Acta Scientific Neurology

Volume 2 Issue 4 April 2019

Mini Review

Bacterial Intelligence

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Received: February 22, 2019; **Published:** March 18, 2019

Abstract

The recent findings clearly indicate that bacteria communicate with each other as well as with the surrounding. This communication is done through chemical molecules as well through electrical signaling. Moreover, the bacteria organize and make various structures in Biofilm. We call these types of behaviors of bacteria as intelligence.

Keywords: Bacterial Communication; Chemical Signaling; Electrical Signaling; Biofilm; Intelligence

Introduction

Some bacteria are able to communicate with their surrounding bacteria by using a chemical signaling. This chemical signaling mechanism is formally known as quorum sensing. Microbiologists intensively studied this critical biochemical phenomenon to understand the information processing system of different bacteria and their collective behaviour during last few decades. Bacterial communication system is controlled by autoinducers (chemical signaling molecules). Bacteria prepare their optimal survival strategies to survive in different environment by using different quorum sensing circuits. Quorum sensing bacteria eject autoinducers in the environment and the surrounding bacteria can take in the autoinducers. In this fashion the concentration of the autoinducers increase as a function of cell number density (See figure 1). When the concentration reaches as minimal threshold, a collective bacterial behaviour is initiated, this triggers cascade of signaling events and regulate an array of biochemical process such as biofilm formation, swarming, virulence, bioluminescence, symbiosis, competence, antibiotic production, sporulation, conjugation and gene expression [1]. At the same time bacteria communicate through potassium ion-channels mediated electrical signaling process and coordinate metabolism within the biofilm and hence conduct a long range electrical signaling within bacterial biofilm communities through the propagating wave of potassium [2]. Motile bacterial cells are attracted towards biofilm and the attraction depends on membrane potential (See figure 2). Bacterial biofilms are in general bacterial community, which undergo metabolic oscillations and coupled through electrical signaling process (K+ waves) and synchronized biofilm growth dynamics. This Coupling increases competition by also synchronizing demand for limited nutrients. It has been observed that biofilms resolve this conflict by switching from in phase to anti-phase. Different biofilm communities take turns consuming nutrients. Thus, distant biofilms can coordinate their behavior to resolve nutrient competition through time-sharing [1].

Theoretical approaches

Baskarana., *et al*. [3] broadly classified various theoretical approaches into three main categories as follows:

I. Flow induced by individual or pairs of swimmers moving in a viscous fluid by studying simplified models of moving Particles.

II. Physics on length scales large as compared with the size of the swimmers by proposing phenomenological hydrodynamic equations built by modifying the well-understood hydrodynamics of liquid crystal to include non-equilibrium terms that account for the activity of the system.

III. A third approach has been the derivation of the continuum hydrodynamic equations from specific microscopic models of the dynamics.

Figure 1: (a) Schematic visualization of bacterial life and a multistage process of bacterial biofilm formation, (b) bacterial quorum sensing mechanism, where bacteria (single cell) can emit quorum sensing molecules, but no quorum sensing occurs in low cell density. On the other hand, bacteria secrete quorum sensing molecules, which are sensed by the other bacterial cells in the vicinity at high cell density (quorum sensing occurs), (c) illustration of densely packed bacterial cells, which can be considered as course grained system

Figure 2: (a) Illustration of potassium ion-channels mediated electrical communication process in bacterial communities, (b) Illustration of species independent attraction of motile bacterial cells toward biofilm through electrical signaling.

The observational findings indicate that water fluidity is modified, in a nontrivial manner, by the presence of bacteria above a threshold number density. Under such threshold conditions swimming bacterial suspensions impose a coordinated water movement on a length scale of the order (10 - 100) micrometers compared with a bacterial size of the order 3 micrometers. Koch., *et al*. [4] consider it as living fluid.

One of the present author (SR) along with Rodolfo Llinas [5] emphasize that densely packed bacteria may be viewed as 'bacterial fluid' or 'living fluid 'similar to that of dense granular systems. In this framework, there exists a non-thermal fluctuation associated to the finite size of the bacteria similar to the finite size of the granules, which is called non-local noise. This is non –thermal in nature. This kind of fluctuation helps to understand the communication of bacteria at the level where communication occurs through chemical signaling depending on the kinematic viscosity associated with this non-local noise. Complex Ginzburg-Landau equation is used to describe the behavior of bacteria based on chemical signaling where the kinematic viscosity can be traced back to its origin to the above mentioned non-local noise. The kinematic viscosity of bacteria will be small as it requires to have large density for quorum, so that emergence of metastable state is possible for short time scale. During this time period the fluctuation of stress due to autoinducing molecules will produce fluctuation in the configuration of the system which induce shear somewhere else. This process is known as self-activated process which occurs in rheology.

This mechanical stress is responsible for the gene expression of the bacteria and quorum happens.

Recent studies show [2] that apart from using chemical molecules, bacteria can communicate over a long distances which is enabled by bacterial ion channels. This electrical communication within bacterial communities occurs through spatially propagating waves of potassium.

The electrical communication among the bacteria is described by a special form of Ginzburg-Landau equation where the noise arising out of opening and closing of ion channel plays a significant role. As soon as one considers the effect of non- local noise as perturbation to this particular type of Ginzburg-Landau equation we reach at the original complex Ginzburg-Landau equation. Moreover, we show different spatiotemporal patterns and chaotic behavior of this complex bacterial communication process [6].

Concluding Remarks

Iberall and Llinas [7] postulated that the basic organizing force for the living system control dynamically the ratio of bulk to shear viscosity. In the present scenario of densely packed bacteria the ratio of bulk viscosity and the shear viscosity is associated to this type of self-activated process which makes the expression of genes possible and synchronization happens. So, this study may shed new light in understanding the basic organizing force for living system.

Margulis and Sagan [8] in their thought provoking book "Microcosmos" tried to retrace evolutionary history from the novel perspective of the bacteria and they used the term bacteria intelligence. Infact, the organizing capacity and the formation of various patterns or structures by the bacteria is nothing but the intelligence. The bacteria will orient themselves, they will work together to make structures. This ability of bacteria to respond specifically to the environment and to act creatively is a property of life. We can call it the intelligence of bacteria.

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