1/31/19 Slide Notes

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Barold SS. Willem Einthoven and the birth of clinical electrocardiography a hundred years ago. *Card Electrophysiol Rev* 7:99-104, 2003.

Excerpts from abstract: Willem Einthoven (1860–1927) who was professor of physiology at the University of Leiden, The Netherlands, began his studies of the ECG with the mercury capillary electrometer, and improved its distortion mathematically. He later further improved ECG recordings with the introduction of a string galvanometer of his design. Einthoven published his first article about the string galvanometer in 1901, followed by a more detailed description in 1903 which included a report of ECGs. The clinical use of Einthoven's immobile equipment required transtelephonic transmission of the ECG from the physiology laboratory to the clinic at the Academic Hospital about a mile away as documented in the 1906 paper on the "teleecardiogramme". Einthoven introduced the bipolar system with 3 limb leads. Einthoven also conceived the famous equilateral triangle with leads I, II, and III at its sides and the calculation of the electrical axis (in the frontal plane) depicted as a single vector with an arrow at the center of the triangle. Einthoven recognized the great potential importance of the ECG as a diagnostic and investigative tool and his achievements made him the founder of modern electrocardiography. He was awarded the Nobel Prize in 1924 in physiology and medicine, "for the discovery of the mechanism of the electrocardiogram."

Additional reading:

Silverman ME. Willem Einthoven--the father of electrocardiography. *Clin Cardiol* 15:785-787, 1992.

Barold SS. Centennial of Einthoven's first recording of the human electrocardiogram with the string galvanometer. *Pacing Clin Electrophysiol*. 2002;25:399-401

Top left

from http://www.nobelprize.org/nobel_prizes/medicine/laureates/1924/einthoven-facts.html

Top right

Geddes LA and Baker LE, Principles of Applied Biomedical Instrumentation, 2nd ed., John Wiley & Sons, New York, 1975.

Fig. 11-87a. Einthoven's string galvanometer. From: Enthoven W, Arch Int Physiol 4:132-164, 1906.

Bottom

Cooksey JD, Dunn, M, Massie E. Clinical Vectorcardiography and Electrocardiography. Year Book Medical Publishers, Chicago, 1977.

Fig. 3-1A. The string galvanometer electrocardiograph.

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Upper left

Early attempts by Einthoven to measure the ECG used a capillary electrometer. Because it relied on the movement of a meniscus of mercury, it had a very slow frequency response. However, Einthoven improved the slow response by using a mathematical correction, leading to the trace shown on top in which he assigned labels to the different parts of the waveform. The lower trace is that obtained by his string galvanometer.

Upper right

Geddes LA and Baker LE, Principles of Applied Biomedical Instrumentation, 2nd ed., John Wiley & Sons, New York, 1975.

Fig. 11-87b. Method of using the device with immersion electrodes to record lead I (right-left arm) electrocardiogram. From: Enthoven W, Arch Int Physiol 4:132-164, 1906.

Slide 7

Katz M. Physiology of the Heart, Raven Press, New York, 1977.

Fig. 15.10 (p. 267). Temporal relationships between the ECG (top) and a representative cardiac action potential (bottom). The QRS complex is produced by the upstrokes (phase 0) of all of the action potentials throughout the ventricles; the S-T segment corresponds to the plateau potentials (phase 2), while the T wave is inscribed during repolarization (phase 3) of the ventricular mass. The isoelectric segment which comes after the T wave corresponds to ventricular diastole (phase 4).

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Right

Gauthier LD, Greenstein JL, Winslow RL. Toward an integrative computational model of the guinea pig cardiac myocyte. *Front Physiol*. **3**:244, 2012.

Slide 9

Top

Severs NJ. The cardiac muscle cell. *BioEssays* **22**:188-199, 2000.

Figure 2. Confocal microscopy of cardiac muscle.

