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The Central Question in Virology: The Origin and Evolution of Viruses

Luka AO Awata[1]*, Beatrice E Ifie[2], Pangirayi Tongoona[2], Eric Danquah[2], Samuel Offei[2] and Phillip W Marchelo D'ragga[3]

[1]*Directorate of Research, Ministry of Agriculture and Food Security, South Sudan*

[2]*College of Basic and Applied Sciences, University of Ghana, Ghana*

[3]*Department of Agricultural Sciences, University of Juba, South Sudan*

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***Corresponding author:** Luka AO Awata, Directorate of Research, Ministry of Agriculture and Food Security, Ministries Complex, Parliament Road, P.O. Box 33, Juba, South Sudan

Abstract

Viruses are major threats to both animals and plants worldwide. A virus exists as a set of one or more nucleic acid molecules normally encased in a protective coat of protein or lipoprotein. It is able to replicate itself within suitable host cells, causing diseases to plants and animals. While the three domains of life trace their linages back to a single protein (the Last Universal Cellular Ancestor (LUCA), information on parental molecule from which all viruses descended is inadequate. Structural analyses of capsid proteins suggest that there is no universal viral protein and different types of virions are mostly formed independently. As a result, it is impossible to neither include viruses in the Tree of Life of LUCA nor to draw a universal tree of viruses analogous to the tree of life. Although the concepts on the origin and evolution of viruses are well documented, the structure and biological activities of viruses are paradoxical. This assay will provide a brief background on the discovery of viruses and highlight the universal hypotheses that have been adopted to explain the origin of viruses. The text will also look at the current views on the nature of viruses and how they evolved; and an attempt will be made to draw some assumptions towards understanding of how modern viruses originated. The views formulated would shed some lights on understanding of viruses and their evolution.

Keywords: Viruses; Protein; Cellular ancestor; Parasitic organisms

Abbreviations: LUCA: Last Universal Cellular Ancestor; TMV: Tobacco Mosaic Virus; DNA: Deoxyribonucleic Acid; RNA: Ribonucleic Acid; mRNA: Messenger Ribonucleic Acid; TRV: Tobacco Rattle Virus

Introduction

Viruses are a set of one or more nucleic acid molecules normally encased in a protective coat(s) of protein and can organize its own replication only within suitable host cells [1]. They are parasitic organisms that live in infected cells and produce virions to disseminate their genes within the host's cells hence causing various diseases to plants and animals [2]. Generally, viruses are smaller than the smallest bacteria however, there are some few instances where a virus such as Mimivirus (400nm in diameter) is much larger than the smallest bacteria Mycoplasma (*Ralstonia pickettii*) which is just 200-300nm long [3]. Viruses affect all the three domains of life - Archaea, Prokaryotes and Eukaryotes [1,2,4]. They are obligate cellular parasites and can replicate only after they invade the host's cells. This is because viruses do not have biochemical or genetic potential to generate the energy necessary to drive all biological processes such as synthesis of macromolecular [3]. Viruses are the most abundant life forms and the range of viral genes is greater than that of cellular genes [5].

While the three domains of life trace their linages of protein back to a single protein (the last universal cellular ancestor (LUCA), so far there is no information to clearly point to the original molecule from which all viruses descended [3]. Structural analyses of capsid proteins suggest that there is no universal viral protein and different types of virions are mostly formed independently. This makes it impossible neither to include viruses in the Tree of Life of LUCA nor to draw a universal tree of viruses analogous to the tree of the LUCA [2,5]. During the intracellular phase of the viral life cycle the viral molecules are complete but lack virus specific membrane (eclipse phase) and thus, are invisible and free or dispersed within the host's cells [5]. Concepts on the origin and evolution of viruses are well documented however, the structure and biological activities of viruses still make the concepts remain a paradox in the mind of many. This assay will provide a brief background on the discovery of viruses and highlight the universal hypotheses have been adopted for origin of viruses. The text will also look at the current views on the nature of viruses and how they evolved; and lastly conclude by drawing up some assumptions towards understanding of how modern viruses originated.

History of Virus Discovery

Though viruses might have existed in the universe sine the evolution of life, not much was known about the nature of viruses until 1892, when a prominent Russian botanist Dimitri Ivanovsky published the first report showing that the agent causing tobacco mosaic disease passed through porcelain filters and could not be seen or cultivated [4]. He proposed that the agent that passed through the very small pores of the porcelain filters and caused the diseases was not the tobacco mosaic microbial pathogen, but a toxin produced by this pathogen. This finding was later proved in 1898 by a Dutch microbiologist Martinus Beijerinck, that the filterable tobacco mosaic agent (toxin) was a novel type of microorganism that he termed "a contagious living fluid. In years that followed, Karl Landsteiner and Erwin Popper, and others after them, found that viruses could affect animals and human beings as well. Salvador Luria, Max Delbruck, and many others (1930s) used these viruses as model systems to investigate many aspects of virology, including virus structure, genetics and replication.

In 1935, American biochemist Wendell Stanley, crystallized tobacco mosaic virus and found that it contained particles which were not fluids but other forms that were fundamentally different from the conventional cellular microorganisms. Best and others confirmed the nucleoprotein nature of tobacco mosaic virus (TMV) and they detected that the virus contained 95% protein and 5% nucleic acid. Crick and Watson observed that protein coats of small viruses are made up of numerous identical subunits either arranged as helical rods or as spherical shell with cubic symmetry. Lister, using sucrose density gradient fractionation, discovered the multiple-component (bipartite) nature of TRV genomes. Thus, it became clear by the1970s, that during their intracellular stage, "DNA viruses" have both nucleic acids, DNA and RNA. During the 1980s, major advances were made and better methods or diagnosis of viral diseases centering on serological procedures based on nucleic acid hybridization were developed. This led to a holistic definition of viruses by Matthew. Discoveries of viruses played very important role in understanding of all types of viruses, including those of humans which are much more difficult to propagate and study. However, history of virology went beyond viruses, to include development of experimental tools and systems with which viruses could be examined and which opened up whole new areas of biology, including not only the biology of the viruses themselves but also the biology of the host cells on which these agents are entirely dependent.

