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Human bodies as chemical sensors: A history of biomonitoring for environmental health and regulation☆

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ABSTRACT

The testing of human blood and urine for signs of chemical exposure has become the "gold standard" of environmental public health, leading to ongoing population studies in the US and Europe. Such methods first emerged over a century ago in medical and occupational contexts, as a means to calibrate drug doses for patients and prevent injury to workers from chemical or radiation exposure. This paper analyzes how human bodies have come to serve as unconscious sensors of their environments: containers of chemical information determined by expert testers. As seen in the case of lead testing in the US, these bodily traces of contaminants can provide compelling evidence about dangerous exposures in everyday life, useful in achieving stronger regulation of industry. The use of genetic testing of workers by Dow Chemical provides an example of industry itself undertaking biomonitoring, though the company discontinued the program at the same time its studies indicated chromosomal damage in connection with occupational exposure to certain chemicals. In this case and others, biomonitoring raises complex questions about informing subjects, interpreting exposure in the many cases for which health effects at low doses are unknown, and who should take responsibility for protection, compensation, or remediation. Further, the history of biomonitoring complicates how we understand human 'experience' of the global environment by pointing to the role of non-sensory—yet detectable—bodily exposures.

1. Introduction

This essay examines the emergence of human biomonitoring in the 1960s and 1970s as a tool for assessing population-wide exposure to hazardous chemicals. The testing of human blood and urine for signs of chemical exposure has since become the "gold standard" of environmental public health, leading to ongoing large-scale studies in the US and Europe (Sexton, Needham, & Pirkle, 2004). The use of human bodily products and tissues to measure exposures occurred first in medical and occupational contexts from the late nineteenth century, as a means for calibrating drug doses for patients and preventing chemical (or radiological) injury to industrial workers.[1] In the post-World War II period, government agencies began using radiological protection and chemicals regulation to set exposure limits for populations at large. Yet limiting exposure relied on being able to measure hazardous substance levels, outdoors as well as indoors. While environmental toxicologists expanded testing of air and waterways and companies adopted new laboratory tests for drugs, consumer products, and chemicals, public health officials began monitoring the bodies of citizens themselves to determine exposure levels.[2]

There are two main approaches to human biomonitoring (van Sittert & de Jong, 1985). The first, and oldest, uses the techniques of analytical chemistry to detect the presence of specific chemicals in human bodily fluids and tissues. Sometimes not only is the original compound sought, but also its so-called metabolites, the products of its chemical conversions in the body, such as by detoxification enzymes in the liver. These by-products can be just as reliable signatures of exposure as the presence of the compound itself (and in some cases these metabolites are themselves also toxic). This kind of biomonitoring relies on the sensitivity of the chemical assays and instruments, which since the 1960s have become able to measure ever-smaller amounts of specific substances. The major public health biomonitoring surveys employ

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[1] Analytical chemistry was also used in human testing, though often of dead bodies, in forensics (Bertomeu-Sánchez, 2013).

[2] Recent studies of biomonitoring by social scientists include Daemmrich (2008); Bauer (2008); Morello-Frosch et al. (2009); Casper and Moore (2009); Washburn (2013); and Roberts (2014).

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this analytical chemistry approach, drawing on the precedent of occupational monitoring of workers for exposure in chemical plants (Sexton et al., 2004).

The second approach, which has never become as widely-used at the populational levels, searches for the *effects* of exposure through damage to genetic material (chromosomes or DNA), or other molecular alterations (usually called adducts) that are chemically induced by exposure. For instance, the occupational exposure of workers to ethylene oxide leads to a detectable chemical modification (alkylation) of hemoglobin molecules in their blood (van Sittert & de Jong, 1985, p. 2). This approach relies on knowing in advance how constituents of the human body—such as DNA or proteins—interact with the substance in question. The resulting data documents actual biological damage, which is potentially more informative than simple exposure level. However, since individuals vary in their susceptibility to such damage, this information may not be generalizable to the population as a whole. This article examines a few attempts to use genetic technologies to assess occupational hazards, efforts that were at times hampered by employer opposition or by disputes over the predictive power of biomarkers for exposure. In fact, scientific uncertainty about the significance of low-level exposures is a more general challenge for interpreting results from human biomonitoring, whether they derive from analytical chemistry or genetic assays.

