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Review

Human biomonitoring in Israel: Recent results and lessons learned

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ABSTRACT

The use of human biomonitoring (HBM) as a tool for environmental health policy and research is developing rapidly in Israel. Despite challenges in securing political and financial support for HBM, the Ministry of Health has initiated national HBM studies and has utilized HBM data in environmental health policy decision making. Currently, the Ministry of Health is collecting urine samples from children and adults in the framework of the National Health and Nutrition Study (MABAT), with the goal of ongoing surveillance of population exposure to pesticides and environmental tobacco smoke, and of combining HBM data with data on diet and health behavior. In academic research studies in Israel, biomarkers are used increasingly in environmental epidemiology, including in three active birth cohort studies on adverse health effects of phthalates, brominated flame retardants, and organophosphate pesticides. Future Ministry of Health goals include establishing HBM analytical capabilities, developing a long term national HBM plan for Israel and participating in the proposed HBM4EU project in order to improve data harmonization. One of the lessons learned in Israel is that even in the absence of a formal HBM program, it is possible to collect meaningful HBM data and use it in an *ad hoc* fashion to support environmental health policy.

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1. Introduction

Israel is a small, densely populated country (population of 8.5 million; 387.3 persons per square km of land) with significant environmental pressures resulting from rapid economic and population growth (Organization for Economic Co-operation and Development, 2011; World DataBank, 2016). Responsibility for environmental health issues, and specifically for chemical management policy, is shared among several ministries, making coherent policy-making regarding chemicals in air, food, personal care products, and water a challenge. Policy making in environmental health in Israel is frequently crisis driven, with other national priorities more pressing, such that resources are not always available for an integrated and systematic evaluation of environmental health problems (Preuss et al., 2006).

Human biomonitoring (HBM) has emerged as a tool for assessing cumulative exposure to complex mixtures of chemicals and for monitoring chemical exposures in the general population (Sexton et al., 2004). Many countries, including the US, Canada, Germany, France, and Belgium, have developed National Biomonitoring Programs (Choi et al., 2015).

As in many developing countries, adverse reproductive health trends and increasing rates of diseases such as asthma, obesity, diabetes, and certain types of cancer have raised concerns about health impacts of environmental chemicals in Israel (Berman et al., 2012; Environment and Health Fund and Ministry of Health, 2014). Although to date there is no formal National Human Biomonitoring Program or network in Israel, and no legal foundation in Israel for HBM, in 2009 the Israel Ministry of Health initiated a national HBM study in an attempt to gather data on integrated chemical exposure of the population from various exposure sources and in order to promote surveillance and prevention of potentially harmful exposures to chemicals in the population.

In addition, academic researchers in Israel are increasingly using HBM tools in environmental epidemiology, and have conducted studies to develop novel biomarkers for environmental exposures. The purpose of this article is to review recent HBM studies in Israel, to highlight regulatory uses of this data in environmental health policy, and to describe challenges and lessons learned in developing a national HBM framework in a small country.

2. Recent HBM studies in Israel

We searched for information on HBM studies conducted in the Israeli population in the last five years (since 2011), excluding studies in occupational settings. Relevant sources were a literature review by PubMed search using key words: human; biomonitoring; Israel; as well as communication with researchers and funding agencies. We briefly present methods and results of these studies. We elaborate on the 2011 Ministry of Health HBM study as it is the most relevant to a national HBM framework.

2.1. *Ministry of health surveillance studies*

2.1.1. *2011 Israel biomonitoring study: methods, results, and policy implications*

The Israel Biomonitoring Study was conducted by the Ministry of Health in 2011 with the goals of measuring urinary levels of several environmental contaminants (organophosphate (OP) pesticides, phthalates, bisphenol A (BPA), cotinine, and polycyclic aromatic hydrocarbons (PAHs)) in the Israeli population, comparing levels with other international populations, and identifying demographic, behavioral, and dietary predictors of exposure to these contaminants (Berman et al., 2013a). Participants from the adult general population (ages 20–73) were recruited from 5 regions in Israel. As the population of Israel is comprised of both Jewish (~75% of the population) and Arab (~21%) citizens, the sample included Jewish (74.1%), Arab (24.3%), and other (1.6%) participants. It is unclear to what extent the study population is representative of the general adult population in Israel, as a convenience non-random sampling technique was employed to recruit individuals to the study. However, the recruitment strategy was designed to include individuals from different ethnic and geographical subpopulations in Israel.

