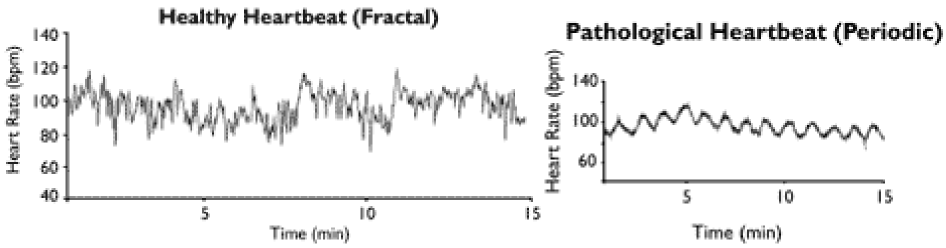
Healthy Heart Keeps Polyrhythmic Beat

Findings Could Aid Diagnosis, Treatment of Cardiac Disease

There is a startling rhythm beneath the steady pulsing of the heart, more like a jazz riff than a metronome. The casual pulse-taker and even the practiced user of a stethoscope may have a hard time picking up this rhythmic under structure, with its unpredictable repetitions and shifting beat.



Healthy heartbeats, as recorded in an electrocardiogram, display a complex patterning that consists of motifs that repeat themselves on different timescales (top). This fractal patterning may break down in the sickest hearts, producing a more periodic beat (bottom).

"You can't feel the sudden syncopations, the jazzy variability that is there," said Ary Goldberger, HMS associate professor of medicine at Beth Israel Deaconess Medical Center. "The resolution of our physical exam does not allow perception of the variations."

Two decades ago, Goldberger surprised the medical world when he demonstrated that far from plodding and repetitive, the healthy heartbeat displays a kind of treelike, or fractal, patterning. That is, it consists of sub patterns that repeat themselves at ever smaller timescales, producing apparently abrupt and unpredictable changes. By contrast, it is the sickest hearts that may beat in the steadiest and most predictable fashion.

Ary Goldberger observes that "there is a remarkable consonance of the natural world outside, which fractal, nonlinear, and nonstationary, is and what goes on inside our bodies."

Photo by Graham Ramsay

It now appears that the heartbeat is even more complex. Goldberger reports in the Feb. 19 colloquium issue of the ***Proceedings of the National Academy of Sciences*** that it consists not just of a single reiterating theme but of many different motifs operating at different points in the pulse. "It is like fractals upon fractals," said Goldberger. Using newly developed statistical techniques, he and his colleagues have discovered that this multifractal patterning breaks down in congestive heart failure.

Stepping Out of the Box

The pattern of Ary Goldberger's thinking may be as fractal as his heartbeat. From cardiology he has branched out, applying the same nonlinear perspective to such apparently disparate fields as music, architecture, and business. The musical foray occurred several years ago when colleague Chung-Kang Peng, HMS assistant professor of medicine at BID, playfully translated a fractal heartbeat pattern into musical notes. Goldberger showed the score to his musician son Zach, who composed an accompaniment. Their collaboration eventually resulted in an album, "Heartsongs: Musical Mappings of the Heartbeat."

Goldberger's involvement with the organizational world came about at a time when many hospitals were experiencing tremendous financial and other pressures. "I realized that nonlinear physiologists might have something to offer," he said, "because hospitals and other complex organizations are physiological systems writ large." The New England Complex Systems Institute invited Goldberger to speak to organizational leaders at a biannual conference. His message is similar to the one he delivers to physiologists - that healthy systems adapt by generating a wide repertoire of behaviors rather than by becoming stereotyped and regimented.

Healthy Irregularity

What is more, Goldberger reports, this principle--unpredictability in health, repetition in disease--describes not just the human heartbeat but many physiological patterns. Jeffrey Hausdorff, HMS assistant professor of medicine at BID, Goldberger, and colleagues have recently discovered that human walking is highly unpredictable and fractal in nature and that this patterning degrades in movement disorders such as Parkinson's disease (*Focus,* Aug. 10, 2001).

Though the findings appear to run counter to prevailing wisdom--that physiological systems seek balance or homeostasis they make sense when viewed in light of evolution. "There is a ruthless complexity and unpredictability to nature," said Goldberger. Organisms survive by developing systems that rather than becoming locked into a stereotypic equilibrium, are continuously variable and resilient. "The healthy systems appear to have an almost infinite array of responses which arise out of the way a system is set up," said Goldberger. He suggests that we may be at our healthiest when our physiological systems are at their bounciest.

If this is true, then a key to detecting, and possibly preventing, disease may be to monitor the variability or loss of variability of such vital signs as heartbeats. "You might be able to diagnose a condition like heart failure earlier or add diagnostic specificity to some other technique," he said.

Diseases might be treated by restoring variability or complexity to a system, though this could be a challenge since it is not clear what exactly causes complexity in the first place. The findings suggest that complexity is a consequence of the nonlinear nature of physiological systems. Rather than one thing simply leading to the next, as it does in a linear system, one thing can affect and be affected by many factors. In such a system, even tiny changes can have enormous consequences. "As soon as you let the smallest dollop of nonlinearity into a system, things can blow up," said Goldberger.

Change of Heart

That was not the lesson Goldberger learned during his medical training. Schooled in the classic view that physiological systems strive for constancy and equilibrium he was struck by the mismatch between the conventional wisdom and what he was seeing in patients. Their heartbeats, as reflected in electrocardiograms, displayed striking, if hidden, variations.

Using mathematical tools developed by statistical physicists, he discovered that healthy heartbeats display a fractal patterning that appears to degrade with some life-threatening heart diseases. Using even more refined methods, Goldberger, working with research associates Plamen Ivanov and Luis Amaral and Boston University colleagues were able to demonstrate the heartbeat's multifractal nature. They were also able to show that this multifractality was not the result of physical activity but, instead, an intrinsic property of the underlying physiological system.

Figuring out how this multifractality and other nonlinear mechanisms break down in conditions of disease is the next challenge. Goldberger believes that the main obstacle in this quest will be identifying usable data. "People have their own data sets and software tools, but they are not communicating," he said.

This is no idle rant. Under the auspices of the National Institutes of Health, Goldberger has established a resource center, PhysioNet, which includes a biomedical signal databank that he hopes will be to physiologists what the human genome project has been to molecular biologists. Maybe more. "It's like a gene bank for physiological signals," he said. "But it goes beyond that because we provide not only a repository and archive of physiological signals but also tools for handling data sets that are nonstationary and nonlinear."

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Source

http://focus.hms.harvard.edu/2002/March8_2002/cardiology.html