Making Sense of a Heart Gone Wild

Armed with computer models, interdisciplinary teams of researchers are studying what triggers life-threatening fibrillation—and the even deeper mystery of why it can be stopped

Richard Gray, a biomedical engineer at the University of Alabama, Birmingham, studies the heart for a living, but last year the heart’s mysteries struck close to home. Gray’s 68-year-old father called 911, complaining of chest pain. The paramedics were already on the scene when he suddenly collapsed. He had gone into ventricular fibrillation—his heart running amok, its muscle fibers all marching in time to their own drummers instead of beating in unison.

Ventricular fibrillation is a death sentence if not treated within 10 minutes, but John Gray was in luck. A member of the rescue squad applied the paddles of a defibrillator to his chest and with a whomp of electricity shocked his heart back into its normal rhythm.

Hundreds of times a day, defibrillators resuscitate people who would otherwise die in minutes. For implantable cardioverter defibrillators (ICDs), the success rate exceeds 99%. (External defibrillators, like the one used by the rescue squad, have a lower success rate, primarily because they are not always applied in time.) It’s a true medical miracle—and as befits a miracle, no one can explain why it works. “We don’t even know how the electric current goes into the heart,” says Gray. Nor does anyone really know how ventricular fibrillation gets started, or why a big shock brings it to an end.

Gray is one of many bioengineers and heart specialists who expect the answers to emerge from mathematical models of the heart. Researchers are experimenting with virtual hearts in part because it is easier than tinkering with a living, beating one. And there is no way to look beneath the surface of a real animal heart. As Alan Garfinkel, a cardiologist at the University of California, Los Angeles, puts it, “You can’t get the light into the meat.”

So far, mathematics has answered some questions but raised others. James Keener, a mathematician at the University of Utah, Salt Lake City, says that if defibrillation worked the way most experts think it does, then we would have a lot more dead patients. “If we invoke the prevailing theory, the probability of success is no greater than 20% in our numerical simulations—regardless of the amplitude of the shock,” says Keener. “Yet defibrillators have a success rate that approaches 100% as the shock gets larger. So we have a problem.”

Some people might argue that this is a good problem to have. If the treatment works, who cares that no one understands why? Garfinkel, for one: “I would urge that electrical defibrillation, the delivery of a huge, painful shock by an implanted $40,000 device, is neither a medically satisfactory solution, nor does it represent any scientific insight into the phenomenon,” he says. If cardiologists could understand fibrillation from first principles, he argues, they might be able to improve the treatment with less expensive equipment, less painful and damaging shocks, and potentially with antiarrhythmic drugs, which have until now been an embarrassing flop.

The mathematical heart

Mathematical models showed long ago that there is some method to the apparent madness of the fibrillating heart. Ventricular fibrillation is first and foremost a malfunction in the heart’s electrical circuitry. In a normal heartbeat, electrical activity starts near...
waves" of electrical activity start pin-
ation sets in, however, one or more "spiral
cells; and rises through the ventricles be-
to the top, in the atria; shoots to the bottom
Along special highly conductive muscle
areas where current is flowing through the
cells, from one conductor to the other. Those
transmembrane currents, to wipe it out (see
virtual electrode theory. About a decade ago,
John Wikswo, a biomedical engineer at
Vanderbilt University in Nashville, Tennessee,
noticed that an electric current applied to the heart
creates several spots of positive and negative
voltage—not just a single spot under each
electrode of the defibrillator. Wikswo
explained this observation with a model that
treats the heart as if it were a coaxial ca-
BLE. Like a coaxial cable, the heart has
two different conductors: the inside of
the cells and the outsides. The positive
and negative spots, or "virtual electrodes," are
places where current is flowing through the
Cell membranes, from one conductor to
the other. Those transmembrane currents,
to cover a scroll wave filament completely

Dana Mackenzie is a writer in Santa Cruz, California.