BENG 186B: Principles of Bioinstrumentation Design

Lecture 11

Biopotential Amplifiers: the Electrocardiogram

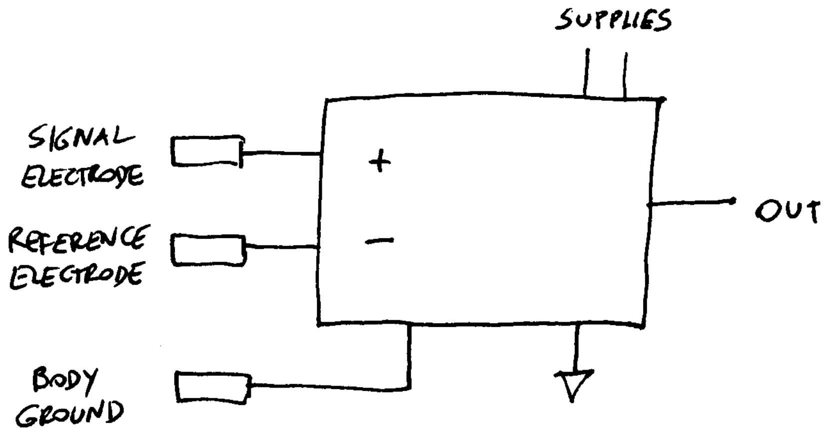
References

Webster, Ch. 6 (Sec. 6.1-6.2) and Ch. 4 (Sec. 4.6 Review).

http://en.wikipedia.org/wiki/ECG

BIOPOTENTIAL AMPLIFIERS

Chap. 6



(possibly driven)

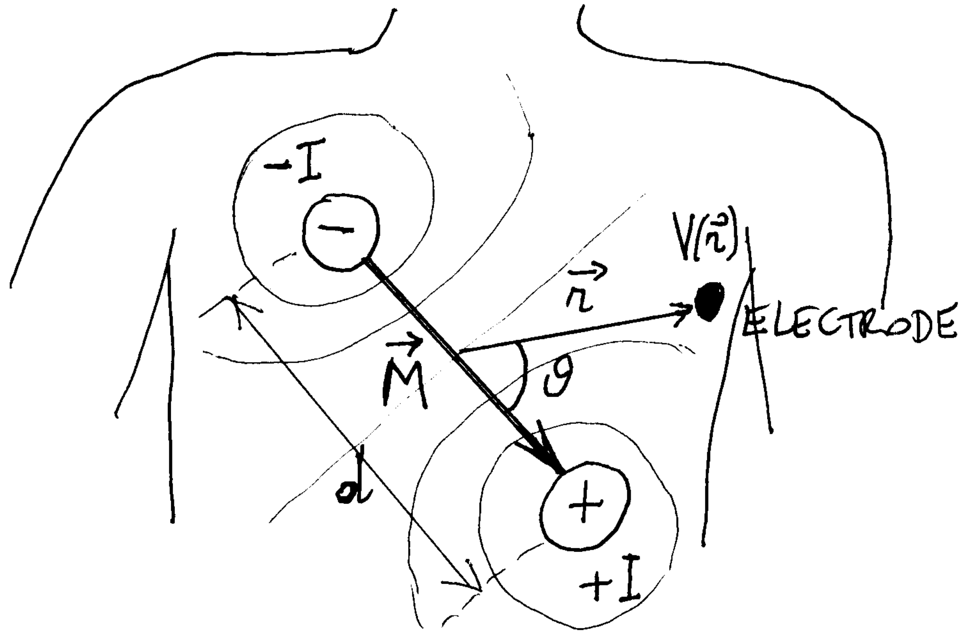
Requirements:

- high gain (differential)
- high input impedance
- input protection (→ input diodes)
- high rejection of artefacts and interference to the signal
  - high common-mode rejection (low common-mode gain)
    - → matched electrode impedances
    - → driven right leg (DRL) active ground
  - high interference rejection
    - → shielding
    - → filtering matched to frequency range of signal

Example: ECG biopotential amplifier

(Sec. 6.2; also Sec. 4.6 revisited)

ECG revisited : DIPOLE MODEL



$\vec{M}$: CARDIAC VECTOR : an approximate linear model of the effect of placement of the electrode at $\vec{r}$, relative to the current dipole of the heart at time t, on the measured potential :

$$V(\vec{r},t) \cong \vec{M}(t) \bullet \vec{r}$$

DOT PRODUCT

CARDIAC VECTOR as a function of time

ELECTRODE POSITION (fixed)

