Microreviews in Cell and Molecular Biology 2012

Arsenic-eating Bacteria?

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Key Words:
Arsenate, phosphate, bacteria, lethal

Wolfe-Simon et al. (1) performed an experiment in 2010 that resulted in the discovery of a class of microbes that can synthesize arsenate in place of phosphate. There are only six essential elements that living organisms explicitly require, but there are countless combinations of other elements that can be lethal. Arsenate is usually one of those lethal combinations. The first research article covered in this microreview postulated the existence of a bacterial species that can alter the chemical composition of their biomolecular structures; DNA, nucleic acids, etc. The second research article was published in 2012 and its basis is the refutation of the first article's hypothesis. It shows the numerous flaws in the experiment and gives specific ideas as to why Wolfe-Simon et al. could have come to the conclusion they did.

Introduction

A common assumption made by most scientists is that phosphorous is essential for all living cells. Well, in 2010, geomicrobiologist Felisa Wolfe-Simon and colleagues (1) thought they may have found bacteria that can synthesize arsenic in place of phosphorous. Mono Lake, California has extremely high arsenic levels and is the breeding ground of a bacterial species known as GFAJ-1. This microbe thrives in conditions thought to be toxic to all life. From the Halomonadaceae family of proteobacteria, GFAJ-1's discovery could potentially change the way we define the chemistry of life (1).

The phosphate ion, PO43-, is vital for maintaining several key processes in a cell. "It maintains the structure of DNA and RNA, combines with lipids to make cell membranes, and transports energy within the cell through the molecule ATP (adenosine triphosphate)," according to Wolfe-Simon et al. (1). Conversely, the arsenate ion, AsO43-, poses a dangerous threat to living cells due to its deadly toxicity. Moreover, "arsenic has the same tetrahedral structure and bonding sites as PO43-, arsenic and phosphorous have similar atomic radii, as well as near identical electronegativities. It is so similar that it can get inside cells by hijacking phosphate's transport mechanism"(1). The inability of metabolic pathways to distinguish between AsO43-and PO43- inevitably permits AsO43- to enter the cell. This contributes to its high toxicity to most organisms (1). The idea is that, because of their similarities, AsO43- should be able to perform phosphate's functions in the cell.

The experiment constructed by Wolfe-Simon et al. used samples of mud obtained from Mono Lake, which were mixed into an artificial salt medium that contained no PO43- and varying levels of AsO43-. The primary distinguishing factor used to identify the supposed "AsO43--driven" specimen was 16S ribosomal RNA (rRNA) sequence phylogeny. Each mixture was extensively diluted to "prevent accidental carryover of autochthonous phosphorous." To be sure of the process, the experimenters performed six decimal-dilution transfers to attain a dilution of 10-7, followed by inoculation of agar plates containing the same elemental makeup as the synthetic medium. Various isolated colonies were selected from these plates and reintroduced into a synthetic liquid medium lacking PO43-. From these final samples the AsO43-concentration was gradually increased to determine the optimal level for growth.

Once cultures were grown, the researchers attempted to find arsenic situated within DNA. Using various types of spectroscopy (ICP-MS, NanoSIMS, MicroXANES, MicroEXAFS, MicroXRF, and even X-ray) Wolfe-Simon et al. were able to quantitatively measure the presence of arsenic in various biomolecules (1).

These experiments demonstrated AsO43--dependent growth. Indeed, when PO43--driven GFAJ-1was

compared with AsO43--driven samples there were observed morphological differences between the two. Some organisms have developed resistance genes to manage arsenic's toxicity, while other arsenic-utilizing microbes can "conserve energy for growth from the oxidation of reduced arsenic species." In other words, the organisms can use ASO43- during respiration. However, GFAJ-1 is merely a facultative arsenophile and "grows considerably better when P concentration is dominant (1).

Wolfe-Simon et al. reported they had discovered a new strain of bacteria that could alter its basic biomolecules through substitution of arsenic for phosphorous. They did not, however, have an explanation for how arsenic is physically situated within the biomolecules, nor did they present any information as to how the mechanisms of such molecules function.

Recent Progress

The research behind this article seemed sound until earlier this year. In January, microbiologist Rosemary J. Redfield (2) refuted the results obtained by Wolfe-Simon et al. Redfield provides essential insight into the experiment by pointing out several glaring errors performed throughout the experiment. Contaminated samples, contaminated reagents, and improper DNA and chromosomal DNA fraction purifications were all implicated as possibly giving false results.

The experimenters "meticulously sterilized the equipment and reagents to be used." But they only did so for the first step of their experiment, the elemental analysis (3). However, she pointed out that little effort was put in toward eliminating contamination of the biological samples themselves. The second step of Wolfe-Simon's experiment was the inoculation of agar plates. Redfield notes that the reagents used for the cultures were impure. From Redfield's perspective, trace phosphate that was not eliminated from the growth media prior to inoculation was sufficient to account for all of the observed growth. Redfield made clear that the hypothesis that GFAJ-1 cells can grow in arsenic environments is potentially incorrect. Redfield brought light to several errors in experimental procedure performed by Wolfe-Simon et al. Her work clearly emphasized doubt of arsenic-driven life.

Discussion

The overall response to the research conducted by the respective authors is that of respect and scientific gratitude. If scientists did not actively try to discredit one another's ideas, there would be no progression toward a more insightful perception of how our world functions. The first two articles, however far-fetched they seem to readers, are a complement to the idea of scientific discovery, and prompted the desired response from peers within the scientific community. To conclude, it should be well documented that errors in scientific experiments are a much more common method of obtaining the correct answer than actually getting the right answer from the start. The idea that life could be sustained using arsenic in place of phosphorous was a profound ripple in the ever-growing ocean of scientific failures.

References

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