A computer's heart: Simulating the heart's electrical system

Within a University of Vermont computer beats a heart that generates an electrocardiogram (EKG) virtually identical to a human heart's electrical trace. This computer model of the heart's electrical activity during a heartbeat is one of several being developed in North America and Europe. The research is aimed at helping doctors make better diagnoses from the electrical patterns they monitor on the body surfaces of their patients.

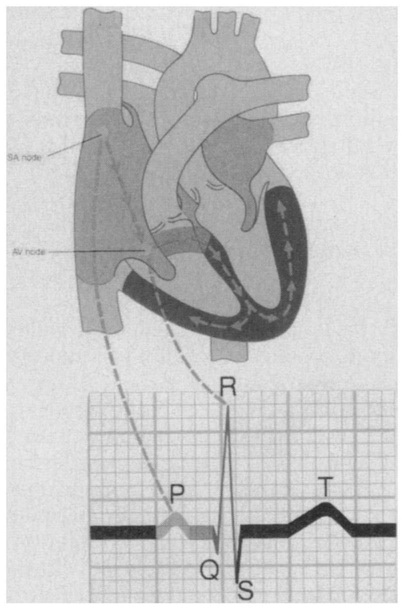
Although electrocardiograms have been recorded for almost a century, these computer simulations are showing that an EKG's jagged hills and valleys potentially contain more information than previously thought. For example, at one time it was said that vast areas of the myocardium (the thick, muscular, middle layer of the heart's wall) were electrically silent. Thus, some major infarctions (areas of heart tissue damaged or killed by a shortage of blood) were thought not to show up on an EKG. Using a computer model developed several years ago, Ronald H. Selvester and his colleagues at the University of Southern California showed that any infarct revealed itself in the EKG waveform. The result was the development of a new set of criteria for infarctions anywhere in the heart.

"What was silent wasn't areas of the myocardium, but the criteria," says Selvester. "We did not have the appropriate criteria for an infarct in certain locations of the heart." Autopsy findings later verified the predictions of the computer model, and the results were published in a series of papers last year.

Successes like this have encouraged the development of more detailed computer simulations. Typically, three main factors influence what an electrocardiogram looks like. One is the shape and size of the heart and its location and orientation in the chest. The second is the nature of the electrical conduction system that carries the signals within the heart. The third consists of the characteristics of the volume in which the heart sits. A tall, skinny person will have a different electrical voltage distribution across his body (arising from the heart's electrical activity) than a fat person or someone whose lungs contain fluid. All these variables are programed into a computer simulation.

A lot of attention has been paid to simulating the heart's electrical conduction system. An impulse that starts at the sinoatrial node (SN), the heart's "pacemaker" (see diagram), initiates a heartbeat. Stimuli from the pacemaker flash down to the atrioventricular node (AN), close to where the heart's four chambers converge. This node relays the signal through a bundle of fibers that forks into three branches (only two are shown in diagram), each spreading into a profusion of tendrils called Purkinje fibers. The electrical activity itself, which shows up in the surface potentials observed in EKGs, results from the flow of sodium and calcium ions across cell membranes as the exciting wave passes through. The EKG reflects the various phases of this ionic motion.

Computer models like Selvester's and the one currently being developed by Stanley Rush at the University of Vermont use an array set up inside the computer to model the heart's conduction network. Each memory location in the array takes on the job of representing a cell's electrical activity. Rush's model contains 2.5 million cells. Within the computer, once a cycle starts in a designated location, each "cell" communicates the digital equivalent of the electrical event to the adjacent "cell." The activity spreads to neighbors not previously excited, until the whole "heart" is activated. "That's just the way it works in the heart," says Rush.



The Heart: The Living Pump © 1981 U.S. News & World Report Bks

The activation process creates tiny batteries at the interfaces between two cells. The computer calculates the net effect of all these battery-like sources as seen at the surface of the body, taking into account the body's anatomy. Rush's computer program calculates the voltage at several hundred points and produces a surface potential map, reminiscent of a geographical contour map. A sequence of these maps depicts the changes that occur during a heartbeat. A regular EKG trace, like the one shown, simply shows the changes in voltage with time at one particular surface position.

Rush and his group are just beginning to examine the correspondence between the effects that they see in their simulated version of an electrocardiogram and the one physicians see in practice. Over the next year or so, the researchers plan to examine all possible infarct situations and will try either to verify or to disprove the hypotheses that have been associated with the causes for each. "We would like to develop ... more precise diagnostic criteria for various conditions," says Rush.

Selvester's earlier model, which used about 1 million current sources, simulated the QRS portion of the EKG waveform (see diagram). Selvester sees Rush's more sophisticated model as potentially providing valuable information on the T, or recovery, wave, in addition to the QRS section. These data could provide better criteria for determining the degree of danger from ischemia, a local deficiency of oxygen in heart tissue due to a constriction or an obstruction in the blood vessel supplying that part. In some cases, nothing happens; in others, a massive heart attack may occur. "If you get a simulation that really simulates this recovery accurately, you can simulate the local area of ischemia and begin to draft quantitative criteria for ischemia," says Selvester. It would be possible to predict whether bypass surgery, for example, is really necessary in individual cases.

Although results from simulations can be ambiguous, the use of simulations has several advantages. "Once you've got a simulation that mimics the real world to a fairly high level," says Selvester, "you can produce experiments in an afternoon that would take you a couple of lifetimes" if you collected those data from autopsies, particularly if the type of infarction is not common.

David Geselowitz, head of the bioengineering program at Pennsylvania State University, has developed a computer model that concentrates on the T-wave portion of the EKG. He sees simulations as a valuable tool. No one really has a good quantitative feel for the effects of differences in body shape, heart orientation or lung conductivity on measured surface voltages, he says. Playing with simulations, "we could come up with a firmer explanation for the normal variability and pinpoint how much of it is due to variation in the sequence of the activation, how much is due to extra fat tissue, and so on," Geselowitz says.

Next month, most of the researchers working on computer models of the heart's electrical system will be at a conference in Banff, Alberta. Although the specific topic is computer-assisted diagnosis, this "particular group of people can't escape the notion that if you want to program a computer to recognize waveforms, and put criteria and a diagnosis down, you've got to be always upgrading your criteria," says Selvester. The conference participants will debate where the field is going during the next few years. Selvester says, "The role of simulation seems very straightforward at this stage of the game." —*I. Peterson*