(A) Single ventricular myocyte viewed by confocal microscopy. Image prepared by combining a stack of serial optical sections

through the cell. Myofibrils (seen as striations) visualised by immunostaining with an antibody against a-actinin (a component of the myofibril Z-bands).
(B) Distribution of vinculin in a section of cardiac muscle revealed by immunofluorescence labelling. The image shows numerous cells like that in panel (A), joined together at intercalated disks (id). Vinculin is seen as a series of bright dots along the lateral surfaces of the plasma membrane (series of small arrows), marking the sites of costameres. Vinculin extends from the surface plasma membrane along the transverse tubule membranes penetrating into the cell (seen as striations) and is also abundant in the transverse segments of the disk, where the myofibrils join the plasma membrane via fasciae adherentes junctions.
Bottom left
Sands GB, Smaill BH, LeGrice IJ. Virtual sectioning of cardiac tissue relative to fiber orientation. *Conf Proc IEEE Eng Med Biol Soc* 2008:226-229, 2008.
Fig. 3B: Shown here is a tangential section of the myocardium. Fiber angles are measured on the 30% plane in a grid of sub-regions (green) which are then averaged to give the mean fibre angle (white line). Scale bar is 200 microns.
Bottom right
Torrent-Guasp F, Buckberg GD, Clemente C, Cox JL, Coghlan HC, Gharib M. The structure and function of the helical heart and its buttress wrapping. I. The normal macroscopic structure of the heart. *Semin Thorac Cardiovasc Surg* **13**:301-319, 2001.
It has been proposed that the ventricular myocardium, both right (RV) and left (LV), exists as a continuous muscle band.1-4 The band is oriented spatially as a helix formed by basal and apical loops.
Figure 1. Five successive phases of the unwinding of the ventricular myocardial band. In the first specimen (upper left) the band appears in its normal position, as it is in the intact heart. In the last specimen (bottom), the band is fully extended.

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Upper right
Severs NJ, Bruce AF, Dupont E, Rothery S. Remodelling of gap junctions and connexin expression in diseased myocardium. *Cardiovasc Res*. **80**:9-19, 2008.
Figure 2 Characteristic distribution pattern of Cx43 gap junctions in ventricular myocardium. (A) Longitudinal section from rat left ventricle. The Cx43 gap junctions appear in rows, corresponding to edge-on viewed intercalated discs. Inset shows a single intercalated disc viewed face-on from transversely sectioned human myocardium. Note larger gap junctions at the periphery of the disc. (B) The presence of multiple discs of different size is best appreciated in views of isolated myocytes (in this example, from rat). The steps of the disc are indicated by the white line. Note that some apparently isolated gap junctions at the lateral surface (indicated by spot on the line) can be considered as components of extended intercalated discs.

Slide 13
Jack JJB, Noble D, Tsien RW. Electric Current Flow in Excitable Cells. Clarenden Press, Oxford, 1975.
Adapted from Fig. 10-1. Simple electrical circuits representing excitation and conduction. Top: The external current generator is removed. The potential change on the capacitance continues as current flows through the sodium circuit and replaces the external current generator as the source of excitatory current. Bottom: The 'excited' circuit is connected to a 'passive' circuit and now acts like the external current generator in applying current to the passive circuit. Thus, the excitation may propagate from circuit to circuit. Since the sodium current in the 'excited' circuit is the only inward current flowing, R_{Na} must be low (i.e. g_{Na} high) in order to allow sufficient sodium current to flow to continue charging the local capacitance and to excite the passive circuit. Hence, there will be a minimal value of g_{Na} below which propagation cannot occur.

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Right
de Bakker JMT, Hauer RNW, and Simmers TA. Activation mapping: unipolar versus bipolar recording. In: Zipes DP and Jalife J. Cardiac Electrophysiology - From Cell to Bedside, 2nd ed., Chap. 94, pp. 1068-1078, W. B. Saunders Co., Philadelphia, 1995.
Adapted from Fig. 94-2 (p. 1069). *Upper panel*. Isopotential map of a current dipole. The current source is located at Q_1; the current sink at Q_2. The distance between Q_1 and Q_2 is L. Numbers indicate the amplitude of the potential at the isopotential lines in arbitrary units. Potential values are positive to the right of the zero isochrone and negative to the left. *Lower panel*. Potential values measured at sites along horizontal line a-e.

