

BIOMONITORING:

Measuring Levels of Chemicals in People
– and What the Results Mean

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Executive summary

Because of improvements in the ability of scientists to measure exceedingly low concentrations of chemicals, it is now possible to detect thousands of substances in human blood, urine, and other biological samples. In recent years, government agencies and other researchers have collected samples from volunteers in communities across the country in order to measure the background level of chemicals in people due to exposures resulting from their environment. These are called biomonitoring programs.

This report discusses the sources of these exposures, the biological samples that are examined, and how the results of biomonitoring should be interpreted. There may be substantial benefits to broadly implementing programs that measure human exposures to the many chemicals found in our food, consumer products, air, water, and dust. However, since in most cases the source of the chemical being measured in the biological samples will not be known, there is also a large risk of misinterpreting the data from these programs.

Perhaps the most common misperception is that the mere detection of a chemical in our bodies suggests a health hazard rather than simply providing a measure of exposure. It is important that those who design and conduct biomonitoring programs carefully consider how the data should be interpreted and how that information should be conveyed to the public.

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Introduction

In the simplest terms, biomonitoring is the sampling and measurement of specific chemicals in biological tissue. The concentration of a chemical in human tissues or the total amount of a chemical in the body is sometimes referred to as the “body burden” of an individual. Due to the constant relationship we have with our environment, we are exposed to thousands of natural and man-made chemicals every day. This exposure occurs from air, food, and water, as well many consumer products with which we come into contact on a daily basis. In addition to tens of thousands of chemicals that naturally occur in foods, there are also natural sources of chemical exposure, including minerals leaching into ground water from soils, dioxins from forest fires or volcanic eruptions, and biological processes (as with pollen, hormones, and hydrogen sulfide). Of course, virtually everyone is also exposed to many man-made chemicals, such as those in paints, cosmetics, pesticides, drugs, plastics, household cleaners, carpeting and fuels. Each of us has ingested, inhaled, or absorbed most of these chemicals, many of which are easily measured in blood or urine.

Biomonitoring data can indicate the amount of a substance actually absorbed into the body. Because of technological advancements, it is now possible to detect extraordinarily low concentrations of chemicals in human tissue. Data from both toxicology (the study of the chemicals, generally done on animals) and epidemiology (the study of distribution of human disease) suggest that the vast majority of chemicals currently detected in biomonitoring programs of the general population would not produce adverse health effects.

Data from biomonitoring are becoming more widely available and are often considered newsworthy. However, these data are often presented without proper context, which can lead people to the mistaken conclusion that the low levels of chemicals found in our tissues are generally harmful, simply because a chemical is present. But merely detecting a chemical does not equal hazard or risk. For example, when physicians detect triglycerides in blood at a concentration of 75, that information by itself is not helpful to the layperson. But if the physi-

cian tells the patient that scientific information indicates that concentrations less than 150 are considered “ideal,” then the information has some meaning. This is the same challenge that faces those who collect biomonitoring data and then attempt to tell the public how much of a particular chemical in a sample should be of concern.

Many factors need to be considered before it is possible to determine if the detected levels of a chemical might pose a human health hazard. Reporting data without context can frequently generate confusion and unnecessary anxiety. It is not very useful to say, for example, “Mary has 20 parts per trillion (ppt) of benzene in her blood.” For most of the over 200 chemicals that are now being monitored by the Centers for Disease Control and Prevention (CDC) and others, interpreting results is difficult. Fortunately, there is a good possibility that in the near future, scientists will be able to present biomonitoring data in a way that will be informative and perhaps helpful in improving public health. To use the example of Mary again, it is likely that within a few years we will be able to say “Mary has 20 ppt of benzene in her blood. This places her at about the 50th percentile of benzene levels for adults in the United States. It is believed that about 80% of the benzene in her body has come from miscellaneous exposure to chemicals in the environment and the remainder is due to her own natural biological processes. The concentration measured in Mary is about 10% of the average level seen in petroleum workers – who have been shown not to have an elevated occurrence of benzene-related disease.” This kind of risk communication could well be beneficial to society.

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What biomonitoring studies have been and are being conducted?