Beginning with lead testing in the 1960s and then expanding to include synthetic chemicals, human biomonitoring has come to play an important role in environmental health policy in the US. In many cases, results from large-scale tests have provided incontrovertible evidence of widespread exposure to mass-produced chemicals such as DDT and pesticides, enabling stronger regulations to be enacted in the name of public health. But human biomonitoring also raises unanswerable questions about the health consequences of low dose exposures, and reveals the permeability of our bodies to the artificial environment in surprising and disturbing ways.[3] There is the further issue of treating ordinary people as chemical sensing devices. During the same period that saw the rise of global monitoring, whether for military or environmental surveillance (Boudia, 2014; Edwards, 2010; Hamblin, 2013; Turchetti & Roberts, 2014), the human body itself became seen as a repository of relevant data. What does it mean for individuals, tapped for their traces of chemical encounters, to provide data on global pollution and exposure? Is their human experience stripped out as it becomes objectified, or does it remain a part of the larger infrastructure of environmental knowledge?

To some degree, the answer to this question hinges on what is meant here by 'experience.' Needless to say, many people affected by toxic exposures are physically aware of it, even when the effects are hard to quantify or disregarded by experts (Murphy, 2006). In his insightful ethnography of domestic formaldehyde exposure, Nicholas Shapiro has argued that an accumulation of "minor enfeebling encounters" can coalesce into what he calls the "chemical sublime," as affected individuals learn to recognize their bodily sensations and afflictions as responses to chemical exposures (Shapiro, 2015). Such sensitivities can prompt ethical reflection and political action: citizen science at an intimate level.[4] By contrast, human biomonitoring usually registers exposure at levels far below conscious sensory experience. For those seeking stronger environmental public health, such quantitative measures of exposure provide an objective, and perhaps more credible, source of information than individual perception or subjective testimony.[5] But this political utility comes at the cost of a strange disconnect between biomonitoring data and lived experience, raising questions about the relationship of scientific technology to perception in defining health. Moreover, considering human bodies as receptacles of residual pollutants, some of which are dispersed throughout the world, has reinforced a view of our environment as undeniably global.

2. From occupational health to environmental exposure

The publication of Rachel Carson's *Silent Spring* in 1962 and the first Earth Day in 1970 marked the growing public consciousness of the burden of industrial pollution, particularly from synthetic chemicals. In the United States, the passing of the Clean Air Acts (1963 and 1970), the establishment of Environmental Protection Agency (1970), and the amendments that created the Clear Water Act (1972) expanded administrative law for regulating pollutants. Originally, most federal government oversight had been aimed at occupational safety or specific industrial products, such as drugs and pesticides. The more stringent regulation of toxic chemicals—especially carcinogens—in the environment at large posed new challenges around detection, risk assessment, and enforcement (US Congress, Office of Technology Assessment, 1987).

An important precedent for environmental protection laws derived from government efforts to identify, study, and ultimately control contaminating radioactivity from atomic weapons testing and nuclear waste sites.[6] After World War II, the US established several kinds of surveillance programs for radioactive fallout from nuclear weapons, both to detect any Soviet bomb tests and to evaluate the traces and consequences of the US's own atomic tests. These became key forerunners to other global monitoring efforts (Hamblin, 2013, ch. 4). Moreover, the regulation of radioactivity levels from nuclear waste, both military and civilian, required measuring contaminant levels via environmental sampling of air, water, and soil. In 1958, the AEC updated the federal code for radiological protection to include a population limit for exposure to ionizing radiation; previous regulations had focused on occupational exposures (e.g., of industrial workers and military personnel). As Soraya Boudia has observed, such national radiological safety standards provided a legal precedent for considering the population-level health effects of low-dose environmental contaminants, including chemicals (Boudia, 2013).

Techniques for analyzing water samples had long been utilized to protect municipal water supplies. Occupational safety provided the context in which tools for monitoring of air developed. In the chemical industry, most worker safety standards relied on measuring levels of hazardous substances in ambient air (Third Task Force for Research Planning in Environmental Health Science, 1986, p. 212). Extending these approaches to the environment at large, to enforce regulation of "point-sources" of pollution, proved costly. The US federal government estimated its expenses for monitoring national air-quality in fiscal year 1999 to be $139 million (US Government Accounting Office, 2000, p. 6).

[3] On the permeation of industrial chemicals from consumer products and foods into human bodies see Murphy (2008); Langton (2010); Thomas (2014). Nash (2006) and Walker (2010) probe late nineteenth and early twentieth century understandings of illness in response to agricultural and industrial toxins in California and Japan, respectively.

[4] The scholarship on citizen science is large and growing. A few useful references are Epstein (1995); Frickel and Moore (2006); Charvolin, Micoud, & Nyhart (2007); McCray (2008); Fan (2012).

[5] For an insightful history of official neglect of complaints about chemical exposure, especially coming from women workers in white-collar office buildings, see Murphy's account of sick building syndrome (2006).

[6] For more on this history, see Gordin (2009), esp. ch. 5; Hecht (2012); Creager (2013), ch. 9; Turchetti and Roberts (2014); and Aronova (2015). On contemporary environmental monitoring, see Gabrys (2016).

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