Participants provided a spot urine sample and completed an in depth interview including questions on health, lifestyle, and diet (24 h recall and food frequency questionnaire). Urine samples were analyzed at the University of Erlangen-Nuremberg in Germany.

Higher socioeconomic status (education and income) emerged as an important predictor of increased exposure to both OP pesticides and BPA, likely due to increased consumption of fruits and vegetables and more eating outside the home in higher socioeconomic groups (Berman et al., 2013b, 2014). On the other hand, higher socioeconomic status was associated with lower exposure to environmental tobacco smoke (ETS) (based on cotinine) in non-smokers (Levine et al., 2013). We identified dietary predictors for BPA, OP pesticides and PAH metabolites (Levine et al., 2015) but also identified the need for more targeted questions on dietary patterns in order to improve our methodology for identifying dietary predictors of exposure to environmental contaminants in future HBM studies.

In order to identify contaminants as a potential public health cause for concern and priority for public health policy intervention, we compared urinary levels in our population to other international populations and/or to health based threshold values (HBM1 and biomonitoring equivalent values). We note that for the contaminants measured in our study health based threshold values were available only for BPA and phthalates.

Median creatinine adjusted concentrations of several OP metabolites (dimethyl phosphate, dimethyl thiophosphate) were high in our study population compared to the general US and Canadian populations (Fig. 1). Adjusted concentrations of total dimethyls were almost 10 times higher than in NHANES adults and almost 3 times higher than in Canadian adults. For the chlorpyrifos specific metabolite 3,5,6-trichloro-2-pyridinol (TCPy), median urinary levels in our population were high compared to the US general population (2.34 μg/g compared to 0.88 μg/g), as were 95th percentile values (8.52 μg/g compared to 3.2 μg/g) (unpublished data).

The percent of non-smokers with quantifiable urinary cotinine (63%) was relatively high in our study population, reflecting widespread exposure to ETS. Since cotinine is measured in serum in the US National Health and Nutrition Examination Survey (NHANES) and was not measured in the French study "Exposure of the French population to environmental pollutants" in 2006–2007, we limited our comparison to the Canadian general population in 2009–2011. Compared to 14.6% of non-smokers aged 20–39 and 11.2% aged 40–59 with urinary cotinine levels above the level of detection (1 μg/L) in Canadian adults, in our population rates were higher, 67% and 45% respectively.

Phthalate metabolite concentrations were higher in our study population compared to the general US population but values were below health-based threshold values. For example, for the phthalate metabolite mono(2-ethyl-5-hydroxyhexyl)phthalate (5OH-MEHP), both median (30.4 μg/L) and 90th percentile values (91.1 μg/L) in our study population were very low compared to the HBM-1 value (300 μg/L for women of reproductive age and 750 μg/L for males 14 years and older) determined by the Human Biomonitoring Commission (2015).

Median creatinine adjusted urinary BPA concentrations in the study population (3.0 μg/L) were comparable to those in Belgium and Korea; higher than those reported for the general US, German,