Biomonitoring studies were first used to measure levels of substances absorbed by workers who were exposed to them at high levels in occupational settings. For example, beginning in the late 1800s, substances such as lead were measured in the blood and urine of factory workers in order to monitor their exposure and prevent workers from being exposed to dangerously high levels. The monitoring of potentially dangerous substances such as mercury and benzene has also helped to protect the safety of many workers.

More recently, biomonitoring studies have measured the exposure of the general population to chemicals found in the environment. These studies attempt to identify baseline concentrations of specific substances so that scientists can monitor whether levels are increasing or decreasing and compare the exposures of various groups to different substances. The National Center for Environmental Health (NCEH) of the CDC has been conducting national biomonitoring of the general population, basing results on blood and urine samples from participants in the CDC's national health and nutrition survey. Their first report was issued in 2001 (on 27 chemicals) and the second in 2003 (on 116 chemicals). The third report will be published in July 2005 and will include data on human exposure to approximately 150 substances, including lead, mercury, pesticides, herbicides, phytoestrogens, and PCBs. In addition to the CDC reports, other agencies and researchers have conducted assessments of biological samples from specific communities.

Where do the chemicals being detected in our bodies come from?

People are often alarmed to find out that they have tiny levels of many chemicals in their bodies and wonder how they got there. The substances found by biomonitoring studies generally come from three types of sources:

1) Man-made (anthropogenic) –

Workers who are occupationally exposed to chemicals (such as factory workers who work with metals or chemicals) are exposed to levels of man-made chemicals that are much higher than the levels to which the general population is exposed. By studying these workers and the levels of chemicals found in their bodies, scientists have been able to determine that such high exposures to certain chemicals have sometimes led to increased health risks.

The general population is exposed to much lower levels of these substances by various routes such as consumer products, food, and water. Plants used for food, for example, may contain trace levels of chemicals from pesticides, from incinerators, or from other sources. When animals eat these plants, the chemicals also accumulate in their meat and milk. Since people consume these foods, some level of these chemicals may be detected in human tissues and fluids.

2) Biological function –

Some of the chemicals detected in human biological samples are generated by normal biological functions. For example, the chemical phenylketonuric acid can be found in urine because of a person's exposure to styrene (a synthetic chemical used to manufacture plastics and other products), or it can be naturally produced due to genetic abnormalities. In cases where the presence of a substance could be due to a variety of sources, it can be difficult for scientists to associate the data with exposure to specific man-made chemicals.

3) Naturally occurring in food –

All foods contain chemicals that occur naturally – and some of those chemicals can be toxic or cause cancer at high doses in animal tests. Our overall exposure to these natural chemicals – such as hydrogen peroxide in tomatoes and benzene in coffee – is estimated to be much higher than our exposure to synthetic chemicals.¹

How does biomonitoring measure the levels of chemicals that can be found in people?

Because of well-developed technologies, it is now possible to detect in human tissues basically any substance that is in the environment. It has become possible for scientists to measure parts per quadrillion (ppq) of some chemicals found in humans (to visualize this fraction, imagine one inch out of a trip from earth to somewhere about 170 times as far away as the sun [16 billion miles]). In biomonitoring, scientists measure a person's exposure by testing either for the substance itself, its metabolites (substances formed when a chemical is processed by the body), or another biological indicator that would demonstrate exposure (such as a reduced white blood cell count in workers who have been exposed to high levels of benzene).

Biological samples that are measured in biomonitoring programs include blood, urine, hair, saliva/sputum, breast milk, fat, and semen. Each sample type has advantages and disadvantages, sometimes depending upon the characteristics of the substance that researchers are measuring. The samples must be handled and evaluated carefully to [avoid potential complicating factors in measuring people's exposures to chemicals. For example, when using hair in biomonitoring studies, factors such as what part of the hair is being used (near the base or near the tip) and whether the substance is present because of internal or external sources (such as shampoo, which may contain metals) are essential to consider.

