Relative Oral Bioavailability of Manganese in Electric Arc Furnace Steel Slag is Influenced by High Iron Content and Low Bioaccessibility

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Abstract:

Electric Arc Furnace (EAF) slag is a rock-like aggregate produced in association with carbon steel; it is used for several construction applications, including land and unpaved road cover. The potential human health risks due with EAF slag have recently been of interest because EAF slag is enriched with manganese (Mn) (~3%) and several other metals, including iron (Fe) (~18%). However, because these metals are bound in highly alkaline mineral matrices, *in vitro* bioaccessibility (IVBA) of Mn (27%) and Fe (10%) is limited. As an essential nutrient, Mn absorption and excretion is controlled by homeostasis, and absorption of Mn is also affected by an excess or deficiency of other divalent metals, including Fe. To assess Mn absorption from incidental EAF slag ingestion, as compared to Mn in diet, an *in vivo* relative bioavailability (RBA) study using F344 rats was conducted. Mn in diet was used because the EPA oral reference dose for Mn are based on the upper bound of Mn in the human diet. At 9 weeks old, rats were divided into six dose groups (n=6 for dose groups 1 through 3; n=8 for dose groups 4through 6) and administered Mn in their diet for 14 days. Dose groups 1 through 3 received 10 ppm (control), 250 ppm, and 500 ppm Mn in enriched chow, respectively. Dose groups 4 through 6 received the control diet (10 ppm Mn in enriched chow) in addition to 1000 mg Mn/kg in 3.5-g, 6-g, and 8-g EAF slag doughballs, respectively. Total Mn doses ranged from 0.24 to 21 mg Mn/kg-day in dose groups 1 through 3and 17 to 40 mg Mn/kg-day in dose groups 4 through 6. Mn and Fe concentrations in liver, and Mn in lung and striatum, the target tissue of the brain, were quantified using EPA Method 3051 and, following elimination of outliers, Mn levels in each tissue were fit by dose to linear, exponential, and polynomial models to evaluate their relative dose-tissue concentration (D-TC) relationships. Across the models evaluated for each tissue type (liver, lung, and striatum), the linear model had the best fit to the data and was therefore chosen to derive tissue-specific D-TC slope coefficients and ultimately, RBA values. The D-TC relationship was the most highly significant for the liver Mn content, where both the enriched chow and EAF slag had a positive slope (P value <0.001); the RBA for Mn in EAF slag based on liver data was 47%. The lung Mn content D-TC relationship showed a positive slope for the enriched chow administration group (P value <0.05) but a slightly negative and statistically insignificant (P > 0.05) slope for the EAF slag doughball group, indicating that there may be a decrease in systemic Mn absorption with increasing Mn dose associated with Mn in EAF slag. The RBA for Mn in EAF slag based on lung data was 19%. In comparison to the liver and lung tissues, the striatum showed little relationship (P > 0.05) between Mn tissue concentration and D-TCs remained relatively constant from administration of the enriched chow and EAF slag, and an RBA could not be calculated. Importantly, Fe concentrations in the liver of the chow-dosed groups were significantly decreased with dose, indicating that Mn inhibited Fe absorption. However, increased Fe was observed in the livers of EAF slag dose groups, likely because slag contains 6 times higher levels of Fe than Mn, and the high iron content of EAF slag may have inhibited systemic Mn absorption. Mn homeostasis is maintained in the liver, and the positive absorption curve for enriched chow and EAF slag is consistent with the relative differences in IVBA between Mn in enriched chow and EAF slag (41%). Lung and liver tissue support that systemic absorption of bioaccessible Mn is limited by competition with Fe, and striatum tissue data support a finding that, even at very high doses, homeostasis was maintained in the target tissue. Overall, these data indicate that incidental ingestion of Mn in EAF slag does not pose a human health hazard.