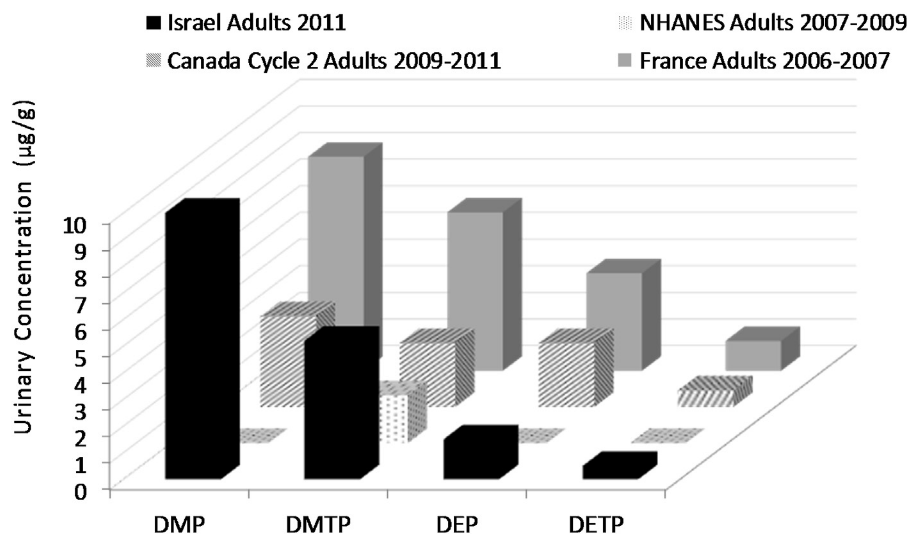

Fig. 1. Median Creatinine Adjusted Dialkyl Phosphate Levels in Israeli Adults Compared to Adults in France, Canada, and the US.

and Canadian populations; and very low compared to health-based threshold values (Human Biomonitoring-1 value of 2500 µg/L and Biomonitoring Equivalent value of 2000 µg/L).

Geometric mean creatinine adjusted urinary concentrations of four hydroxyphenanthrenes (1-hydroxyphenanthrene, 2-hydroxyphenanthrene, 3-hydroxyphenanthrene, and 4-hydroxyphenanthren) were comparable to those found in the general US population aged 20 and older in 2007–2008 whereas concentrations of 1-hydroxypyrene were higher in our study population. Urinary concentrations of all PAHs were significantly higher among current smokers or participants with higher cotinine levels but were not associated with cotinine concentrations in non-smokers in the overall study population (Levine et al., 2015).

We note that differences in participant selection and recruitment, biological matrices and sampling, analytical method, and year or season of sample collection make direct comparison of results from different HBM studies problematic (Lakind et al., 2012). Despite this limitation, using the data interpretation scheme described above, we identified two contaminants as being of potential public health concern and high priority for public health policy intervention: cotinine and OP pesticides.

Our findings on relatively high levels of exposure to organophosphate pesticides were presented to the Ministry of Agriculture in a Ministry of Health position paper and were effective in supporting policy to phase out 11 active ingredients in Israel in 2012–2014 and to restrict uses of 6 additional OP active ingredients. Our findings on widespread exposure to ETS in the non-smoking adult population were presented at Parliament meetings and were used to support legislation to expand the smoking ban in public places to open spaces such as stadiums and railway platforms (Rosen and Peled-Raz, 2015). Though there have been legislative efforts to restrict smoking in public places in Israel over the last twenty years, our findings indicate that there is still a long way to go, especially among males, the younger population and those with lower education (Levine et al., 2013).

2.2.2. 2015–2016 Israel MABAT Biomonitoring Study

For the first time in Israel, HBM was integrated in the Ministry of Health National Health and Nutrition Survey (MABAT), a survey of 1500 children and 4000 adults. Urine samples will be analyzed for pesticides and cotinine in a sub-sample of 200 adults and 100 children. These contaminants were chosen since they were identified in the 2011 study as of high potential public health concern. The study will focus on children since children are highly susceptible to both OP pesticides and ETS and data are not available in Israel on exposure to these contaminants in children.

As part of the survey, participants provided detailed information on diet (24 h recall and food frequency questionnaires), anthropometric data (weight, height, others), and lifestyle and health topics such as socioeconomic status, smoking, physical activity, alcohol, medication use, a wide variety of medical conditions. The survey provides an opportunity to explore associations between HBM and dietary and health data, as well as an opportunity to explore the benefits and obstacles related to using national health and nutrition surveys as a platform for HBM. Finally, we plan to compare urinary cotinine and OP pesticide levels with those observed in our 2011 study, in an attempt to evaluate whether the policies mentioned earlier to reduce public exposure to ETS and OP pesticides have been effective. Although the 2015-2016 study is designed to be a representative national sample, since the 2011 study was a convenience sample and was not nationally representative, comparison of values in the 2011 and 2015 studies may be indicative of trends but will not allow solid conclusions regarding effectiveness of policies to reduce public exposures.

