NeuroToxicology xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

NeuroToxicology

Full Length Article

Evaluation of the effect of an environmental management program on exposure to manganese in a mining zone in Mexico

Marlene Cortez-Lugo[a], Horacio Riojas-Rodríguez[a], Hortensia Moreno-Macías[b], Sergio Montes[c], Yaneth Rodríguez-Agudelo[c], David Hernández-Bonilla[a], Minerva Catalán-Vázquez[d], Raúl Díaz-Godoy[e], Sandra Rodríguez-Dozal[a,*]

[a] Instituto Nacional de Salud Pública, Centro de Investigación en Salud Poblacional, Dirección de Salud Ambiental, México
[b] Universidad Autónoma Metropolitana, Unidad Iztapalapa, División de Ciencias Sociales y Humanidades, México
[c] Instituto Nacional de Neurología y Neurocirugía "Manuel Velasco Suarez", Departamento de Neuroquímica, México
[d] Instituto Nacional de Enfermedades Respiratorias, Departamento de investigación en Epidemiología Clínica, México
[e] Instituto Nacional de Investigaciones Nucleares, México

ARTICLE INFO

Article history:
Received 1 May 2017
Received in revised form 31 August 2017
Accepted 31 August 2017
Available online xxx

Keywords:
EMP program
Impact evaluation
Air Mn
Blood Mn

ABSTRACT

Background: In the state of Hidalgo, Mexico, is found the largest second deposit of Manganese (Mn) in Latin America. Various studies on the sources of emission, exposure, and the effects on the health of children and adults have been conducted utilizing an ecosystem approach. Given the findings of Mn levels in air and the neurocognitive effects, an Environmental Management Program (EMP) was designed and implemented with the purpose of reducing exposure to Mn of the population, including various actions for reducing Mn emissions into the atmosphere.
Objective: To evaluate the impact of the EMP on the concentrations of Mn in air, as well as the modification of exposure to Mn in the blood and hair of adult residents of the communities intervened.
Methods: A quasi-experimental study was conducted in five rural communities, in which Mn concentrations were evaluated in air and in blood in the years 2002 and 2007, pre-intervention, and in 2013, postintervention. In 2003, the concentration of hair Mn among the communities was evaluated. Measurements were carried out of Particulate Matter (PM) of >10 and 2.5 μm (PM10 and PM2.5), and Mn in PM10 and PM2.5 were measured using proton-induced X-ray emissions (PIXE). The method of Difference in Differences (DID) was applied to estimate the impact of EMP on Mn concentrations in particulate matter via linear regression through multilevel models. To evaluate the effect of Mn concentrations in air over Mn concentrations in blood in both study periods in the mining communities per year (2002 and 2013), a linear regression model for each year was employed.
Results: We estimated that the EMP contributed to reducing the average daily concentrations of Mn in PM10 and PM2.5 by 92 and 85%, respectively. The adjusted model did not show an effect of Mn concentrations in air over Mn concentrations in blood in both study periods.
Conclusions: The results suggest that the measures implemented to reduce Mn emissions in air exerted a significant impact on the reduction of inhaled exposure in adult population.

1. Introduction

Manganese (Mn) is an essential trace element that plays an important role in the organism, promoting necessary enzymatic reactions in cellular functioning (Gwiazda et al., 2007). However, it is known that exposure to high concentrations of Mn can cause adverse effects on health, including neurological, reproductive and pulmonary affections, etc., in infantile as well as in adult population(Haynes et al., 2012; Lucas et al., 2015; Lucchini et al., 2007, 2012, 2014; Williams et al., 2012). Exposure to Mn in air is considered the most dangerous route, due to that the particles can reach the brain directly through the olfactory bulb and/or by means of the bloodstream through the lungs, without passing through the homeostatic excretory mechanisms (Schroeter et al., 2012).

Abbreviations: Mn, manganese; EMP, environmental management program; PM, particulate matter of >10 and 2.5 μm (PM_{10} and $PM_{2.5}$); PIXE, proton-induced X-ray emissions; DD, difference in differences.