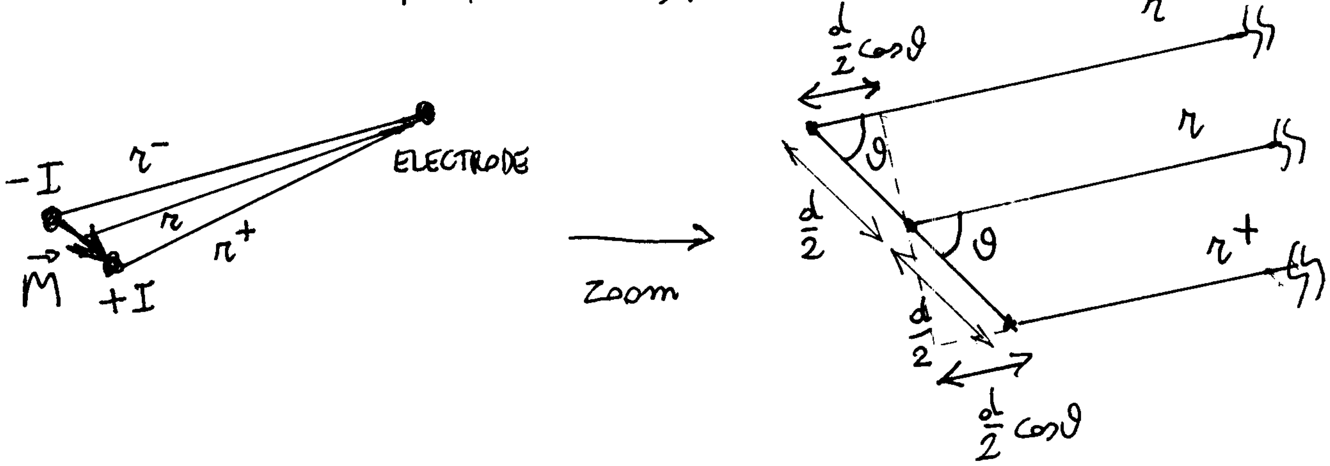
$$= \|\vec{M}\| \cdot \|\vec{r}\| \cdot \cos\vartheta$$

magnitude

angle

The cardiac vector model is valid only for large, and constant, $|\vec{r}|$ relative to the dipole displacement d:

$$|\vec{r}| = r \gg d$$



$$V(\vec{r},t) = \frac{I(t)}{4\pi\sigma}\left(\frac{1}{r^+(t)} - \frac{1}{r^-(t)}\right) \quad \text{and} \quad \begin{cases} r^- \approx r + \frac{d}{2}\cos\vartheta \\ r^+ \approx r - \frac{d}{2}\cos\vartheta \end{cases}$$

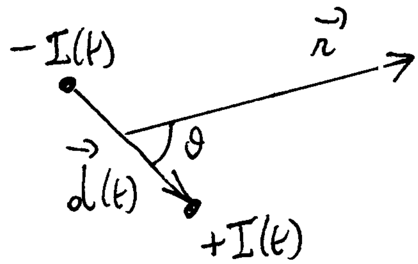
$$\frac{1}{r^+} - \frac{1}{r^-} \approx \frac{1}{r - \frac{d}{2}\cos\vartheta} - \frac{1}{r + \frac{d}{2}\cos\vartheta} = \frac{1}{r}\left(\frac{1}{1 - \frac{d}{2r}\cos\vartheta} - \frac{1}{1 + \frac{d}{2r}\cos\vartheta}\right)$$

$$\approx \frac{1}{r}\left(\left(1 + \frac{d}{2r}\cos\vartheta\right) - \left(1 - \frac{d}{2r}\cos\vartheta\right)\right) = \frac{d}{r^2}\cdot\cos\vartheta$$

