Long-term correlation in the beat rate fluctuations of single cardiac cells

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***Short Abstract* — Statistical properties of the interbeat interval time series of isolated single cardiac muscle cells were investigated. Several typical temporal patterns were identified in the spontaneous beating of single cells. In both patterns, presence of $1/f^{\beta}$ noise, multifractality was verified for sufficiently large timescales. Therefore, these properties were established as intrinsic at the single-cell level.**

***Keywords* — cardiac muscle cells, beat rate, fluctuations, $1/f^{\beta}$ noise, multifractality.**

I. Purpose

SCALE-invariant fluctuations with long-term correlation is found in various types of physiological signals, and the characteristics of fluctuations provide important measures on the physiological state [1]. In contrast, it has been also known that several types of cells, including cardiac muscle cells, nerve cells, and fibroblasts, exhibit scale-invariant fluctuations in the dynamics of membrane potential at large timescales. Because this phenomenon has been observed in multiple types of cells, scale-invariant fluctuations at large timescales are expected to be a generic property independent of the cell type. However, little of the mechanism behind such fluctuations has been clarified so far.

A cardiac muscle cell culture is an excellent model system in order to study the characteristics of long-term fluctuations, because non-invasive measurements of beat timings over an extended timescale is possible. As for cardiac muscle cells, the presence of scale-invariant fluctuations in long timescale was also reported [2-3]. However, as the earlier studies were performed on cell aggregates, it was not clear whether $1/f^{\beta}$ and multifractality, both of which is known to present in *in vivo* heartbeats, are also present at the single-cell level. In this paper, we describe experimental and theoretical results on the statistical properties of spontaneous beating of isolated single cardiac muscle cells.

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II. Results

First, several typical temporal patterns were identified in the spontaneous beating of single cardiac muscle cells. These patterns include steady beating, termed Pattern A, and intermittent bursting, termed Pattern B. Under the same environmental condition, different cells exhibit different temporal patterns. Furthermore, spontaneous transition is also found in the beating of the same single cell during a long-term observation.

We studied the statistical properties of the abovementioned temporal patterns. For Pattern A, the distribution of interbeat intervals (IBIs) formed a Gamma-like unimodal distribution. $1/f^{\beta}$ noise was identified in the IBI time series in a sufficiently large timescale. As for Pattern B, IBIs formed a bimodal distribution. $1/f^{\beta}$ noise was also identified in the IBI time series of Pattern B in a sufficiently large timescale.

We further examined whether multifractality exists in each patterns. As a consequence, both patterns possess multifractality, i.e., local Hurst exponents exhibit a rather wide spectrum with a peak around zero.

The abovementioned experimental trends were successfully explained by an integrate-and-fire type mathematical model, which was originally described by Izhikevich [4], in which a long-term-correlated noise was incorporated.

III. Conclusion

In the present study, it has been established that the $1/f^{\beta}$ noise and multifractality is an intrinsic properties in the spontaneous beating of isolated single cardiac muscle cells.

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