Micro Review of Findings Regarding Arsenic Based Life

**Abstract:**

A bacterium has been discovered recently which contradicts the current model of DNA. It uses arsenic in place of phosphorus throughout the genome. Recent findings using the organism GFAJ-1 drive these new ideas about what constitutes life, but these findings are not without criticism and may not be enough to support the claim of life without phosphorus in the genome and biosynthetic processes.

**Background:**

Carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur are the basic elements required for all currently known and accepted forms of life. These elements are used to make all cells, the basic units able to sustain life, and all of the biosynthetic molecules within them including Deoxyribonucleic acid, DNA. The currently accepted model for the structure of DNA, first published by Watson and Crick, is based on a double stranded alpha helix pattern of repeating nucleic acids with a phosphodiester linked sugar backbone (1). This alpha helical structure has two strands of DNA which run antiparallel and are paired to each other. Each strand consists of two parts: a phosphodiester linked sugar backbone of deoxyribose and a nitrogenous base. Deoxyribose is a five membered ring structure consisting of four carbons and one oxygen with a hydroxyl group on the 1’ and 3’ carbons, and a methoxy group on the 4’ carbon. In the DNA structure the 1’ carbon has a nitrogenous base attached to it. The 3’ and 5’ carbons of the ring structure are phosphodiester bonded to a phosphate group (PO4) which links it to the deoxyribose both before and after it in the phosphate sugar backbone strand. Phosphate groups play an important part in the DNA of all life by linking each nucleotide together to form the strands of DNA.

**Recent Findings:**

In 2010, NASA published a news article stating that their researchers had discovered a new bacterium which can use arsenic alone in place of phosphorus in its DNA and for other biosynthetic molecules within the cell (2). NASA claimed that this discovery could be a sign of other life on other planets that do not have a high enough phosphorus content to support phosphorus-based life. The article was released to the media before any scientific articles had been published or peer reviewed on the subject. The first article that was eventually published on the subject of bacterial integration of arsenic into biosynthesized molecules was published midway through 2011 by Felisa Wolfe-Simon et al. (3). Wolfe-Simon’s article had many arguments in support of the claim of life based on arsenic rather than phosphorus.

Arsenic belongs to the same group in the periodic table as phosphorus, group 5, which indicates that it may shares many similarities such as reactivity and bonding capabilities. Arsenic and phosphorus both have 5 valence electrons and both tend to support 3 covalent bonds to form a stable electron configuration. Wolfe-Simon also noted that similar exchanges between elements of the same group can be made in other organisms in certain biosynthesized molecules. She hypothesized that this could also be the case for a substitution of arsenic for phosphorus in biosynthesized molecules, as cellular machinery cannot discriminate between arsenic and phosphorus. She mentions in her hypothesis that the organism utilizes several mechanisms, of which the mechanics have not yet been discovered, to combat the molecular instability in arsenic based compounds in aqueous systems. She tested this hypothesis by isolating an organism on a media which was made by adding arsenate (AsO4) and not adding any source of phosphate (PO4). The sample used to isolate the organism GFAJ-1 was collected from a lake in eastern California named Mono Lake. Mono Lake is a body of water with a high saline concentration and a high concentration of dissolved arsenic. The sample was tested on a number of growth media with vastly varying concentrations of arsenate and no added phosphate.

The isolated growth was studied on media containing both phosphate and arsenate, neither phosphate nor arsenate, and either phosphate or arsenate. No growth was found when neither arsenate nor phosphate were added. When combined with the result of growth on the media containing only arsenate and no added phosphate, Wolfe-Simon concluded that the growth was able to grow in an arsenate-dependent manner. Transmission electron microscopy was used to examine the contents of the cell and revealed a large vacuole not found in the phosphate dependent growths.

Wolfe-Simon used mass spectrometry to determine if the bacterium was actually using the arsenate from the medium by measuring the intracellular arsenic content and intracellular phosphorus content. Arsenic concentrations were found to be 0.19% and phosphorus concentrations were found to be .019% in the arsenic only media growths. She attributed the phosphorus in the cells to impurities in the reagents rather than carryover. The phosphorus concentration was significantly higher at .54% in growths grown on phosphate containing media. She claimed that .019% is below the minimum amount of phosphorus in a cell to support phosphorus-based life.

Wolfe-Simon attempted to further prove the uptake and usage of arsenate in organic molecules using radiolabeled arsenate. It was found that 1/10 of the radiolabeled arsenate was used in biosynthesis of nucleic acids. This is greater than the calculated estimate of 4% arsenic by mass. Calculations, based on concentration of phosphate in DNA and gross mass of phosphorus per cell, concluded that 4% phosphorus in a cell is in the DNA. Wolfe-Simon reasoned that arsenic is being utilized to fulfill the roles of phosphorus in the cell so 4% of the intracellular arsenic should be in the DNA as well. She also used x-ray studies to show that the arsenic is being used in arsenate in similar roles as phosphorus is being used in phosphate.

Wolfe-Simon states that she believes the organism to be able to utilize both arsenate and phosphate in biosynthesis of organic molecules. She believes that the large vacuole structure in the arsenate based growth contains many of the biosynthesized molecules containing arsenate. She believes this vacuole to not contain an aqueous fluid like the cytosol, but to contain poly-B-hydroxybutyrate. She claims that this stabilizes arsenic ester bonds and helps to achieve a slower rate of hydrolysis which may be the compensatory mechanism to adapt to arsenate based life as opposed to the more stable phosphate based life.

**Discussion:**

Arsenic is a known carcinogen to humans but it has been unclear in how it causes cancer. New studies are specifying that it works through DNA methylation (4). These new studies have linked arsenic exposure over time to even more health detriments than just cancer. It is now being linked to diseases like: diabetes, heart disease, and neurodegerative diseases. The changes have been linked to methylation at 4 different loci so far. The study notes that it is not known yet how much of an effect genetic variation has on the pattern of DNA methylation.

Wolfe-Simon presented a very unique organism which could very well redefine what constitutes life and may have offered a new scope in which to look for the newly redefined life. Several other studies have been published more recently on this topic which refute Wolfe-Simon’s claim. More research will have to be done on the compensatory mechanisms to prevent hydrolysis of the arsenic ester bonds.

**References**:

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