ELEC ENG 3BB3:

Cellular Bioelectricity

Notes for Lecture 20

Tuesday, February 25, 2014

9. CARDIAC ELECTROPHYSIOLOGY

We will look at:

- Introduction to cardiac physiology
- Electrical nature of intercellular communication
- Free wall activation of the heart
- Source models
- ECG measurement and analysis

Introduction to cardiac physiology:

The major cellular components of the heart are:

- working muscle of the atria & ventricles
- specialized conduction cells
- pacemaker cells

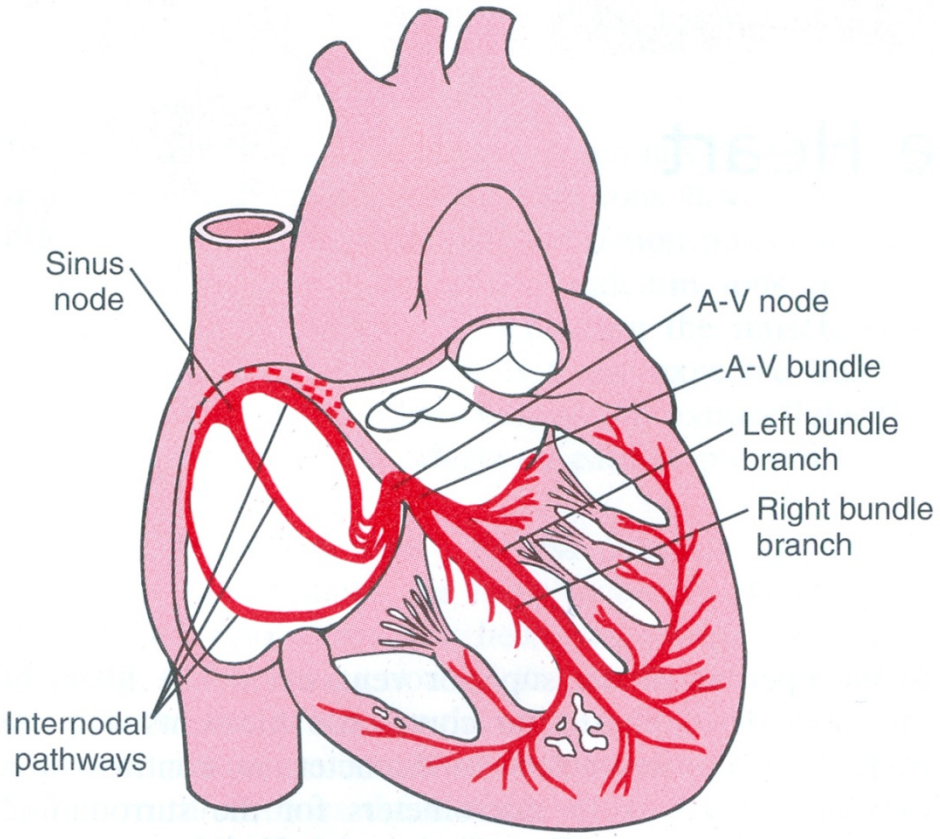

FIGURE 10–1

Sinus node and the Purkinje system of the heart, showing also the A-V node, atrial internodal pathways, and ventricular bundle branches.

Introduction to cardiac physiology (cont.):

Pacemaker cells, located in the *sinoatrial* (SA) *node*, are characterized by being self-excitatory.

Following an action potential, rather returning to a stable resting potential, the transmembrane potential spontaneously increases until threshold is reached and another action potential is generated.

This regular train of action potentials leads to a regular series of heart beats.

Introduction to cardiac physiology (cont.):

Excitation from the SA node spreads *cell-by-cell* through the muscle of the atria.

Non-conducting fibrous tissue separate the muscle cells of the atria and the ventricles. Rather, excitation at the *atrioventricular* (AV) *node* in the right atrium is conducted to the ventricles by means of *Purkinje* tissue.

The specialized tissue of the AV node causes very slow conduction, introducing the necessary delay between excitation of the atria and the ventricles.

Excitation then spreads *cell-by-cell* through the muscle of the ventricles, roughly from *endocardium to epicardium* and from *apex to base*.