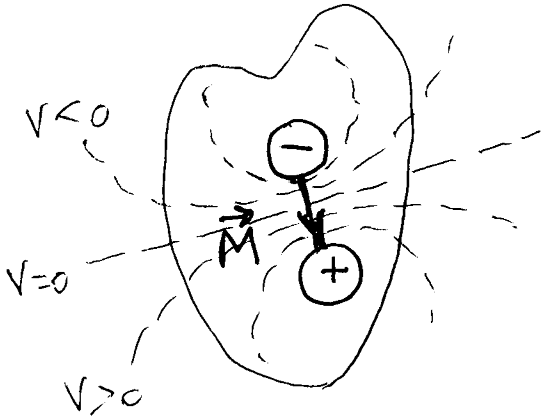
$\left(\frac{1}{1+\varepsilon} \approx 1 - \varepsilon \text{ for } |\varepsilon| \ll 1\right)$

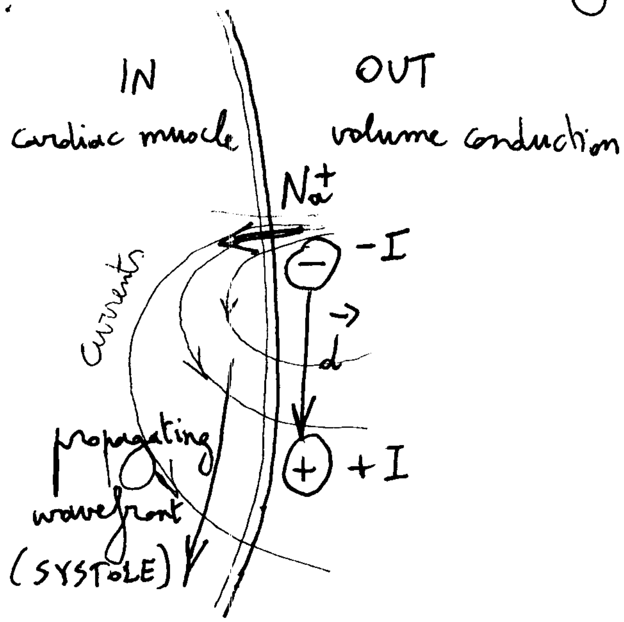
$$\Rightarrow V(\vec{r},t) \approx \frac{I}{4\pi\sigma}\cdot\frac{d}{r^2}\cdot\cos\vartheta = \underbrace{\frac{I}{4\pi\sigma}\cdot\frac{d}{r^3}}_{|\vec{M}|}\cdot r\cdot\cos\vartheta = \vec{M}(t)\cdot\vec{r}$$

$$\Rightarrow \vec{M}(t) = \frac{I(t)}{4\pi\sigma}\cdot\frac{\vec{d}(t)}{r^3}$$

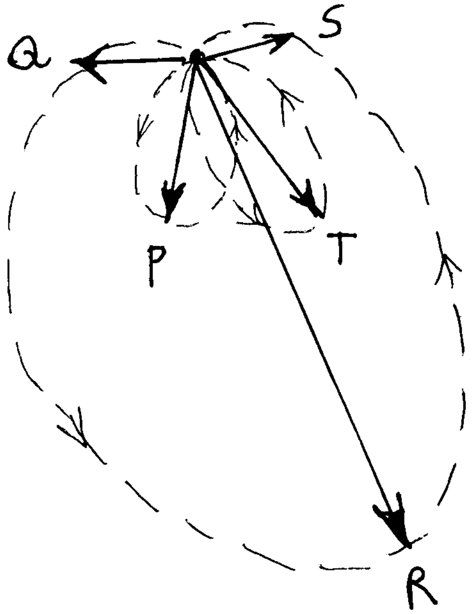


The cardiac vector varies with time over the cardiac cycle, e.g. ventrical depolarization:





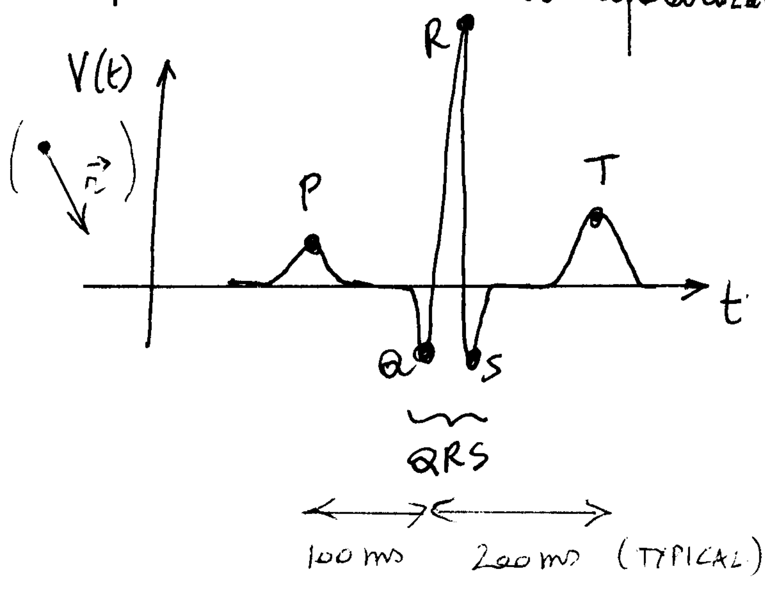
$\vec{M}(t)$: traverses three main loops :