As urine samples will be analyzed in the study for nutritional biomarkers in adults in the study, urine samples have been collected to date for all adults in the study. Urine samples have been collected for 104 children ages 4–12, 49% male and 51% female. The sample includes 59% Jewish children and 41% Arab and Druze children; in both groups children were sampled from both urban and rural areas. Due to delays in available funding, samples have yet to be analyzed.

2.2.3. WHO study on POPs in breast milk

As part of the national implementation plan following signing the Stockholm Convention, Israel participated in the Fourth WHO-Coordinated Survey of Human Milk for Persistent Organic Pollutants. Donors of breast milk were recruited from three hospitals and breast milk was collected from 52 primipara women in 2011–2012, aged 23–35, living in Israel for the last 10 years who gave birth to singleton full term healthy infants (Wasser et al., 2015). A single pooled sample was analyzed at the WHO Reference Laboratory, State Laboratory for Chemical and Veterinary Analysis of Food in Frieburg, Germany. Out of over 50 Persistent Organic Pollutants listed in the analysis, 16, including aldrin, endrin, parlar and mirex were not found at detectable levels in the Israeli pooled sample. DDT levels were lower than those reported in many European countries (Fig. 2).

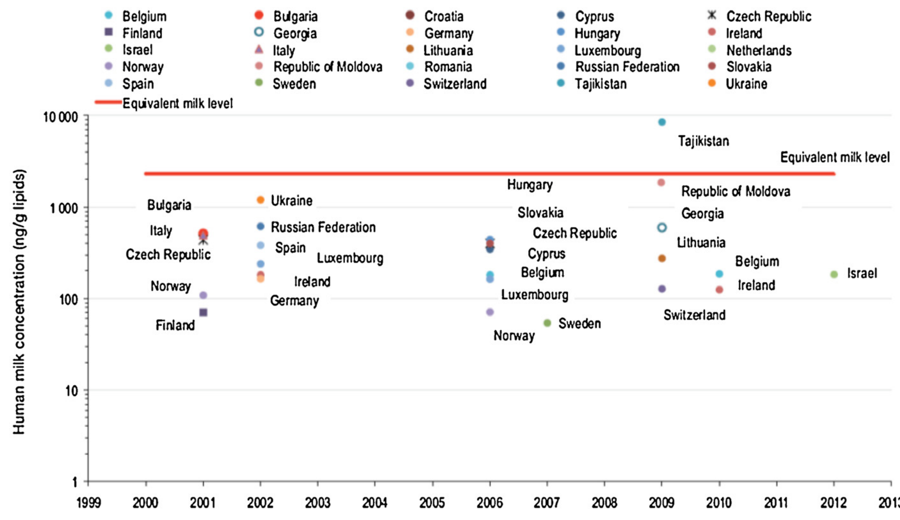

Fig. 2. DDT levels in human milk in the WHO European Region: data from the WHO/UNEP Human Milk Survey 2000–2012.
Reproduced from WHO Regional Office for Europe (2015).

Contaminant concentrations in breast milk were compared to those measured in 52 Israeli women in 1981–1982 in the framework of the United Nations Environment Program (UNEP)/WHO project on Assessment of Human Exposure to Pollutants through Biological Monitoring (Slorach and Vaz, 1985). We note that both studies were conducted using the comprehensive protocol and guidelines developed by WHO, such that sampling methods and quality assurance were comparable. Compared to levels in breast milk in 1982, levels of POPs contamination as measured in breast milk have declined significantly. For example, concentrations of p,p′-DDT decreased from 290 ng/g lipid wt to 4.3 whereas concentrations of hexachlorobenzene decreased from 80 ng/g lipid wt to 5.6. This study demonstrated that environmental health policy (restrictions on agricultural, industrial, and other uses of many POPs) were likely instrumental in reducing public exposure to POPs in Israel.