* Corresponding author.
E-mail addresses: lrodriguez@insp.mx, dozalsan@gmail.com (S. Rodríguez-Dozal).

http://dx.doi.org/10.1016/j.neuro.2017.08.014
0161-813X/

In the central part of Mexico, in the northern region of the state of Hidalgo, the second largest deposit of Mn of Latin America is located, with a surface of 180 km^2, where the settlements of 42 highly marginalized communities are found. The population of this zone is potentially exposed to Mn emissions in air, deriving from the extraction, benefit, and production of diverse products of Mn, in the hands of the sole mining-producer company of Mn nodules in the world. Studies conducted in this manganese zone during the last 15 years have reported average daily concentrations of Mn in PM_{10} from 0.04–5.86 $\mu g/m^3$, (Riojas-Rodríguez et al., 2010, 2006; Santos-Burgoa et al., 2001a) and in $PM_{2.5}$ from 0.02–0.27 $\mu g/m^3$, (Cortez-Lugo et al., 2015; Torres-Agustín et al., 2013), as well as Mn levels in blood within a range of 9.3–88 $\mu g/L$ in adult population (Rodríguez-Agudelo et al., 2006; Santos-Burgoa et al., 2001b). In infantile population, Mn levels in blood and hair have been measured within a range of 5.5–18 $\mu g/L$ and 4.20–48.0 $\mu g/g$, respectively (Hernandez-Bonilla et al., 2011; Riojas-Rodríguez et al., 2010). In addition, Mn exposure was associated with a decrease in cognitive functioning and alterations in attention and motor function in adults (Santos-Burgoa et al., 2001b; Rodríguez-Agudelo et al., 2006; Solís-Vivanco et al., 2009), while in school-aged children of the zone, high Mn levels in hair were associated with a decrease in Intelligence Quotient (IQ), verbal memory and learning, motor function, visuoperception and visual short-term memory (Riojas-Rodríguez et al., 2010; Hernandez-Bonilla et al., 2011; Torres-Agustín et al., 2013; Hernández-Bonilla et al., 2016).

These findings led the mining company and the Government of the State of Hidalgo to actions to reduce Mn emissions in air as the implementation of the Environmental Management Program (EMP) from 2009 to 2012. In two mining units, the company carried out activities focused on reducing the emissions of dust into the atmosphere deriving from the process of Mn nodulation, drying, milling, and packaging, as well as waste management, erosion, and resuspension.

Diverse environmental-health programs have been implemented in different countries, including Mexico, with the purpose of avoiding or preventing adverse effects on health, through the control or diminution of the emission of environmental contaminants. Among these programs can be highlighted those to eliminate lead from gasoline, evaluated by lead levels in air and in biomarkers (Kennedy et al., 2014; Llop et al., 2013; Maresky and Grobler, 1993; Martínez et al., 2013; Pirkle et al., 1994; Quinn and Delves, 1989; Schuhmacher et al., 1996; Wietlisbach et al., 1995). For example, the prohibition of leaded gasoline in Spain was an action that increased the protection of the health of the Spanish population; the results of its evaluation, led to the application of substantial changes in diverse industrial, energy, and environmental policies (Llop et al., 2013; Schuhmacher et al., 1996). In Mexico, the evaluation of these programs has permitted catching a glimpse of what is still lacking, the control of emissions in primary lead smelting, and that it is important to strengthen the legal control framework to provide adequate measures of execution and supervision (Flores and Albert, 2004).

The evaluation of the EMP in Hidalgo will aid in forming future interventions designated to reduce the health impacts related with exposure to Mn in air. The evaluation of the efficacy of the EMP is essential for at least two reasons:1) to evaluate whether the EMP is effective for preventing and controlling non-occupational exposure to high levels of Mn in air, and 2) to determine whether the EMP should be renovated or improved. Therefore, the aim of this study was to estimate the effect of the average daily concentrations of Mn in air, using a Differences in Differences (DD) focus (a quasi-experimental method that can be used for estimating the causal effects of public health policies), as well as the modification of the exposure to Mn in air on Mn levels in blood and hair in adult residents of the intervened communities.