Introduction to cardiac physiology (cont.):

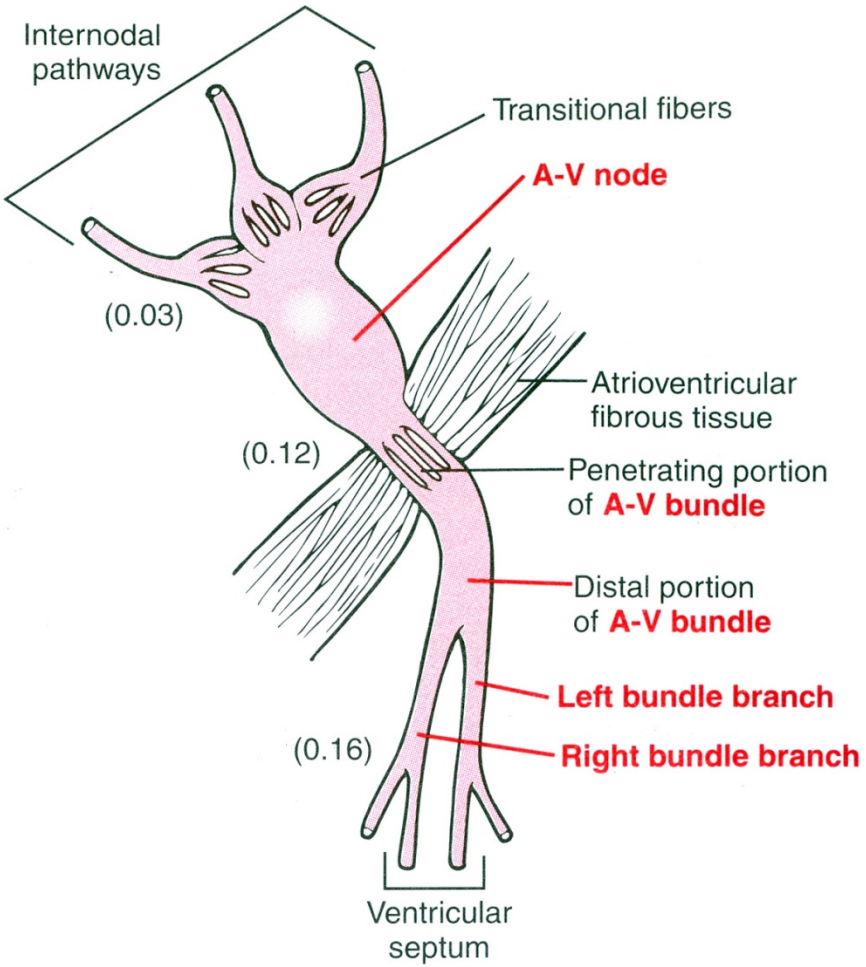

FIGURE 10–3

Organization of the A-V node. The numbers represent the interval of time from the origin of the impulse in the sinus node. The values have been extrapolated to humans.

Introduction to cardiac physiology (cont.):