Slide 15
Cooksey JD, Dunn, M, Massie E. Clinical Vectorcardiography and Electrocardiography. Year Book Medical Publishers, Chicago, 1977.
Fig. 1-14. The potential variations at electrodes *A*, *B*, and *C* during depolarization (**A-D**) and repolarization (**E**). The depolarization and repolarization wave fronts are represented by single equivalent dipoles. The potentials at the three electrodes are plotted against time to obtain the voltage deflections recorded by each lead during cellular depolarization and repolarization. (See text for details)

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Cooksey JD, Dunn, M, Massie E. Clinical Vectorcardiography and Electrocardiography. Year Book Medical Publishers, Chicago, 1977.
Fig. 5-5. Sequence of the ventricular activation in the isolated human heart. Inset shows the section levels. The shaded areas represent time intervals in msec from the onset of ventricular depolarization. Note that the initial activation occurs simultaneously in three separate areas of the left ventricle. Activation of the right ventricle begins 10-15 msec after that of the left ventricle in a small area of the lower right septum and at the base of the anterior papillary muscle. Because of the sparsity of the Purkinje network in the right ventricular endocardium activation requires twice as much time as in the left ventricular endocardium. (From Durrer D, van Dam RT, Freud GE, Janse MJ, Meyler FL, and Arzbaecher RC. Total excitation of the isolated human heart, Circ 41:899, 1970)

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Einthoven envisioned a triangle that connected the left arm, right arm and left leg. Although Einthoven chose to use the left leg, the right leg could also have been used. The electrical potentials would be close, although perhaps slightly different. Currently, the right leg is often connected to the instrumentation ground to improve signal-to-noise ratio.
Cooksey JD, Dunn, M, Massie E. Clinical Vectorcardiography and Electrocardiography. Year Book Medical Publishers, Chicago, 1977.
Adapted from Fig. 4-3A.

Slide 18
Cooksey JD, Dunn, M, Massie E. Clinical Vectorcardiography and Electrocardiography. Year Book Medical Publishers, Chicago, 1977.
Adapted from Fig. 2-5. The Einhoven triangle is represented as an equilateral triangle.

Slide 19
Malmivuo M, Plonsey R. Bioelectromagnetism. Oxford University Press, New York, 1995. Fig. 15.3A. The generation of the ECG signal in the Einthoven limb leads.

Slide 20
Malmivuo M, Plonsey R. Bioelectromagnetism. Oxford University Press, New York, 1995. Fig. 15.3B. The generation of the ECG signal in the Einthoven limb leads.

Slide 21
Malmivuo M, Plonsey R. Bioelectromagnetism. Oxford University Press, New York, 1995. Fig. 15.3C. The generation of the ECG signal in the Einthoven limb leads.

Slide 22
Malmivuo M, Plonsey R. Bioelectromagnetism. Oxford University Press, New York, 1995. Fig. 15.3D. The generation of the ECG signal in the Einthoven limb leads.

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The Wilson Central Terminal is defined to be the average of the right arm, left arm and left leg potentials. It is similar to what would be measured far away at "infinity," assuming the body is connected electrically to such a remote point.
Right
Scher AM. The electrocardiogram, Chap. 38, pp. 796-819. In: Patton HD, Fuchs AF, Hille B, Scher AM, Steiner, R, eds. Textbook of Physiology, Vol. 2. W. B. Saunders Co, Philadelphia, 1989, 21st Ed.
Fig. 38-15 (p. 805). Positions of unipolar precordial (chest) leads as routinely recorded in electrocardiography. V_1 is immediately to right of sternum at fourth intercostal space. V_2 is just to left of sternum in fourth intercostal space. V_4, in fifth intercostal space, is in midclavicular line. V_3 is between V_2 and V_4. V_5 is in fifth intercostal space in anterior axillary line. V_6, in fifth intercostal space, is at midaxillary line. The two portions of the figure indicate the vertical and horizontal positions of these leads.

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Building Brain Machine Interfaces – Neuroprosthetic Control with Electrocorticographic Signals
Nitish Thakor, 2012
http://lifesciences.ieee.org/lifesciences-newsletter/2012/april-2012/building-brain-machine-interfaces-neuroprosthetic-control-with-electrocorticographic-signals/

(Electrocorticographic signals can be used for neuroprosthetic control)
Figure 3: Different signals from the brain, from macroscopic, namely EEG and ECoG, to microscopic signals, namely local field potentials, LFPs, and action potentials or spikes. (Courtesy Dr. M. Mollazadeh).
Ben-Jacob E, Boccaletti S, Pomyalov A, Procaccia I, Towle VL. Detecting and localizing the foci in human epileptic seizures. *Chaos.* 2007;**17**:043113
FIG. 1: (Color online) Subdural ECoG grid of electrodes placed on the surface of the brain for chronic evaluation of epileptic patients before surgical resection.