypertrophy

- Thickening of chambers of heart
- Can be indicative of pathology
  - Right ventricular hypertrophy may indicate blockage in pulmonary artery
- Most info from lead V1
- Vectors turn toward hypertrophic side



72

Athletes' Heart

- With exercise training, hypertrophy can occur naturally
  - Many athletes exhibit left ventricular hypertrophy
  - Normal finding
  - Regular (smooth) thickening
  - Ventricular cavity also enlarged
  - Goes away with cessation of training
- Know your patient
  - History, history, history!

73

Hypertrophic Cardiomyopathy

- Thickening of septum of heart
  - Wall dividing left/right
- Interferes with proper blood flow
  - Syncope, dizziness with exertion
  - One of the most common causes of sudden death in young athletes
- Echocardiogram required for diagnosis
  - Irregular thickening
  - Ventricular cavity not enlarged
  - Does not change with cessation of exercise
- Inherited trait

74

Hypertrophic Cardiomyopathy

- *Competitive sport prohibited!!!!*
- See:
  - Hank Gathers (RIP)
  - Reggie Lewis (RIP)
  - Eddy Curry (???)
- ***Must differentiate from physiologic ventricular hypertrophy!***

75

Learn to Use EKG

- Dubin D, *Rapid Interpretation of EKG's, 5th ed, Cover Publishing, 1996.*
- He went to jail:
  - Reasons to be discussed…

76