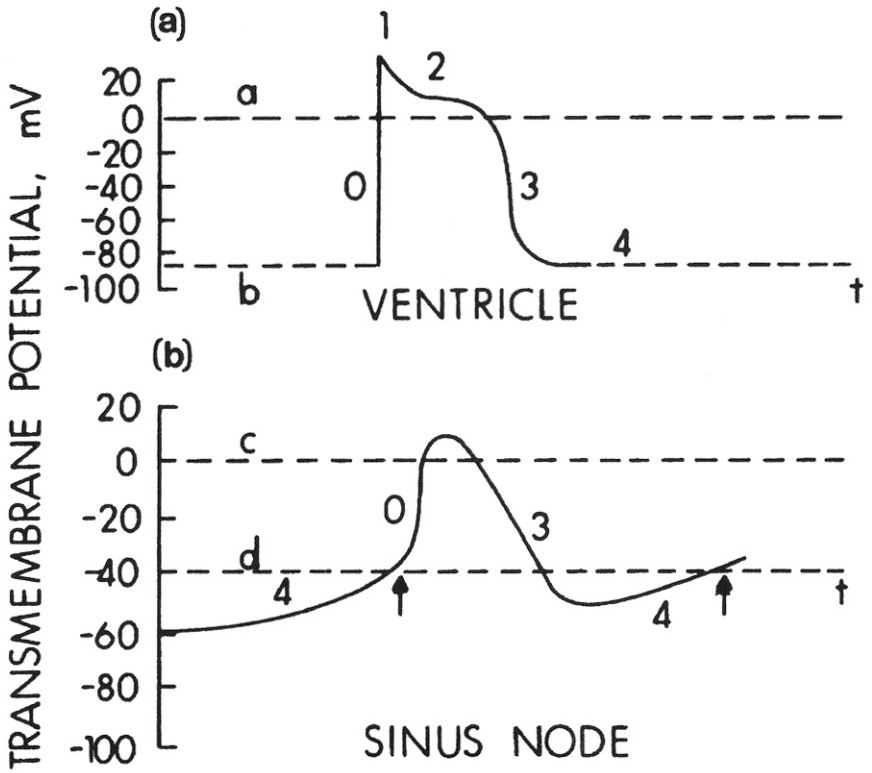

Figure 9.2. (a) Ventricular action potential; (b) pacemaker action potential. Phase 0 corresponds to activation, 1 to rapid recovery, 2 to the *plateau*, 3 recovery, 4 rest or slow depolarization (for pacemaker or *automatic* cells). [From B. F. Hoffman and P. Cranefield, *Electrophysiology of the Heart*, McGraw-Hill, New York, 1960. Copyright 1960, McGraw-Hill.]

Introduction to cardiac physiology (cont.):

Purkinje fiber action potentials are similar to those of the ventricle muscle cells, but with a sharper initial peak.

Purkinje tissue is a specialization of cardiac muscle cells that behaves in many ways like a nerve axon.

The spread of excitation cell-by-cell in the cardiac muscle and Purkinje fibers is achieved through electrical synapses – *gap junctions*.

Electrical nature of intercellular communication:

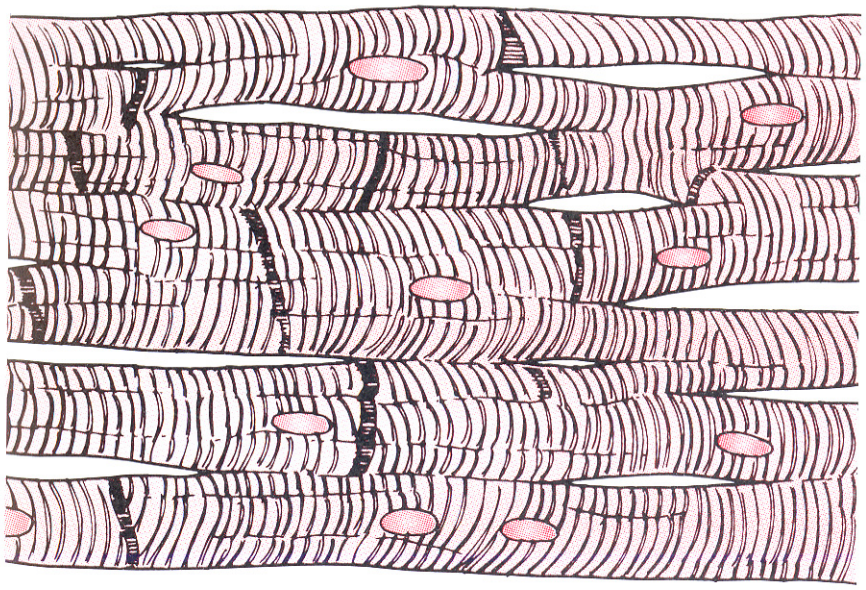

FIGURE 9–2

"Syncytial," interconnecting nature of cardiac muscle fibers.

(from Guyton & Hall)

Electrical nature of intercellular communication (Cont.):

