

Hydrogen bond dynamics of cellular water and stress adaptive response

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ABSTRACT

The hydrogen bond network in liquid water responds "instantaneously" to ions and other species in its surroundings (1,2). Here we provide evidence that the hydrogen bond network in water of living cells can change during stress-adaptive response, and that such changes can reflect the cellular chemistry landscape and elucidate the paths through which a biological system adapts to changes in its environment (3).

We used high-resolution Fourier Transform Infrared (FTIR) spectromicroscopy in the mid-infrared region to investigate how descendants of some of the oldest bacteria can survive oxygen stress from the modern Earth atmosphere. Microbes, such as the ubiquitous sulfate reducing bacteria (SRB), are the oldest (>3.5 billion years) and the smallest (about 1/8000th the volume of a human cell) living organisms on Earth. Strong selection pressure over time and their high surface-to-volume ratio may have enabled these species to cope with many environmental fluctuations. Genome sequencing shows that some SRB descendants have acquired the genetic "blueprints" to survive transiently in an oxygenated atmosphere. This includes the potential capabilities to reduce O₂ and cope with the subsequent toxic reactive oxygen species (ROS) in the modern atmosphere, such as superoxide anion radicals (O₂^{•-}), peroxides (H₂O₂), and hydroxyl radicals (HO[•]).

We selected the infrared approach because of the high sensitivity of IR spectroscopy to the hydrogen bond structure and water, which works well for biological applications for several reasons. First, more than 70% of a cell's contents is highly polar water molecules. Second, the hydrogen bond structure of water is a sensitive reflection of the cellular chemical environment because it responds "instantaneously" to ions and other species, such as radicals, small organic acids, and hydrogen gas, which are expected to be present during the functional metabolism of stress adaptive response. Furthermore, the IR spectrum of OH stretch vibrations in the hydride–OH dominated stretch region (1900–3800 cm⁻¹) has already been widely used to characterize the dynamics of hydrogen-bonding structures in both water clusters and condensed phases such as aqueous liquids (see the listing in Ref #3). These studies can be used to guide the interpretation of IR spectra of OH stretch vibrations in the hydride–OH region and to link the variations to the presence of ions and other small molecules in liquid or other condensed phases.

In our study we continuously monitored the changing hydrogen bond structures in water (and other molecules) of living *Desulfovibrio vulgaris*. We observed a sequence of well orchestrated molecular events that correspond to changes in cellular processes in those cells that survive, but only accumulation of radicals in those that do not. By systematically linking the measurements to the *D. vulgaris* genetic "blue prints", we can interpret the adaptive response in terms of transient intracellular

chemistry and link it to oxygen stress and survival. This ability to monitor chemical changes at the molecular level can yield important insights into a wide range of adaptive responses.

REFERENCES

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