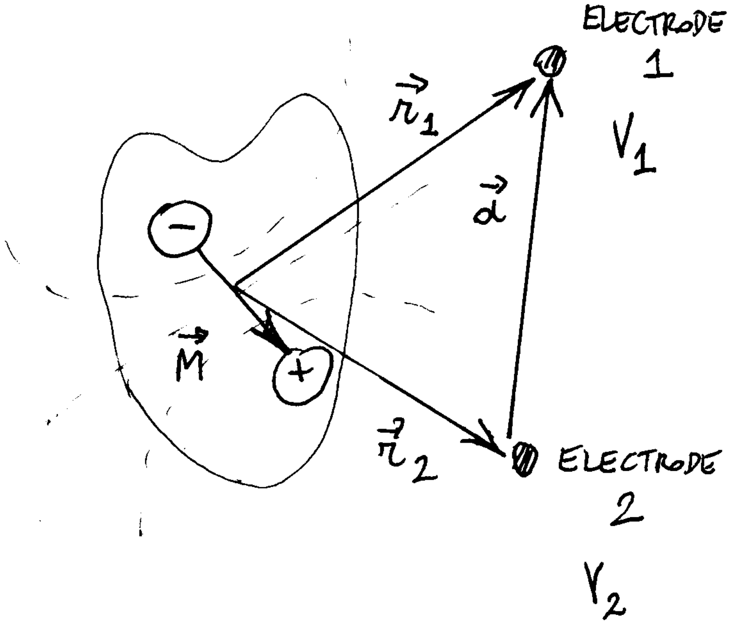
P-wave : atrial depolarization

QRS-complex : ventricular depolarization

T-wave : ventricular repolarization



ECG "leads": differential electrode configurations across the body, each picking up different projections of the cardiac vector time waveform



$\vec{d} = \vec{r}_1 - \vec{r}_2$

LEAD VECTOR

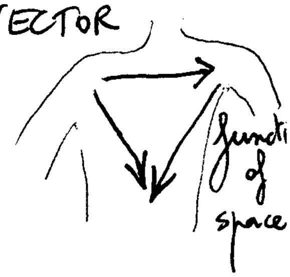
$V_d = V_1 - V_2$

LEAD VOLTAGE (DIFFERENTIAL)

$$V_d = V_1 - V_2 = \vec{M} \bullet \vec{r}_1 - \vec{M} \bullet \vec{r}_2 = \vec{M} \bullet (\vec{r}_1 - \vec{r}_2)$$

$$\Rightarrow \quad V_d = \vec{M}(t) \bullet \vec{d}$$

LEAD VOLTAGE	CARDIAC VECTOR	(DOT)	LEAD VECTOR
measured by a differential amplifier	function of time		function of space



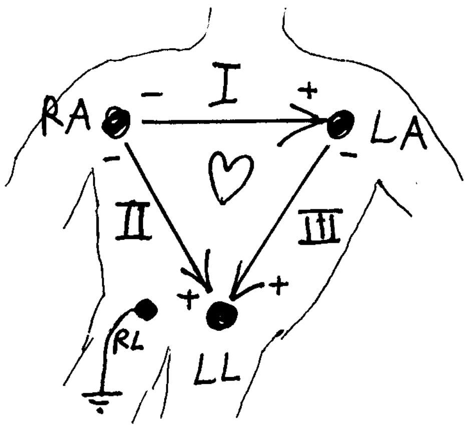
NOTE: this only works when $\|\vec{r}_1\| = \|\vec{r}_2\| = r$!