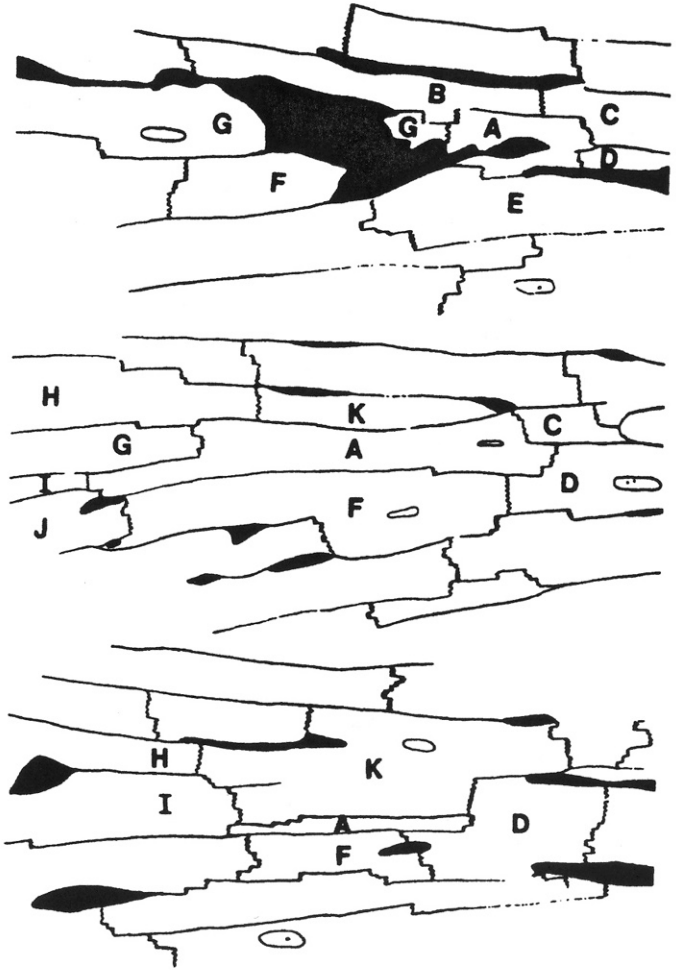

Figure 9.3. Structure of cardiac muscle. The figure shows three camera lucida drawings from a series of 42 consecutive 2-μm-thick plastic sections showing multiplicity of interconnections of the myocytes at intercalated disks. Shaded areas denote prominent interstitial vessels and septae. From top to bottom are shown sections 12, 16, and 22. Myocyte A is followed in its entirety and makes contact at intercalated discs with cells B–K. [R. H. Hoyt, M. L. Cohen, and J. E. Saffitz, Distribution and three-dimensional structure of the intercellular junctions in canine myocardium, *Circ. Res.* **64**:563–574 (1989).]

Electrical nature of intercellular communication (cont.):