1. For more information about natural carcinogens in food, see ACSH's "Holiday Dinner Menu" publication.

Scientists must consider factors such as how a substance is absorbed and how the body processes and eliminates it (its “toxicokinetics”) in order to determine what a measurement of a chemical can tell us about a person’s exposure. Additionally, when performing a study, scientists must decide whether the costs of the study are balanced by the potential benefits. For example, a relatively inexpensive blood lead test for a child living in substandard housing may prove to be useful and have implications for the child’s health, but a very expensive test of dioxin levels in the breast milk of a mother who is simply curious about her “body burden” is very unlikely to be worthwhile – unless she is thought to have had extremely high exposure to dioxins.

How is the data measured and interpreted?

By measuring “body burden” scientists can obtain an accurate measure of actual human exposure and retention of certain chemicals. Other scientific estimates of human exposure to chemicals in the environment often use indirect calculations based on information about how much of a particular chemical is found in food, water, air, dust, and other sources. Using this information, in addition to estimates of people’s behavior (such as how much water a person would typically drink), researchers try to estimate how much of a specific substance a person typically absorbs. While this type of calculation can be useful, it is difficult to know how accurate these estimates of exposure actually are. In biomonitoring, these assumptions are not needed because scientists can directly measure an individual’s specific level of a particular agent.

Exposure to a potentially hazardous substance does not necessarily result in an increased risk of disease. For example, few persons are worried about the risk of ingesting 2 aspirin per day, but most know that there are negative health effects associated with ingesting 20 or more aspirin per day.

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Researchers are now accumulating a considerable amount of information on the background concentrations of many chemicals in the body; this helps determine if a person has experienced a heightened exposure. In recent years, the federal government has conducted studies in which the blood of hundreds of persons has been sampled in an attempt to establish baseline data for more than 100 industrial chemicals found in our society. Currently, there are comparatively few human data that allow scientists to predict the health consequences of a person having slightly elevated levels of these chemicals. Sometimes, data from studies of occupationally exposed workers and, more rarely, studies of the general public, are helpful in characterizing the concentrations of chemicals found in the general population.

Scientists still use data from classic toxicology experiments (experiments that give high doses of a substance to animals) in order to try to predict what exposures may be considered safe. However, because of biological differences between humans and animals, as well as the high doses to which experimental animals are exposed, it can be difficult to apply toxicology data to advance our understanding of human exposures. Also, because toxicology studies generally measure the effects due to specific amounts given to animals, as opposed to the level of the substance found in biological samples (such as parts per billion in blood), it can be inappropriate to try to correlate such animal data to human biomonitoring data.

The detection of a chemical in biomonitoring doesn't reveal its source, which poses a challenge when there might be many different sources of exposure (such as food, air, or consumer products). Biomonitoring also only gives a picture of a person's "body burden" at one particular point in time, and it can be difficult to determine when an exposure might have occurred. For example, some chemicals such as dioxins and PCBs do not degrade easily, and trace levels of them can be measured in people for years after they have been exposed.

What are the potential uses and benefits of biomonitoring?

According to the CDC (2003), there are a number of reasons to conduct large or national biomonitoring programs:

- 1) To determine which chemicals get into Americans and at what concentrations.
- 2) For chemicals with a known toxicity level, to determine the prevalence of people with levels above those toxicity levels (e.g., a blood lead level [BLL] greater than or equal to 10 micrograms per deciliter [$\mu\text{g/dL}$]).
- 3) To establish reference ranges that can be used by physicians and scientists to determine whether a person or group has an unusually high exposure.
- 4) To assess the effectiveness of public health efforts to reduce exposure of Americans to specific chemicals.
- 5) To determine whether exposure levels are higher among minorities, children, women of childbearing age, or other potentially vulnerable groups.
- 6) To track, over time, trends in levels of exposure of the population.
- 7) To set priorities for research on human health effects.

It is important to note that with the exception of lead, at the present time, *the purpose of national biomonitoring programs is not to assess the safety of chemical exposure in the general population.* Rather, the goal is to collect data so that trends can be understood and to track whether public health control measures have been effective. At some point in the future, scientists or public health agencies may be able to determine the significance of these levels to human health, but it could be many years before enough data will be available to do so for most of them.