2.2. Academic and government collaboration on HBM

2.2.1. Exposure to organophosphate pesticides in pregnant Palestinian women

Regional HBM studies can highlight differences in environmental exposures in populations with close geographical proximity but with differences in culture, diet, lifestyle, and regulatory oversight of environmental chemicals. For this reason, researchers from Al Quds University, Hebrew University, the Israel Ministry of Health, and the University of Erlangen-Nuremberg in Germany collaborated to study exposure to OP pesticides in pregnant Palestinian and Israeli women.

Six dialkyl phosphate metabolites were measured in urine samples collected from 148 pregnant women in the West Bank Area and concentrations were compared to those in pregnant women from the Jerusalem area. Sampling for these studies (timing of fieldwork, questionnaires, week of gestation in women) was different. However, exclusion criteria were similar and in both studies hotspots were avoided. In addition, urine samples from both studies were analyzed by the same analytical procedure and calibration, at the same laboratory (Abdeen et al., 2016).

Median total dimethyl phosphate (DMtotal) levels were significantly lower in Palestinian women compared to Jerusalem pregnant women ($p = 0.041$). DMtotal levels were significantly higher in Palestinian women reporting that their place of residence was near an agricultural field ($p = 0.037$). Lower urinary levels of dimethyl phosphate pesticide metabolites in Palestinian women compared to Israeli women may result from lower consumption of fruits and vegetables in the Palestinian population.

Table 1
Birth Cohort Studies underway utilizing HBM in Israel.

Birth Cohort	Sample	Relevant Contaminants	Biological Media
Asaf Harofeh/Ichilov Hospital	340	Brominated Flame Retardants, PCBs, Phthalates	Maternal blood, urine, cord blood, breast milk, paternal blood and urine; infant meconium
Hadassah Hospital	300	Organophosphate Pesticides, Phthalates	Maternal and infant urine
Ben Gurion University–Soroka Hospital	140	Heavy metals	Maternal urine

2.3. Academic research studies utilizing biomarkers

There are currently three longitudinal birth cohort studies underway in Israel using biomarkers (Table 1). These studies are focused on studying adverse pregnancy and developmental effects of a wide variety of environmental contaminants, including brominated flame retardants, PCBs, phthalates, OP pesticides and heavy metals. The overall goal of these studies is to contribute to scientific knowledge on exposures to environmental contaminants during pregnancy and their effects on developing offspring.

Preliminary findings show that urinary concentrations of OP pesticides and phthalates in pregnant women in the Jerusalem area are comparable to those in the general population in Israel in 2011 (personal communication). Karakis et al. (2015) reported that in pregnant Bedouin-Arab women in Southern Israel, urinary concentrations of aluminum were higher for women residing within 10 km of a local industrial park (Prevalence Ratio (PR) = 1.12, p-value = 0.012) or who reported using a wood burning stove (PR = 1.37, p-value = 0.011) and cooking over an open fire (PR = 1.16, p-value = 0.076). Exposure to aluminum was adversely associated with minor anomalies (OR = 3.8, p-value = 0.046) after adjusting for history of abortions (OR = 6.1, p-value = 0.007). Fetuses prenatally exposed to arsenic were born prematurely (p-value = 0.001) and at lower weights (p- value = 0.023).

Sela et al. (2013) measured concentrations of metals in hair samples in the general population in Southern Israel. Women from the

Bedoin population were more highly exposed to several heavy metals including magnesium and lead, probably due to wearing large amounts of silver jewellery and cooking with colored aluminum pots and kitchen utensils with glaze that contains heavy metals. Elevated levels of arsenic in hair of male Bedouins was correlated with their heavy smoking of tobacco in traditional nargilas.

Researchers at the Hebrew University Center for Excellence in Agriculture and Environmental Health at Hadassah Hospital and Tel Hashomer Hospital are currently using HBM to study the impact of OP, pyrethroid, and triazine pesticide exposure on male reproductive health. An additional collaborative research project at Hadassah-Hebrew University, Asaf Harofeh Hospital, and Mount Sinai Hospital in NY is focused on exposure biomarkers for cotinine, phthalates and adverse effects on respiratory function in children. Additional HBM exposure assessment studies will be funded by the Ministry of Environmental Protection as part of the National Plan to Reduce Air Pollution in the Haifa Bay.