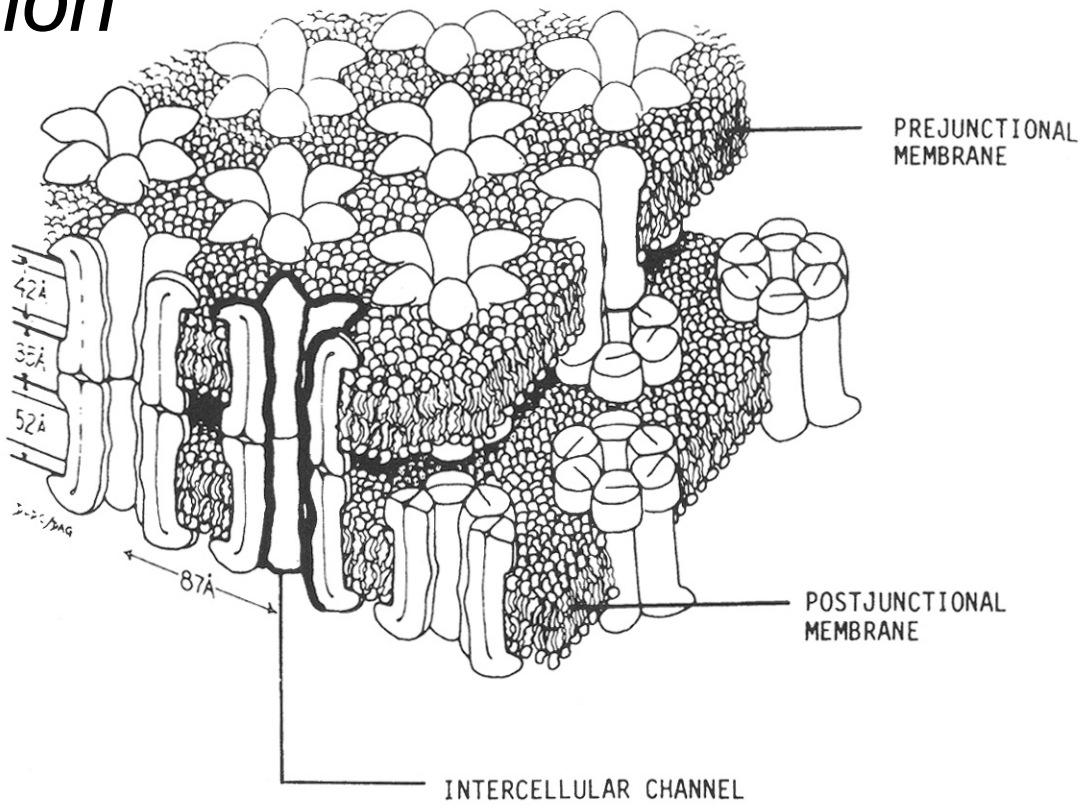

Figure 9.4. Details of the communicating-type intercellular cardiac junction (connexon array) is shown. Each unit (connexon) is a protein channel running transverse to the opposing membranes. Connexons from abutting cells align themselves to form structural continuity. The structural detail shown is based on morphometry obtained from X-ray diffraction, electron microscopy, and chemical studies. The gap spacing is given as 35 Å. [R. Plonsey, The use of a bidomain model for the study of excitable media, *Lectures on Mathematics in the Life Sciences* **21**:123–149 (1989). From L. Makowski, D. L. D. Caspar, W.C. Phillips, and D. A. Goodenough, Gap junctional structures II. Analysis of x-ray diffraction, *J. Cell Biol.* **74**:629–645 (1977). Reproduced from the Journal of Cell Biology, 1977, vol. 74, pp. 629–645 by copyright permission of the Rockefeller University Press.]

Electrical nature of intercellular communication (cont.):

Cable analysis of Purkinje fibers gives $\lambda \approx 1$ mm and $\tau = 18$ ms.