Fundamental Theories and Hypotheses on the Origin of Viruses

It was recently proposed that the living world can be divided between ribosome-encoding organisms (modern cells) and capsid-encoding organisms (viruses). However, as the modern cells are descents of a single ancestor, the LUCA, there is not a single protein molecule common to all viruses. In addition, new viruses have also emerged during the cause of evolution. The RNA molecules that existed before cells, cell components and micro-organisms have been suspected as possible origins of viruses. Additionally, recombination between virus strains, reassortment between virus strains, acquisition of cell genes and errors during nucleic acid replication have been implicated in evolution of viruses [6]. Of recent, understanding the origin of viruses has attracted a lot of attention from scholars. As a result, three universal theories have been adopted on the origin of viruses [1,2,5].

The first virus hypothesis (Independent entities theory)

Viruses have evolved from a self-replicating material that existed in the prebiotic mRNA world. They are the remnants of the pre¬-cellular life forms. RNA and its origin, perceived as the first molecules of life, was able to act as a nucleic acid carrying information and capable of self-replication hence an entity of independent existence. In this theory, RNA viruses are thought to have been descendants of the RNA world and the DNA viruses evolved later from RNA.

The second virus hypothesis (Reduction/degenerate/regressive evolution theory)

This states that viruses originated as a result of reduction of unicellular organisms via parasitic-driven evolution. This means that cells of unicellular organisms lost their membranes, cell walls and other structures as well as their cytoplasm, hence retaining only the nucleic acid and some vital proteins in order to live in other cells as parasites.

The third virus hypothesis (The escape theory)

Viruses are thought to have originated from fragments of genetic material that escaped from the control of the cell and became parasitic. Plasmids and mobile genetic elements are extracellular genetic materials capable of exit and entry into the genomes of other cells. This phenomenon provides a glimpse of the possibilities of escape by the genetic elements provided by this theory.

Current Opinions on the Origin and Evolutionary of Viruses

The evolutionary origin of viruses remains controversial and recently, several authors have suggested that evolution from the RNA world up to the LUCA could have occurred before the invention of cells. Forterre [2] argues that evolution of the RNA world came due to completion between cells and viruses resulting into evolution of prokaryote and eukaryote and the three cellular domains of archaea, bacteria and eukaryotes. Jalasvuori & Bamford [7] have recently suggested that Life started with protoviruses infecting non-living vesicles that became protocells. In this scenario, protoviruses may have been membrane-surrounded RNA.

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Bandea [5] hypothesizes a fusion model which states that "viruses resulted from fusion of parasitic cellular species with their host cells in order to gain better access to host resources". By losing their membrane and cellular structure within the host cell, the parasitic species gained full access to precursors for their survival and evolution. The fusion theory is supported by the evidences that new viral lineages have originated from parasitic cellular species and the process might still be active. Forterre & Prangishvili [2] suggest that viral genes originated in the virosphere during replication of viral genomes and/or were recruited from cellular lineages which are now extinct. This suggestion agrees with the structural analyses of capsid proteins which revealed that at least two types of virions originated independently before the LUCA [8,9].

General Observations on the Above Hypotheses

Although the universal hypotheses of the origin of viruses have provided greater insights into the understanding of viruses and their evolution, more controversies remain. Hypotheses one and two are already strongly disputed while several new assumptions are being suggested by different authors. It is observed in this essay that the three hypotheses seem to have some gaps. Hypothesis one (Independent entities) proposes that viruses started from a unit material that was able to replicate itself alone and form viruses. This hypothesis does not explain why and how viruses left their own domains and migrated into the world of LUCA or into the smaller worlds (archaea, prokaryotes, and eukryotes) after disintegration of the LUCA. If viruses were separate entities during the pre-cellular period, not all viruses would have migrated meaning, some ancestral forms of viruses may have been around in this present time, surviving on their own.

Hypothesis two (reduction theory) stipulates that viruses were unicellular organisms and they were reduced into the present forms due to interactions between viruses and the host's systems over time. This assumption concentrates on the modification of the unicellular organisms (viruses) from within the hosts but falls short of explaining whether the unicellular organisms before entry into their hosts were already complete parasitic forms (viruses). If viruses existed prior to migration into LUCA of the domains of life then, viruses should show linages that trace back to their own LUCA.

The third theory suggests that viruses might have originated from fragments of genetic material that escaped the cellular control of the host's cells and became parasitic. This theory though has been considered more relevant to viral definition, does not tell the divergence between virus linages and the LUCA from which the three domains of life originated. If viruses were modifications of other cells of the organisms, both viruses and the cellular organisms should have shared same tree of life.

Conclusion

Understanding of how viruses came to existence is very intricate as the viruses themselves are even more complex. Further discussions into the origin of viruses bring more insights as well as challenges. Based on the theories and observations on evolutionary origin of viruses, the following arguments could be presented to shed more lights on the origin of and evolution of viruses.

a. Two members of LUCA might have existed independently in the pre-cellular world and each one developed its own domains (domains of life and domains of viruses).

b. Parasitic interactions might have existed between some domains of viruses and the domains of life.

c. Natural extinction might have occurred at the disadvantage of viral domains hence the parasitic viruses might have survived and parasitized on the domains of life to the present day.

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