There are a number of research projects underway on biomarker development in the field of environmental health. Benor et al. (2015) have shown that respiratory symptoms and airway inflammation is positively correlated to ultrafine particle (UFP) content in exhaled breath condensate (EBC) of symptomatic children, indicating the feasibility of measuring UFP in the EBC of asthmatic children as a potential method for screening and biological monitoring in a pediatric population. Fireman et al. (2015) have shown that induced sputum can be used to monitor the accumulation of airborne particles in the lungs of children with asthma. Lavi et al. (2016) mapped particulate matter dispersion in metropolitan Tel Aviv by biomonitoring techniques using induced sputum samples.

Novack et al. (2015) have explored the use of umbilical cord cell proliferation as a biomarker of environmental exposure. Finally, researchers at the Hebrew University Center of Excellence in Agriculture and Environmental Health have developed a new technique for measuring carbamazepine and its metabolites in human urine as a biomarker of environmental exposure to pharmaceuticals (Fedorova et al., 2016). Using the novel technique, they have shown that healthy individuals consuming reclaimed wastewater-irrigated produce excreted carbamazepine and its metabolites in their urine, while subjects consuming fresh water-irrigated produce excreted undetectable or significantly lower levels of carbamazepine, and that the carbamazepine metabolite pattern at this low exposure level differed from that observed at therapeutic doses (Paltiel et al., 2016).

To date, there is no formal framework for using results from academic HBM or biomarker studies to support environmental health policy. However, there is frequent communication and cooperation between researchers and policy makers at the Ministries of Health and Environment.

3. Challenges and lessons learned

3.1. Framework and study designs

In a small country with limited resources and other pressing national priorities, and where environmental health is a relatively new field, ensuring solid political and financial support for HBM has been challenging. For this reason, Israel has yet to develop a formal National HBM Program, with long term goals and commitments. However, one of the lessons learned in Israel is that even in the absence of a formal HBM program, it is possible to collect meaningful HBM data and use it in an *ad hoc* fashion to support environmental health policy. In fact, in Israel the lack of a formal HBM program has allowed flexibility in goals and funding sources and has facilitated collaboration with the research community.

There is no formal framework or structure for prioritizing chemicals and sample populations for HBM studies in Israel. In the 2011 study, chemicals were chosen based on inclusion in other national HBM programs, suspected widespread exposure in the Israeli population based on previous pilot studies in Israel or findings in other populations, and suspected or known associations with dietary intake. Chemicals for the 2015–2016 HBM study were those deemed as a "public health cause for concern" based on findings of increased exposure relative to international populations in the 2011 study. In the study on POPs in breast milk the chemicals and sample population was determined by the WHO–UNEP protocol. As Israel is part of the HBM4EU initiative, decisions regarding priority chemicals and populations will be made in the future as part of efforts to harmonize and coordinate HBM activities in participating countries (European Environmental Agency, 2016).

Since resources for HBM are limited in Israel, there have been attempts to link the HBM survey to the existing infrastructure of the Israel National Health and Nutrition Surveys (MABAT) in Israel. The 2011 study was originally designed to be linked to the MABAT, however due to considerable delays in the MABAT, the biomonitoring study was conducted independently. In the 2015–2016 study, recruitment and sample collection for HBM was linked to the existing MABAT framework, saving valuable time and resources. However, there are drawbacks, including the relatively inflexible framework for adding specific questions to the questionnaire on environmental exposures, and potential problems related to data management and ownership. One of the lessons learned is that in order to maximize the potential of health and nutrition surveys as a platform for HBM surveys, HBM elements should be considered and integrated early in the stages of the planning process, and should not be a supplementary part of the MABAT survey.

