Arsenic and the Gut Microbiome: A Case Study for Application of Synchrotron Radiation in Microbiome Research

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Synchrotron radiation is rarely employed in microbiome research, despite its potential utility for elucidating important features of intermolecular dynamics, reaction geometries, and speciation in these complex biological systems. Our work serves as a case study for the application of synchrotron science to microbiome research. The human gut microbiota and its genes and genomes (or, the "microbiome") play a role in nutrition, immunity, and detoxification of ingested substances. Conventional risk assessment fails to emphasize possible microbiome interactions with ingested environmental contaminants, instead relying upon universal dose-response curves. We focus on characterizing the effects of chronically ingested arsenic on the gut microbiome, laying groundwork for the novel field of microbiome-based risk assessment and informing future interventions in affected communities worldwide. In the US, 13 million Americans are exposed to arsenic levels exceeding US Water Quality Standards, and over 25 million people in Bangladesh are chronically exposed. Synchrotron analyses at the SLAC Synchrotron Radiation Lightsource (SSRL) play a vital role in tracking the potential arsenic biotransformative capability of the microbiome, as XAS analyses provide an extremely accurate and sensitive tool for detecting arsenic speciation changes at environmental concentrations in mixed solid and liquid phase samples, as well as provide insights into reaction geometries via EXAFS. At SSRL, we analyzed a time series of samples from anaerobic bioreactors inoculated with stool from one healthy human subject under two arsenic regimes: a 1 mM arsenate (As(V)) spike at inoculation and a 0.1 mM As(V) spike at inoculation. Our preliminary feasibility study illustrated that within a 45.5-hour time series, biotransformation of arsenic occurred at significant rates in the 1 mM bioreactor; by hour 29.5, 25% of the total arsenic had been converted from As(V) to As(III), and by hour 45.5, 40% of the total arsenic was As(III). EXAFS data showed suspected arsenic-arsenic interactions. In follow-up analyses of a 54.5-hour time series from one individual's inoculum, we found that (1) the 1 mM As(V) reactor illustrated ~50% conversion from As(V) to As(III) and (2) there were concentration effects, with the 0.1 mM reactor converting As(V) to As(III) at slower rates than the 1 mM regime. We also analyzed the unaltered stool, and detected no arsenic. The results are encouraging, illustrating the potential biotransformative capability of the gut microbiome, along with the viability and utility of this type of sample analysis on synchrotron radiation sources. Synchrotron analyses allow for simultaneous assay of extracellular and intracellular matter, as well as finer insights at the molecular level via EXAFS—both advantages over conventional instrumentation. Future work includes analyses of two US healthy subjects and six Bangladeshi subjects (chronically/minimally exposed, with/without disease) under the same reactor regimes.