ARSENIC, LEAD, AND CADMIUM BIOAVAILABILITY IN CONTAMINATED SOILS: COMPARISON OF IN VIVO ANIMAL MODELS AND PREDICTION USING IN VITRO BIOACCESSIBILITY ASSAYS

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Introduction

When evaluating arsenic (As), lead (Pb), and cadmium (Cd) exposure via incidental soil ingestion, daily intake is greatly influenced by their bioavailability (i.e., the proportion of metals that are absorbed into the systemic circulation). Different animal models (i.e., swine and mouse) have been used to estimate their relative bioavailability (RBA; relative to the adsorption of soluble references) (Bradham et al., 2011; Smith et al., 2011) based on different dosing approaches and biomarkers. These include a single gavaged-dose of soil to fasted animals with area under the blood As concentration time curve (AUC) versus steady-state urinary excretion (SSUE) or accumulation in the liver, kidneys, or femur following multiple doses via diet. However, there is a lack of comparison among different in vivo assays, which come with uncertainty when assessing the risks of heavy metals with soil ingestion.

Although desired, cost and ethical considerations have limited the use of in vivo animal assays. Therefore, in vitro assays have been developed to determine the amount of metal extracted from soil matrix in simulated human gastric and intestinal fluid, i.e., bioaccessibility. Common in vitro assays include the SBRC, IVG, DIN, PBET, and UBM (Juhasz et al., 2009). However, to determine if these assays provide good prediction of RBA of heavy metals in contaminated soils, it is important to establish good in vivo-in vitro correlations. So far, this has been achieved in mining/smelting contaminated soils. However, to ensure their robustness, in vitro assays needed to be further correlated with RBA data using additional soils. In addition, limited research was performed on urban soils, which may be more relevant for metal exposure as children's contact with them is more often.

The objectives of this study were to compare RBA of heavy metals in contaminated soils determined using different animal models (i.e., mouse vs swine), different feeding schemes (i.e., single gavaged dose vs multiple diet doses), and different biomarkers (blood, urine, liver, and kidney) to determine how these parameters impact RBA determination of heavy metals in soils. In addition, based on recommended in vivo mouse assay, which is easy to handle with low cost, the RBA predictive ability of common in vitro assays for both contaminated soils and urban soils from China was assessed.

Methods

In this study, As-RBA in 12 As-contaminated soils from Australia with known As-RBA via swine blood AUC model was measured by mouse blood AUC, SSUE, and liver and kidney analyses. In addition, 12 As-, Pb-, or Cd-contaminated soils from China were measured for RBA and bioaccessibility of As, Pb or Cd using mouse steady state liver, kidney, and femur analyses and 4 in vitro assays (e.g., SBRC, IVG, DIN, and PBET). Furthermore, 38 urban soils from parks in 27 provincial cities of China were measured for Pb-RBA and bioaccessibility using the mouse steady state kidney assay and the SBRC assay.

Results

For the 12 As-contaminated soils from Australia, compared to swine blood AUC assay (7.0−81%), though well correlated (R^2 = 0.83), the mouse blood AUC assay yielded lower As-RBA values (2.8−61%). Similarly, strong correlations of As-RBA were observed between mouse blood AUC and mouse SSUE (R2 = 0.86) and between urine, liver, and kidney (R^2 = 0.75−0.89), suggesting As-RBA was congruent among different animals and biomarkers. Similarly, strong linear correlations of Pb-RBA (R^2 = 0.74−0.89) were observed in the mouse model between different biomarkers (liver, kidney, and femur). For Cd-contaminated soils, there was strong linear correlation between mouse liver and kidney (R^2 = 0.81).

Based on contaminated soils from China, the gastric phase (GP) of UBM and SBRC assay was best correlated with Pb-RBA among different in vitro assays, while IVG-GP and PBET-GP showed strongest correlation with As-RBA and Cd-RBA. For urban park soils, strong correlation was observed between Pb-RBA and the SBRC assay. Therefore, proper in vitro assays to predict metal bioavailability in contaminated soils are metal- and soil-dependent.

Conclusion

Different animals and biomarkers had little impact on the outcome of in vivo assays. In vitro assays have potential to predict RBA of heavy metals in contaminated soils and urban soils.

References

Bradham, K. D.; Scheckel, K. G.; Nelson, C. M.; Seales, P. E.; Lee, G. E.; Hughes, M. F.; Miller, B. W.; Yeow, A.; Gilmore, T.; Serda, S. M.; Harper, S.; Thomas, D. J. (2011). Relaive bioavailability and bioaccessibility and speciation of arsenic in contaminated soils. *Environ. Health Perspect., 119*, 1629-1634.

Smith, E.; Kempson, I. M.; Juhasz, A. L.; Weber, J.; Rofe, A.; Gancarz, D.; Naidu, R.; McLaren, R. G.; Gräfe, M. (2011). In vivo-in vitro and XANES spectroscopy assessments of lead bioavailability in contaminated periurban soils. *Environ. Sci. Technol., 45*, 6145-6152.

Juhasz, A. L.; Smith, E.; Weber, J.; Naidu, R.; Rees, M.; Rofe, A.; Kuchel, T.; Sansom, L. (2009). Assessment of four commonly employed in vitro arsenic bioaccessibility assays for predicting in vivo relative arsenic bioavailability in contaminated soils. *Environ. Sci. Technol., 43*, 9487-9494.