Since biomonitoring can directly measure a person's exposure to specific chemicals, there are a number of possible benefits from biomonitoring – despite its limitations. Perhaps the primary way it can be

useful is the information it provides for tracking long-term trends in the population. For example, it has been observed that blood levels of PBDEs (brominated flame-retardants) have increased in the general population over the past 10 years in the United States. This suggests that it is worthwhile to understand the sources of exposure and understand why blood levels are increasing. The next step is for public health policymakers and scientists to decide whether reducing the quantity being released into the environment is necessary.

Another potential benefit of a national biomonitoring program is to identify geographical locations where people have much different body burdens than the general population. For example, if one were to observe that the people in a particular area had a higher than expected concentration of PCBs (e.g., three times the 95th percentile of the remainder of the country), then it might mean that there is an extraordinary local source of exposure to PCBs. In that case, scientists would probably want to investigate to find the specific sources of the elevated exposure and decide if and how they should deal with it.

As shown in these two examples, in general, biomonitoring programs in the near term may not be helpful in identifying significant public health hazards. Even a significant upward trend in biomonitoring results for a local area or the nation in general does not by itself indicate that a health hazard exists or that action should be taken. Rather, this information can be an alert that suggests that we need to know more, and then scientists can systematically evaluate the source of the chemical and, perhaps, the affected population.

Biomonitoring also offers potential to be a powerful tool in studies that attempt to examine the relationship between exposure to a hazardous substance and a subsequent risk for disease. Because it allows scientists to use data on actual human exposure, using biomonitoring in risk assessments can eliminate or reduce some of the uncertainties (such as differences between humans and animals, or assumptions about human behavior used in order to estimate human exposure to a chemical) in current risk analyses. For example, if a particular group have concentrations in their blood of a specific chemical at the

95th percentile of national levels, and they have some consistent negative health effect, they could then be studied to help further our understanding of the chemical and its potential health impacts. So far, for only a few chemicals in the general population, such as lead and arsenic, have scientists collected enough data and conducted sufficient risk assessments to establish guidelines about possible health risk associated with certain concentrations of these substances in blood or urine. Biomonitoring data, coupled with health evaluations, have the potential to improve our understanding of low-level effects that might previously have gone unrecognized.

Biomonitoring data can also be used to evaluate the effectiveness of specific policies that attempt to reduce or ban particular substances. For example, blood lead levels in the US have dropped over 90% with the elimination of lead as a gasoline additive; PCB levels similarly have consistently declined in the last 20 years as their industrial use has been eliminated. Scientists thought that lessening the quantity of these chemicals in the environment would lower the body burdens in the US population, and biomonitoring provided the means for demonstrating the timeframe over which the reduction in body burdens occurred, as well as the magnitude of the decline.

Risk/Benefit Analysis

Nearly all of the chemicals detected in human blood by biomonitoring have come from their use in commercial applications. The data about chemicals in blood should be judged partly in terms of the benefits of these chemicals in society. For example:

- The persistent pesticides such as DDT and chlordane effectively controlled exposure to mosquitoes and other pests. DDT has saved millions of lives since it was first introduced in the 1940s. Overall, these chemicals have benefited society greatly, but they persist in our environment and ultimately enter our food supply or other media that we come into contact with and can then be measured in biological samples from humans.

- Phthalate plasticizers such as DEHP have allowed plastics to become an important and beneficial part of our daily lives over the past few decades, as shown by their use in medical devices and equipment and their use in reducing car weight to improve fuel economy and preserve passenger safety. However, because of their use in consumer products, phthalate concentrations in the blood of people in the Western world have significantly increased. Most scientists believe that blood levels do not pose any increased health risk. Although there is no evidence that phthalate exposure in the environment is associated with negative health effects, some scientists think that they may pose a threat that has not yet been identified. Over time, biomonitoring programs can identify populations to study, leading to properly conducted evaluations that are able to address potential health concerns like these.
- The widespread use of flame-retardants in a variety of products (such as electrical appliances) has greatly contributed to the reduction in the number of fires and the number of lives lost to fire in the past few decades. Flame-retardants, in order to be effective, must be stable. However, it is this same desired property of chemical stability that allowed these compounds to persist in the environment and ultimately enter the food chain.
- Before they were banned in the 1970s, polychlorinated biphenyls (PCBs) were used successfully to minimize the threat of fires and fire propagation in and around electrical equipment. However, because of accidental spills and less than perfect disposal practices, they eventually entered the environment, where they persist and can now be measured in the blood of virtually all Americans. To date, studies have shown that these blood concentrations do not pose a significant health hazard, but as a precautionary measure, regulatory and health authorities have decided to conduct biomonitoring studies to increase their confidence that blood levels of PCBs will continue to decrease over time. As in the cases of the other persistent chemicals that are currently of concern, the reason for biomonitoring in this instance is to identify the trend regarding the presence of PCBs in the environment and its transfer into humans, even

