Fractal beat rate variations in heart cells

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Fractals are self-similar patterns across different scales that can have a geometrical form such as a snowflake, or appear in less obvious forms in, e.g., complex time series. It has been well established that a healthy heart exhibits fractal fluctuations in heart rate variations (HRVs), while the fractality may break down with heart failures and aging [1]. Recently, fractal dynamics have been observed in cardiomyocytes (CMs), i.e. individual heart cells [2, 3]. The CMs are derived from human-induced pluripotent stem cells (hiPSCs) out of adult tissues such as skin [4]. In 2012, S. Yamanaka was awarded the Nobel Prize and Millennium Prize for the development of this technology.

We apply detrended fluctuation analysis (DFA) [5] to investigate long-range correlations in HRVs of hiPSC-CMs from healthy subjects and patients with heart diseases, namely long-QT (LQT) syndrome and dilated cardiomyopathy (DCM). We have observed that both healthy and LQT hiPSC-CMs exhibit fractal dynamics, and that direct exposure to pharmacological compounds leads to an increase in the long-range correlation [3]. Through systematic studies on the relation between the electrocardiograms (ECGs) and the cellular level dynamics of the same person, we aim to uncover the pathophysiology of HRVs due to extra- and intra-cardiac inputs, such as diseases, medications, aging, and stress.

The biophysical origin of fractal dynamics in HRVs is not yet deeply understood. However, a computational, data-oriented approach with, e.g., multifractal analysis and advanced detrending algorithms, may provide important insights. The study could potentially lead to many applications in health-tracking industries through improved ECG diagnostics and algorithms for heart monitoring devices.

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