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Review Article

Group Behavior of Unicellular Organisms for Better Survival Leading to Multi-Cellular Organisms

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Abstract

The transition from unicellular to multicellular organization is a major step in eukaryotic evolution. In the beginning unicellular organisms ruled the earth. For more than 3 billion years after the appearance of unicellular microbes, life gradually got more complicated. Today, most plants, animals, fungi, and algae are composed of multiple cells that work collaboratively as a single being. But how did life evolve from unicellular simplicity to multicellular complexity? Explanation to this question is one of the major evolutionary puzzles of our time. In this context it can be said that the group behavior of unicellular organisms with better survival advantage is crucial to the development of multicellularity from unicellular life. It is well known that the bacteria, a primitive life form, remaining in groups in biofilm can well protect themselves from antibacterial substances. This group behavior or colonial form found in other unicellular living forms, like charophytes algae, volvocine algae and choanoflagellates led to increasing organismal size which helped in escaping microscopic predators such as ciliates.It may be presumed that after the development of well advanced eukaryotic cell from prokaryote through endosymbiosis, the well organized genetic structure and better information dissipation capability with critical development of cell membrane signaling pathway with better way of keeping intercellular communication, multiple eukaryotic unicellular forms in a collection followed this group behavior for a long time and receiving triggering factors from multiple sources and switching back and forth of their gene expression based on environmental condition, evolved into multicellular eukaryotic form.

Keywords: Group behavior; Endosymbiosis; Cell differentiation; Cell-cell interaction; Biofilm; Ectoderm; Endoderm; Mesoderm

Introduction

Understanding the evolution of eukaryotic cellular complexity and the development of multicellular living form from unicellular organization is one of the grand challenges of modern biology. More than 50 years ago when the question of how Eukaryotes first evolved arose, it was quite puzzling. But now there is one fact upon which everyone agrees: endosymbiosis, the bringing together of distinct cells, one inside the other, has been an important factor in the evolution of eukaryotic cell. Though Russian botanist Constantin Mereschkowsky [1] is widely hailed as the 'founding father' of endosymbiotic theory and other scientists like Andrey Famintsyn and Boris Kozo-Polyansky, Paul Portier and Ivan Wallin [2,3] helped to lay the foundation for endosymbiotic thinking long before the advent of molecular sequencing, in 1967 Lynn Margulis [4,5] at the University of Massachusetts formulated the hypothesis for the origin of eukaryotic cell that two separate mutually beneficial invasions of a prokaryote cell produced the modern-day mitochondria and chloroplast as eukaryotic organelles. So the development of eukaryotic cell from the prokaryotic one is one step progress towards the pathway of more complex multicellular form of life. But how did life make the spectacular leap from unicellular simplicity to multicellular complexity? Explanation to this question is really one of the major puzzles of evolutionary biology.

Creation of higher life from simple life form is requirement based towards more complexity for better performance and better survival. To explain the creation of multi-cellular organisms from the unicellular organisms it can be said that though multicellular form rarely can be found in prokaryotes as they are the primitive form of cell and their genetic information is not well organized enough to create multicellular form, but later on with the development of eukaryotic cell from prokaryote through endosymbiosis, the well organized genetic structure and better information dissipation capability with critical development of cell membrane signaling pathway with better way of keeping intercellular communication, multiple eukaryotic unicellular forms in a collection followed this group behavior for a long time and probably receiving triggering factors from several sources and switching back and forth of their gene expression based on environmental condition, evolved into multicellular eukaryotic form.

Key features of multicellular organization

For the development of multicellular living form, cells divided and organized themselves into new three-dimensional structural form and the key features of multicellular organization are adhesive interactions between cells to maintain a physically connected form; cell specialization, creating cells with different characteristics at different positions; cell interaction and cell communication by diffusible extracellular molecules like hormones and different means of signaling between cells and restricting reproductive capability to a particular group of cells. Also the defined architectural pattern, shape and size of multicellular organisms require a spatially co-ordinated growth and division of group of cells [6].

Cell differentiation is extremely important towards the development of multicellular organisms. This process can be studied in the embryonic cells changing from their simple form into more specialized cells both in structure and function. While all the cells of a multicellular organism contain the genetic material responsible for cell development, some of the genes, in a group of cells are either expressed or repressed allowing that group of cells to differentiate into specific types of cells for a given function. This has been made possible by certain signals inside and outside the cell that trigger which genes will be expressed or depressed.

Cell-cell interaction in a co-ordinated fashion is another important characteristic of multicellular organisms. Many molecules like peptides, proteins, amino acids and steroids are present in the extracellular spaces between cells and their selective reaction with specific cell surface receptor can transport signals in a co-ordinated fashion to different parts of multicellular organisms for maintaining their normal physiological function.