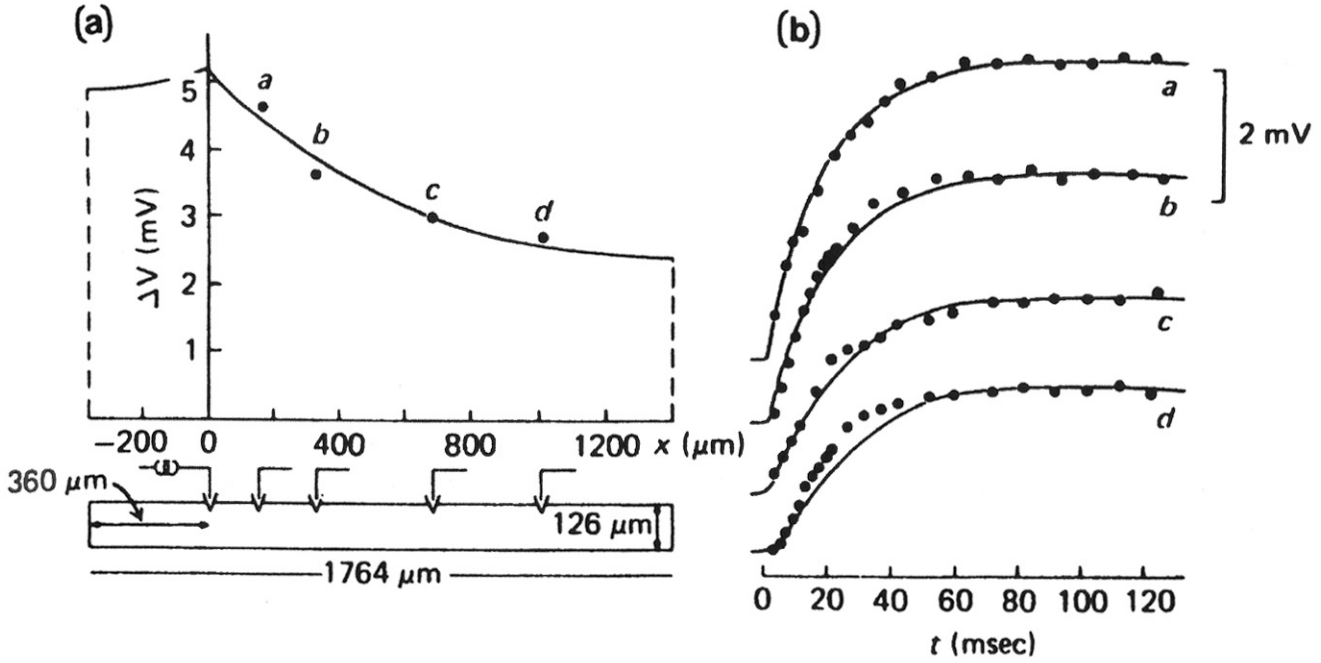

Figure 9.5. Cable analysis of rabbit Purkinje fiber. (a) Steady-state electrotonic response to an applied current step. Inset shows fiber geometry and the location of the current passing and voltage recording microelectrode impalement sites. (b) Temporal response at labeled sites. [From T. J. Colatsky and R. W. Tsien, Electrical properties associated with wide intercellular clefts in rabbit Purkinje fibers, *J. Physiol.* **290**:227–252 (1979)].

Electrical nature of intercellular communication (cont.):

Ventricular spread of excitation.

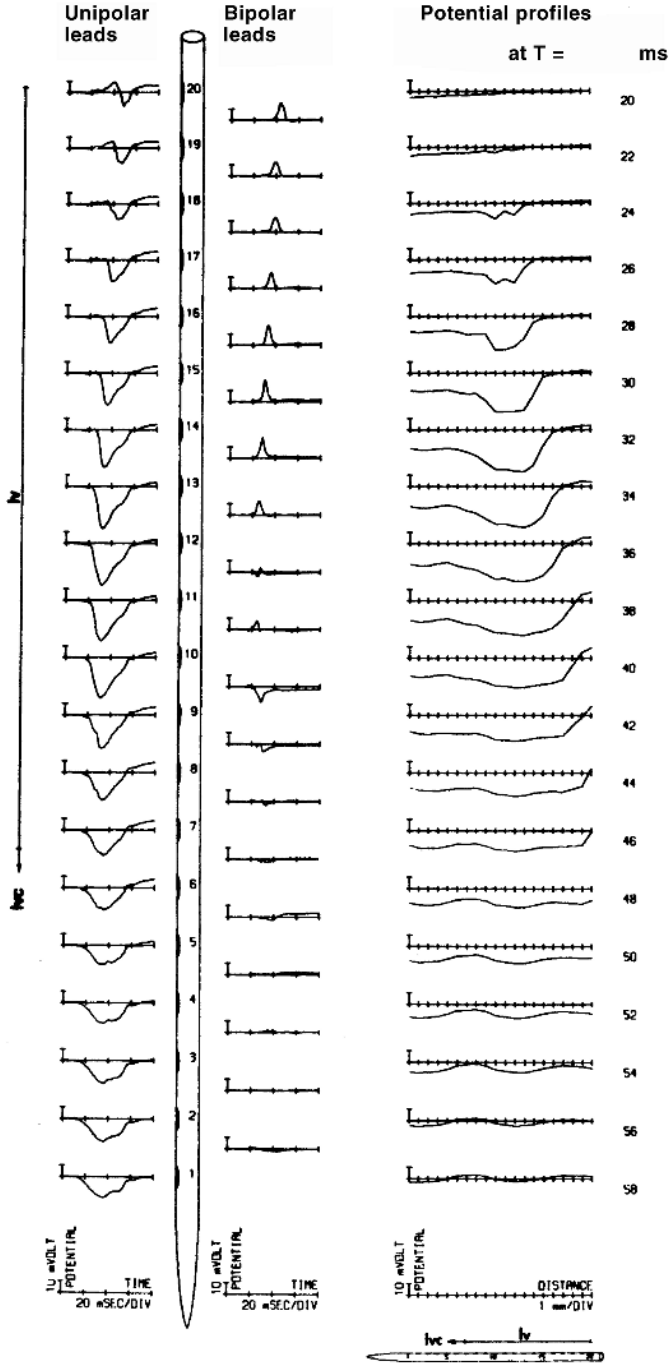

Figure 9.10. Needle Electrode (plunge electrode) with 20 Electrode Points. Associated unipolar and bipolar (adjacent pairs) signals also shown. The profile is the spatial distribution at the time shown at the right. Electrodes 7–20 lie within the ventricular wall. From van Oosterom A, van Dam R. 1976. Potential distribution in the left ventricular wall during depolarization. *Adv Cardiol* **16**:27–31, by permission from S. Karger AG, Basel.

Electrical nature of intercellular communication (cont.):

Ventricular spread of excitation.