While there are numerous existing biobanks in Israel, a national HBM biobank has yet to be established. In addition, capacity limitations in government laboratory freezers have made long term storage of biological specimens collected in HBM studies a challenge. The major lesson learned is that potential use of existing biobanks, or other solutions for long term storage of HBM specimens, should be considered early in the planning stages of the study.

3.2. Funding

Most of the HBM work in Israel in the past decade has been supported by an NGO. Considering the fact that the budget for environmental health issues within the Ministry of Health is limited, and that the Ministry of Environmental Protection allocates funds for environmental monitoring but not biomonitoring, this financial support has been critical. The 2011 National Biomonitoring Study was funded by a private NGO in Israel, the Environment and Health Fund, on the condition that the Ministry of Health would provide matching funds and would attempt to use the study results to gain political and financial support for future HBM studies. Indeed, results of the national HBM study were presented to the Head of the Ministry of Health in January 2014 and HBM was introduced to the Annual Ministry of Health workplan for 2016. Despite some political support for HBM, there have been delays in securing funding for analysing the samples collected in the 2015–2016 MABAT survey.

In the case of the study on POPs in breast milk, funding was provided by the Ministry of Environmental Protection and the Ministry of Health. In that case, the fact that Israel signed the Stockholm Convention and that the Ministry of Environmental Protection viewed compliance with the convention as high priority, helped secure both political and financial support for the study. However, the budget required for that study was very small (recruitment of 52 women and analysis of one pooled samples) so it is unclear if this mechanism for gaining support for HBM studies will prove itself on a larger scale. In the case of the study on organophosphate exposure in Palestinian pregnant women, funding for provided by the US AID – Middle East Regional Cooperation (MERC) program, a program intended to assist Arab and Israeli scientists to create and share solutions to regional development challenges. The US AID – MERC program previously funded a regional HBM project on lead exposure in children in Israel, Jordan, and the Palestinian Authority (Safi et al., 2006). Since Israel has signed a number of treaties related to environmental chemicals (for example the Minamata Convention) and is an active in the WHO Europe Health and Environment Action Plan, it is possible that international commitments will help secure political and financial support for HBM in the future.

Decision making in environmental health in Israel is frequently crisis driven, as has been evident in the government response to the public and political outcry following reports of high levels of air pollution in the Haifa district and increased rates of cancer in the population. The Finance Ministry allocated over 2 million euro for research on the health effects of exposure to air pollution in Haifa, including for research on exposure assessment and biological monitoring. While far from ideal, in this case a public health crisis was instrumental in securing government financial support for HBM research in Israel, albeit research on a specific geographic population and on a limited range of environmental exposures.

Israel is part of HBM4EU, a proposed initiative to use HBM to understand human exposure to chemicals and to inform policy and risk assessment. As participation in the HBM4EU requires financial commitment by participating countries, this is another example of how international commitments can advance allocation of government funding for HBM in Israel. EU funding for the project will help Israel to harmonize future HBM initiatives with those in participating countries (N = 26) and coordinate activities in this field.

HBM studies in Israel have increasingly relied on collaboration with foreign laboratories in Germany, the US, and Canada. In a geographically isolated country like Israel, the cost related to shipment of samples is considerable. Further expansion in the scope of HBM studies in Israel will depend on developing analytical capacity and expertise. A number of laboratories in Israel are currently developing capacity to measure environmental levels of contaminants such as BPA, brominated flame retardants, and phthalates in biological samples (Solomon et al., 2016).

3.3. Communicating results to policy makers and the public

As was the case in Cyprus and Luxembourg (Katsonouri et al., 2015), being a small country has the advantage of relative ease in accessing policy makers in order to use HBM data in inform environmental health policy. Several of the Ministry of Health researchers involved in the 2011 HBM study are also actively involved in policy decisions regarding environmental exposures, including pesticides, consumer products and ETS. This makes it easier to communicate HBM results in decision making forums, including government committees and the Parliament.