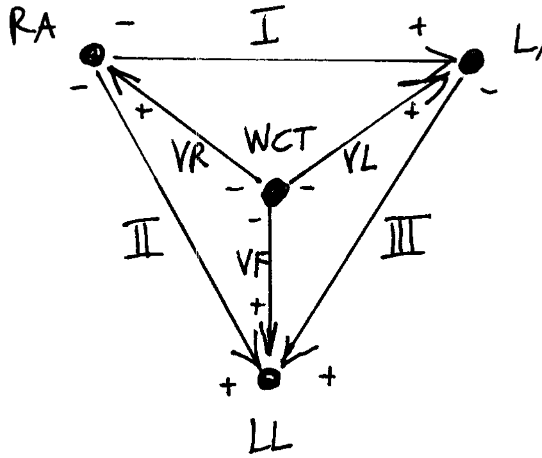
otherwise the two cardiac vectors are different

— Frontal plane : EINTHOVEN'S TRIANGLE

4 electrodes :
- RA right arm
- LA left arm
- LL left leg
- RL right leg — active grounding reference

Placed anywhere on the arms and legs since no current should flow through these.





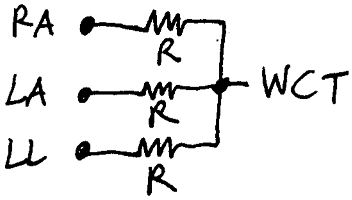
6 leads in the frontal plane from these 3 (4) electrodes:

I : LA − RA	VR : RA − WCT
II : LL − RA	VL : LA − WCT
III : LL − LA	VF : LL − WCT

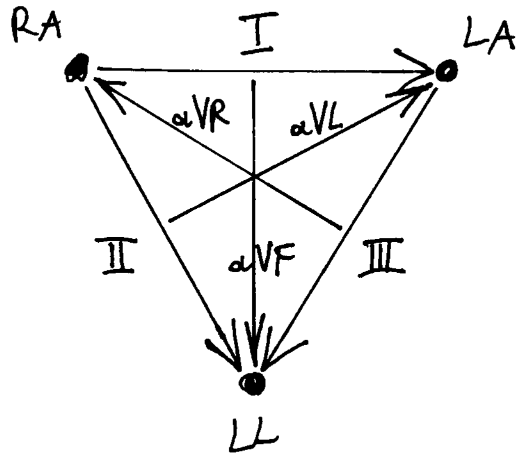
(vector differences)

where WCT is the WILSON CENTRAL TERMINAL :
virtual ground reference at the center of the triangle