2. Materials and methods

2.1. Environmental management program description

Molango mining unit has made the exploration, extraction, benefit and production of: nodules and carbonates of manganese, ceramic grade manganese bioxide and manganese oxide. In 2002, the 2007 production was 240 thousand mt, 389.7 thousand mt in 2007 and 500.3 thousand mt in 2013. In this unit, five dust collectors were purchased, Mn energy-band transfer points, sweepers and rakes for dust collection were modified, the trailers cargo stand was improved, and 57% of the roads and transited areas were paved (32,856 m^2) (Compañia Minera Autlán and S.A.B de C. V., 2013; Compañia Minera Autlán and S.A.B de C.V.,2008; Minera Autlán and S.A.B. de C.V.,2011).

Nonoalco mining unit has made the exploration, extraction, benefit and production of: manganese oxide, ceramic-grade and battery-grade manganese bioxide. In 2002, the production was 15 thousand mt, 16.3 thousand mt in 2007 and 13.0 thousand mt in 2013. This unit, acquired a new ball mill with a hermetic mechanism for avoiding emissions during its functioning (elimination of 90% of the emission of fugitive dust in the processing stages), invested in the repair of a dust collector, and paved 9080 m^2 of transited areas and roads in the community, reducing the generation of suspended dust by 40%. Also, the unit invested in community reforestation programs (between 25 and 40 thousand trees annually) (Compañia Minera Autlán and S.A.B de C.V., 2013, 2008; Minera Autlán and S.A.B. de C.V., 2011, 2003).

The Government of the State of Hidalgo, altogether with the population, carried out the paving of the streets and roads of one of affected communities (730.0 m^2) (Presidencia Municipal de Lolotla, Hidalgo, 2012), thus avoiding the utilization of mine residue for paving. However, in the absence of the evaluation of the implementation of this program, it remains unknown whether the activities engaged in by the EMP had an effect over the exposure to Mn of the inhabitants of the communities settled in the mining district region.

2.2. Study design and population

A quasi-experimental study was conducted to evaluate the impact of Mn concentrations in air, in which the average daily concentrations of Mn in Airborne Particulate Matter <10 μm (Mn in PM_{10}) and Mn in Airborne Particulate Matter <2.5 μm (Mn in $PM_{2.5}$) were compared before and after implementation of the EMP during the 2009–2012 period. To evaluate Mn in PM_{10}, three mining communities (Chiconcoac, Tolago, and Nonoalco) and two no mining communities (Sta. Monica and Agua Blanca) were selected (Fig. 1). In the case of Mn in $PM_{2.5}$, three localities with measurements from the pre- and post-EMP were analyzed (Chiconcoac, Tolago, and Agua Blanca). Concentrations of Mn in $PM_{2.5}$ found in the years 2002 and 2007 (pre-EMP) were evaluated, with those of 2013 (post-EMP) (Fig. 2). (Riojas-Rodríguez et al., 2010, 2006Riojas-Rodríguez et al., 2010Riojas-Rodríguez et al., 2010, 2006)

The blood levels of adults in the three communities of the mining zone (Chiconcoac, Tolago, and Nonoalco) were used to evaluate the modification of the exposure to Mn in air. Mn levels in blood found in 2002 and 2013 were evaluated (Riojas-Rodríguez et al., 2010, 2006Riojas-Rodríguez et al., 2010Riojas-Rodríguez et al., 2010, 2006). Also, the concentration of Mn in hair in 2013 among the communities was evaluated.

The selected localities were representative of the region in their geographic and socioeconomic conditions, and similar to the exposed communities. The details of selection procedure were

Please cite this article in press as: M. Cortez-Lugo, et al., Evaluation of the effect of an environmental management program on exposure to manganese in a mining zone in Mexico, Neurotoxicology (2017), http://dx.doi.org/10.1016/j.neuro.2017.08.014