though identifying the presence of a chemical does not imply that there is a health risk.

How can biomonitoring data be misused?

There has been increased concern by the public about the presence of persistent chemicals in breast milk, as well as their possible health effects in the babies who ingest this milk – particularly since some of these substances appear in higher concentrations in breast milk and many other biologic tissues. Although many groups who have shared their views about the presence of these chemicals in mothers' milk have done so in a responsible manner, others – including some journalists, health departments, and environmental groups – have not. As a consequence, many women have received mixed messages, causing them to wonder whether they should breastfeed their children. While it is true that many of the chemicals to which mothers have been exposed will be detectable in extremely small quantities in breast milk, research indicates that breastfeeding offers advantages over formula for many reasons, including the immune system support that it provides for infants.

Some reports have not given proper context to the biomonitoring data on breast milk and therefore are excellent case studies of how biomonitoring data can be misused and have a negative impact on public health. One example involves a health bulletin issued by a county health department in California (San Mateo County, 2005). The bulletin noted that tests of breast milk had indicated that PBDE (polybrominated diphenyl ether) levels in the United States were 10 to 40 times higher than in Europe. It also implied that the PBDE concentrations potentially posed a significant risk to nursing children. Under the heading “What’s the problem?” the bulletin stated:

These [PBDE] compounds are everywhere and are accumulating in fat; they’re not the first. Their levels are still below PCBs, which are hanging around even though we banned them 25 years

ago. What's the problem? PBDEs are endocrine disruptors, wreaking havoc with the thyroid hormones in the third trimester of pregnancy, when brain connections are forming. Lab tests show PBDEs significantly impact exposed rats and mice, creating brain deficits that make it harder for them to learn and move normally. Levels of PBDEs in human breast milk and birds that eat high on the food chain are now close to levels that caused problems for the lab rats.

Currently, biomonitoring studies are largely intended to develop background information on various chemicals in the environment, including PBDEs. These studies are not currently intended to be used to identify or quantify health risks in a community; only when they are examined along with data on the frequency and patterns of disease and death can they be used to address questions about overall health risk. Statements such as "PBDEs are endocrine disruptors, wreaking havoc with the thyroid hormones in the third trimester of pregnancy, when brain connections are forming," are alarmist and are inappropriate in a reasonable discussion of biomonitoring data, since they do not consider the importance of dose, duration of exposure, and the species in which the tests were conducted. The tone of the bulletin is inflammatory and clearly intended to stimulate some type of action by the public even though immediate action may not be warranted or appropriate.

Additionally, these kinds of discussions leave the public at a loss for what to do in response. Should they attempt to remove all the items from their homes and automobiles that contain flame-retardants? Should women choose not to breastfeed? Should they demand that the federal and state governments remove PBDEs from all products and allow the greater fire hazard to return?

The California bulletin closes by suggesting that people become "knowledgeable consumer[s]" and, for example, seek out PBDE-free flooring. The author also suggests that, "If you are breastfeeding, rest assured that breast milk, with its remarkable protective abilities, is still the best food for a baby even when it's contaminated with the chemical residues of our industrial culture." This awkward

display of backhanded reassurance is a poor example of public risk communication. It throws away the opportunity for a thoughtful consideration of the potential impact of PBDEs on our society, taking into account the risks and benefits of various approaches to dealing with the real problems that occur when flame propagation is not controlled. Specifically, over the past 35 years, at least four different classes of flame-retardants have been banned or taken out of commerce due to societal pressure that was brought about by these kinds of abuses of scientific data. In each case, the health or environmental hazards posed by the new material was more poorly understood than the one it replaced. Through experience, it is well known among environmental scientists that dealing with the substance that you understand is usually more prudent than introducing one you don't.