$$WCT = \frac{1}{3}(RA + LA + LL)$$

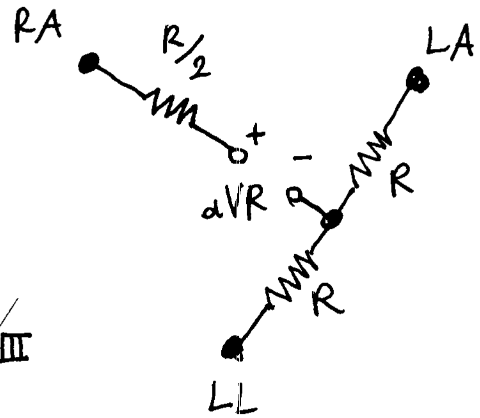


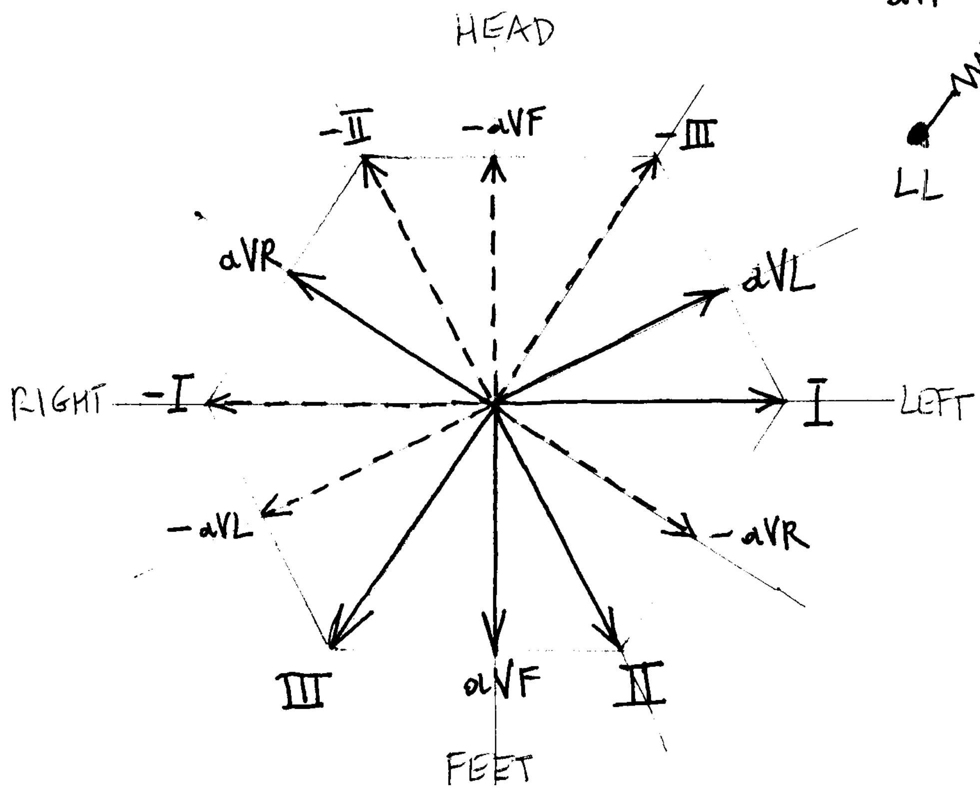
"Augmented" leads: alternative constructions of the VR, VL and VF leads with magnitude closer to the I, II, III leads:



$$aVR = RA - \frac{1}{2}(LA + LL)$$
$$aVL = LA - \frac{1}{2}(RA + LL)$$
$$aVF = LL - \frac{1}{2}(RA + LA)$$

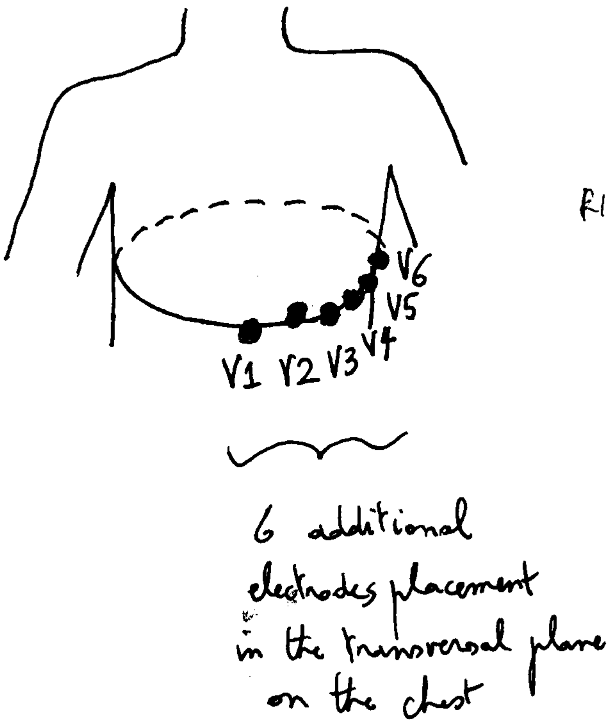
e.g.: aVR :