Driving forces behind multicellularity

For more than 3 billion years after the appearance of unicellular microbes, life gradually got more complicated. But what were the underlying driving forces that influenced the evolution of multicellularity? Multicellular organisms in comparison to unicellular one require a whole set of tools and genetic informations for their survival. Multiple cells have to stay sticking together, communicating with one another, sharing oxygen, food etc. and cell differentiation with specialized jobs in different parts of the body. Though unicellular prokaryotes like bacteria and archaea have been living on earth for the last 3.5 billion years and complex multicellular animal first emerged somewhere between 600 and 800 million years ago, so during these time gap multicellularity gradually evolved. Some evolutionary biologists share the opinion that during the course of evolution, transition from unicellular to multicellular form happened separately different times.

In this context it can be said that the group behavior of unicellular organisms with better survival advantage is crucial for the development of multicellularity from unicellular life. It is well known that the bacteria which can be considered as the primitive life form, remaining in groups in biofilm can well protect themselves from antibacterial substances. This group behavior of bacteria inside biofilm pertains to survival advantages. This same property of group behavior or colonial form found in other unicellular living forms, like charophytes algae, volvocine algae, chlamydomonas and choanoflagellates led to increasing organismal size which helped in escaping microscopic predators such as ciliates. Among them charophyte algae are the closest relatives of land plants and predicts the transition from unicellularity to multicellularity of land plants. Volvocine algae predict the graded series of increasing cell specialization and developmental complexity. They are well suited for the study of origin of multicellularity and they contain genera that are unicellular and multicellular [7]. Choanoflagellates are the closest unicellular ancestors of animal and recent researches have focused on choanoflagellates for the origin of animal multicellularity (King., *et al*. 2008, Alegado and King 2014) [8,9].

Certain characteristics that predict unicellular to multicellular transition

One early multicellular form probably was undifferentiated filaments. Prevalence of filamentous forms in both aquatic and terrestrial environment in diverse algal lineage suggests that filamentous form has multiple advantages as filaments may serve as protection against grazing predators. It can also anchor colonies in place effectively while allowing maximum contact with the surrounding environment which is likely to be useful in nutrient exchange (Niklas., *et al*. 2013) [10]. Another characteristic feature which predicts unicellular to multicellular transition can be found in coenocytic algae (also called siphonous algae) that are large single cell with multiple nuclei in a common cytoplasm. Their sizes vary from centimeters to meters making them one of the largest single cells on earth with multiple types of specialized subdomains. One example of algae with multiple specialized subdomains is marine alga Caulerpa which has multinucleate cell and contain three distinct tissue types resembling roots, stems and leaves (Jacobs, 1970) [11]. In the genus Eudorina, large spheroidal colonies of 32 to 64 cells can be formed by the extensively secreted extracellular matrix in which the cells of the colony are embedded which is very similar to the group of bacterial cells remaining in biofilm which is also extracellular matrix. Volvocine algae are well suited of the study of multicellularity because multicellular or colonial volvocine genera can be arranged in a graded series of increasing cell number, colony size and degree of cell differentiation which is termed volvocine lineage hypothesis and predicts how complexity evolved in specific sub-lineages. (Kirk DL. 2005) [12].

After the development of multicellular eukaryotic form, as the plant kingdom was capable to capture sunlight to produce their own food, so the survival requirement of them was less in comparison to the animal kingdom, so the need or requirement based evolutionary development of organized body systems like gut, locomotory organ, nervous system is lacking in plants but can be found in animals. In this respect it is worth mentioning that Nicole King, a biologist at the University of California, Berkeley, studied choanoflagellates, the closest living relative of animals and stressed on the influence of bacteria on the development of animal life. (Nicole King, 2008) [8,9].

Conclusion

However, it can be presumed that after the development of well advanced eukaryotic cell from prokaryote through endosymbiosis, the well organized genetic structure and better information dissipation capability with critical development of cell membrane signaling pathway with better way of keeping intercellular communication, multiple eukaryotic unicellular forms in a collection followed this group behavior for a long time and receiving triggering factors from multiple sources, one of the most important of which may be the bacterial world, and probably switching back and forth of their gene expression based on environmental condition, evolved into multicellular eukaryotic organisms. This multicellular eukaryoyic cellular mass with multiple functional requirements later on distributed its different functions to different group of cells according to its positional advantages. For example, the peripheral cells of the mass with its positional advantages were involved in keeping communication with the surrounding environment. This trend was maintained and if we examine the embryonic tissue of higher living forms then we observe that the nervous system which is responsible for maintaining communication with the surrounding environment and executing motor function accordingly is also developed from the peripheral ectodermal tissue of embryo. Similarly it was easy for unicellular living forms in taking their nutrients from their surroundings by diffusion, phagocytosis etc. But in multicellular living form, though the peripheral cells were getting their nutrients from the surrounding, the middle and inner cell mass were having difficulty in getting their nutrients. So the middle cell mass gradually transformed into connective tissue of circulatory system which supply food and oxygen to different parts of the body and inner cell mass transformed into storehouse of nutrients as gut. This trend was maintained and if we examine the embryonic tissue of higher living forms then we observe that the circulatory system which is responsible for transporting nutrients to different parts of the body and the gut which stores and digests the nutrients, are also developed from the middle cell mass(Mesoderm) and inner cell mass(Endoderm) respectively.

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