In some cases, HBM results have been met with scepticism in policy forums. For example, when presented with HBM data showing that the Israeli population is highly exposed to OP pesticides, Ministry of Agriculture representatives responsible for agricultural pesticide registration noted that levels in Israel were comparable to those in France, where many OP pesticides had been phased out beginning in 1995. They raised legitimate questions about whether results indicated exposure to parent compounds or less toxic OP breakdown products on agricultural produce. One of the lessons learned is that HBM data should be presented as part of a body of evidence supporting regulatory action and is frequently not sufficient in itself to justify specific regulatory interventions.

Another challenge in communication of HBM data is the lack of health based thresholds for some of the contaminants of public health concern in Israel, for example OP metabolites and cotinine. In the case of cotinine, the major finding that over 60% of non-smokers in the 2011 study had quantifiable cotinine levels in their urine was widely reported in the press and was presented by the Ministry of Health at official policy discussions at the Israeli Parliament. However, in the absence of a health based threshold for cotinine (such as HBM values), it was challenging to put the results into public health context.

On the other hand, in the case of OP pesticides there was concern that results could be misunderstood and misinterpreted. Results of the 2011 study showed that the Israeli population is highly exposed to OP pesticides, likely resulting from high consumption of fruits and vegetables, and specifically that OP metabolite levels in urine are positively correlated to fruit intake. In communicating these results to the public it was important to communicate the nutritional benefits of consuming fresh fruits and vegetables. The factsheet on the study published on the Ministry of Health website emphasized the importance of consuming fresh fruits and vegetables, so that HBM results wouldn't be misconstrued as indicating risks associated with fruit and vegetable consumption.

3.4. Communicating individual results and ethical considerations

In the 2011 study, we reported results to 18 study participants (out of 249) who requested their results and to one study participant with an exceptionally high BPA urinary concentration. We reported results to individuals in tabular form showing their individual results, the mean urinary concentration in the study population, and the range of urinary concentrations in the study population. For the individual with the unusual urinary BPA concentration we included information on possible exposure sources. In the 2015–2016 study in adults and children, the ethical committee who approved the study required reporting of individual results. This will be highly challenging in light of the time lapse between sample collection and analysis (due to budgetary delays). In addition, as stated previously, for the two exposures we measured in the 2015–2016 study (cotinine and pesticides) there is no health based threshold. We plan to introduce health promotion materials on the risk of exposure to ETS, and the health benefits of fruit and vegetable consumption, when communicating results to study participants.

3.5. International collaboration

Gaining financial and/or political support for HBM is key, but not sufficient, for developing an HBM framework in a small country. HBM is a highly technical and scientific field and a high level of expertise is required to implement HBM studies and interpret results. In the case of Israel, consultation and collaboration with leading international HBM experts has been crucial, both for technical issues relating to preventing potential contamination during sampling, to shipment of samples, but also to scientific issues related to data analysis and interpretation.

For these reasons, participation in HBM4EU is valuable for Israel, as local expertise in the technical and scientific aspects related to HBM are limited and as data harmonization is an important goal. This is an important lesson learned for other small countries planning to develop HBM activities: it is highly valuable to seek out assistance and if possible collaboration with international experts and institutions with proven experience in HBM. In the case of Israel, progress and achievements in the field of HBM are largely due to frequent consultations and successful collaboration with international experts in the field.

4. Conclusions

The use of HBM in environmental health policy and research has advanced rapidly in Israel but there are major challenges ahead. The Israel Ministry of Health views HBM as an important tool for measuring integrated chemical exposure of the population from various exposure sources, for promoting surveillance and prevention of potentially harmful exposures to chemicals in the population, and for tracking progress in reducing public exposure to environmental chemicals. Advances in this field are largely due to collaboration with international HBM experts, collaborative efforts between government and academic researchers in Israel and abroad, and support from NGOs. We aim to strengthen HBM capacity in Israel and improve data comparability by participating in the regional HBM program, HBM4EU. Next, we aim to use data collected in the 2015–2016 national biomonitoring study to examine trends in exposure to OP pesticides and ETS following policy changes. In the long term, we aim to prepare a National Biomonitoring Plan, which will advance the use of HBM in environmental health policy development and evaluation and in longitudinal tracking of exposure levels.

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