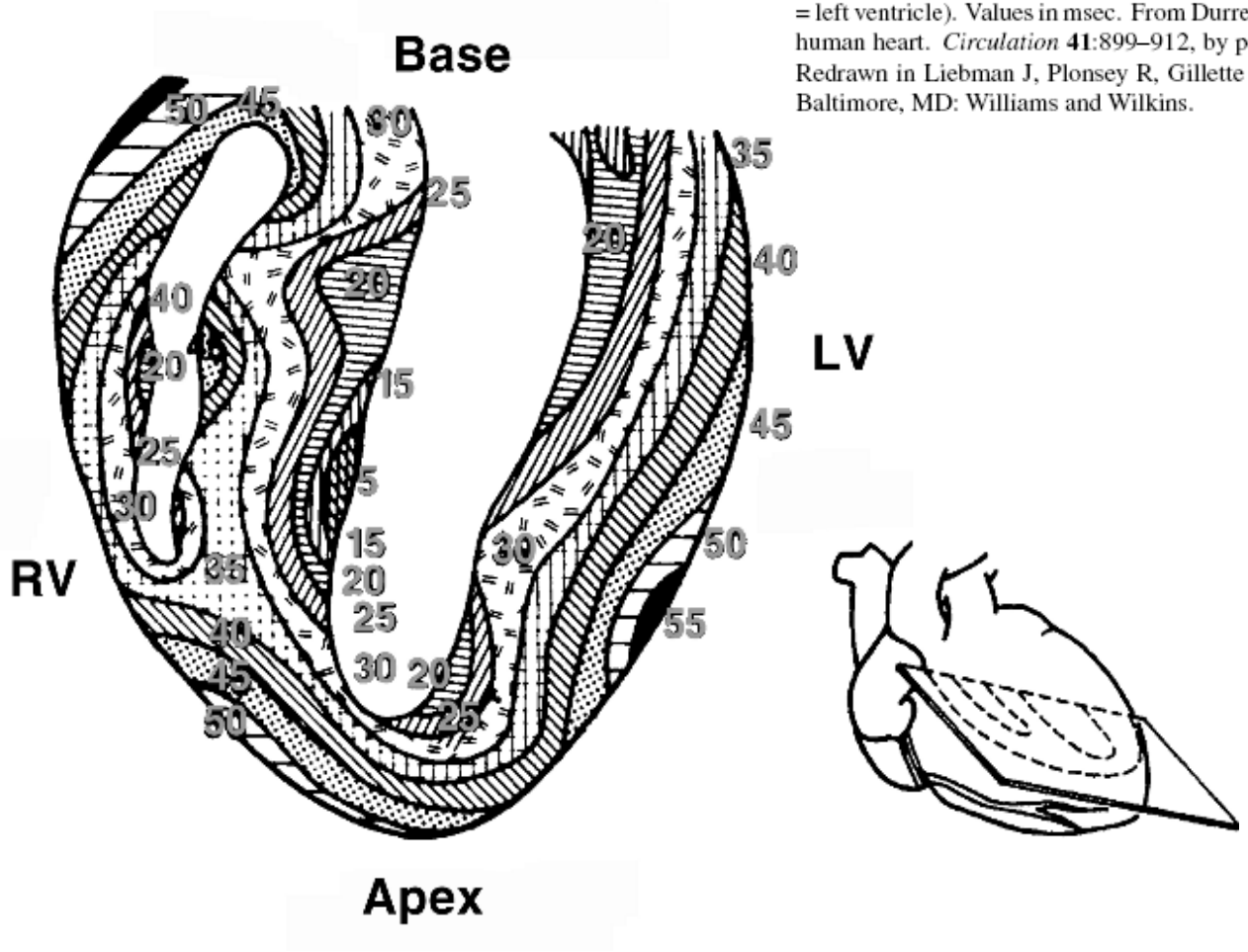

Figure 9.12. Isochronous Lines of Activation of the Human Heart (RV = right ventricle, LV = left ventricle). Values in msec. From Durrer D, et al. 1970. Total excitation of the isolated human heart. *Circulation* **41**:899–912, by permission of the American Heart Association. Redrawn in Liebman J, Plonsey R, Gillette P. eds. 1982. *Pediatric electrocardiography*. Baltimore, MD: Williams and Wilkins.