Conclusions and summary

Using modern analytical technology, it is now possible to measure almost any chemical (naturally occurring or man-made) present in our bodies. Unlike environmental studies, which focus on the concentration of these chemicals in soil, dust, sediment, nonhuman mammals, fish, food, air, and water, biomonitoring programs measure concentrations found in human urine, blood and breast milk. The primary purpose of biomonitoring studies is to establish a baseline of data for the general population so that trends can be identified over time. Because of improved analytical technology, concentrations of chemicals that were undetectable 10 years ago are now measurable.

A major challenge facing those who conduct biomonitoring programs is how to identify the best method for communicating the data to the public. At this time, only the recently conducted CDC studies on blood and urine give adequate information about background concentrations of environmental chemicals (e.g., those not from areas significantly impacted by specific contamination) to allow scientists to begin to understand the trends of these chemicals in the general population. For a variety of reasons, even using the results of those studies

to estimate whether certain members of the public are at higher risk for an adverse effect is not possible. The results of biomonitoring data, by themselves, are not informative in helping individuals understand their health risk. However, skilled scientists can use other information (such as data on toxic substances and patterns of disease) to identify the blood levels that might be worthy of attention. In short, mere detection of a chemical does not equal risk any more than the detection of triglycerides in blood equates to an increased health risk. In fact, it is necessary for humans to have some triglycerides in their blood in order to survive. It needs to be recognized that there is a dose for all chemicals – both natural and synthetic – at which there is no increased health risk.

Scientists anticipate that in the future they will have enough information to properly interpret biomonitoring results. At this point, however, the reporting of biomonitoring data without proper context makes it difficult for consumers to make informed and rational decisions about where resources should be spent. Currently, the limited money available for improving public health should be used to address environmental issues that pose real and known health risks (such as lead in urban housing). Scientists will agree that there needs to be a greater understanding of the potential health effects caused by the chemicals that the public is exposed to on a daily basis. We live in a chemical-filled world; therefore, it is to be expected that some of these chemicals will be identified in the measurement of human biological samples.

It is important to use biomonitoring as a tool to help guide our social and scientific leaders to make intelligent decisions and not as a method for inducing fear. Biomonitoring, in its broadest sense, offers great opportunities for identifying people who are unknowingly exposed to both naturally occurring and industrial chemicals. Over time, it will likely help in identifying those who might be particularly susceptible to certain diseases. Currently, when most biomonitoring data is designed to establish baseline information about specific chemicals in Americans, those performing biomonitoring must be aware of the unintended consequences of sharing data that alone are not inform-

ative about the presence of increased risk.

Some people tend to radically change their behavior when they only have incomplete or out of context information. For example, there have recently been claims that pregnant women should restrict their intake of fish due to the presence of mercury, PCBs, and flame-retardants. This warning, however, failed to address the many benefits of eating fish and the lack of compelling evidence of harm from trace levels of these chemicals in fish. Scientists and the public must carefully weigh the risks and benefits and realize the purposes and limitations of biomonitoring when applying it to further our knowledge about chemicals and health.

Some Reasonable Questions About Chemicals

- What is the range of the level of this chemical found in the general population?
- Have those levels been associated with any harmful effects in people?
- Is there reliable evidence that this substance can increase the risk for harmful health effects?
 - If so, at what dose or level have these effects occurred?
 - If the information about this chemical is from animal tests, what differences between people and animals might affect how the studies can be applied to people?
- Based on that information, are there expected benefits to reducing current exposure levels to the chemical?
- Are there expected costs to reducing my exposure to the chemical (such as monetary costs due to replacing products, health costs from changing eating patterns, etc.)?
- If reducing exposure of myself and/or my family to the chemical is warranted, how could I do so? How much would those changes reduce my/our exposure?

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