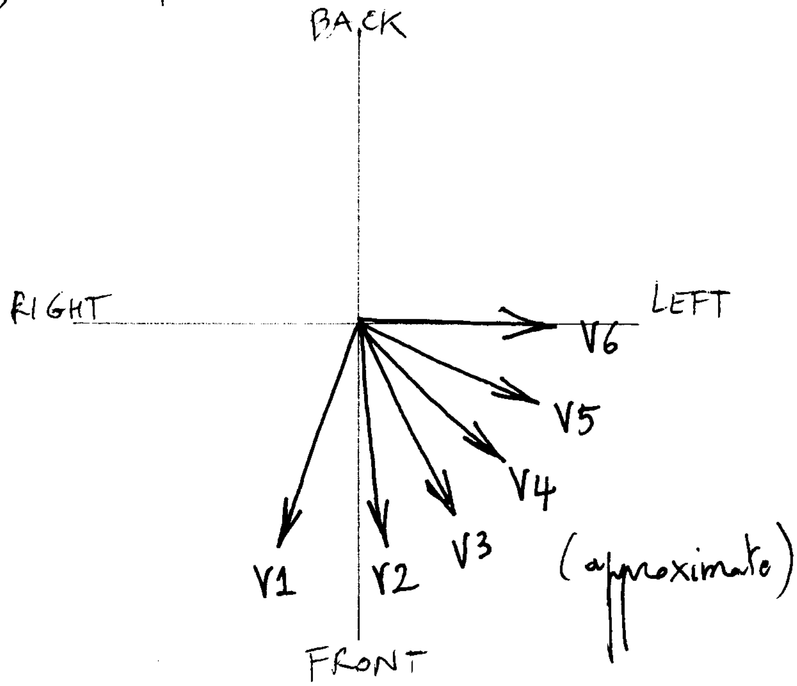




6 leads, and their complements, span 360° in 30° increments on a polar plot.

— Transversal plane : additional 6 leads, from additional 6 electrodes placed on the chest, in the horizontal plane perpendicular to the frontal plane.



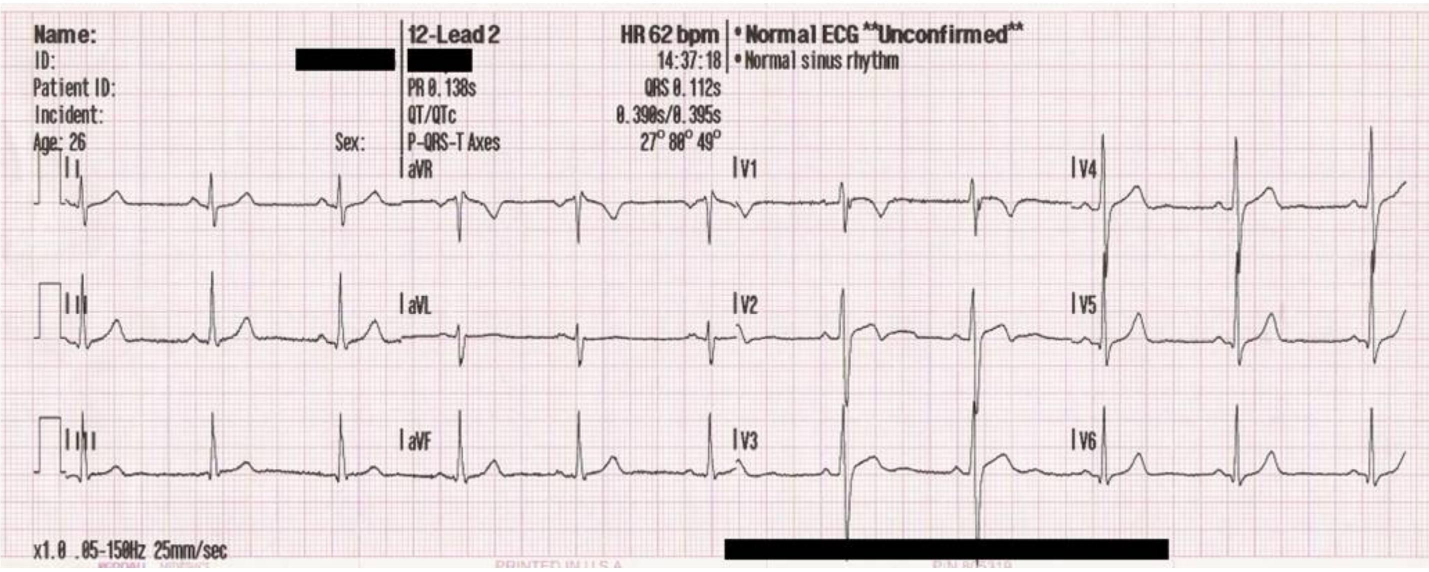


The leads V1 through V6 are taken on the 6 electrodes, relative to the Wilson Central Terminal (WCT).

— The 12-LEAD ECG combines 6 leads of the frontal plane with 6 leads of the transversal plane, from a total of 10 electrodes

- leads : I, II, III, aVR, aVL, aVF, V1, V2, V3, V4, V5, V6
- electrodes : RL (active ground reference) + RA, LA, LL, V1, ... V6

Example 12-Lead Electrocardiogram (http://en.wikipedia.org/wiki/Electrocardiography):



12 Leads on the Torso (ECG Learning Center, http://ecg.utah.edu/):