PM_{10} AIR POLLUTION AND ACUTE HOSPITAL ADMISSIONS FOR CARDIOVASCULAR AND RESPIRATORY CAUSES IN OSTRAVA

Hana Tomášková[1, 2], Ivan Tomášek[1, 2], Hana Šlachtová[2], Pavla Polaufová[1], Anna Šplíchalová[1], Jiří Michalík[1], David Feltl[3], Jaroslav Lux[2, 4], Marie Marsová[5]

[1]Institute of Public Health in Ostrava, Ostrava, Czech Republic
[2]Centre of Epidemiological Research, Faculty of Medicine, University of Ostrava, Ostrava, Czech Republic
[3]University Hospital Ostrava, Ostrava, Czech Republic
[4]Municipal Hospital Ostrava, Ostrava, Czech Republic
[5]Vítkovice Hospital, Ostrava, Czech Republic

SUMMARY

Background and Aim: The city of Ostrava and its surroundings belong to the most long-therm polluted areas in the Czech Republic and Europe. For identification of health risk, the World Health Organization recommends a theoretical estimation of increased short-term PM_{10} concentrations effect on hospital admissions for cardiac complaints based on a 0.6% increase per 10 $\mu g.m^{-3}$ PM_{10} and 1.14% increase for respiratory causes. The goal of the present study is to verify the percentage increase of morbidity due to cardiovascular and respiratory causes, as per WHO recommendations for health risk assessment, in the population of Ostrava.

Method: The input data include data on PM_{10} air pollution, meteorological data, the absolute number of hospital admissions for acute cardiovascular and respiratory diseases in the period 2010–2012. To examine the association between air pollution and health outcomes the time series Poisson regression adjusted for covariates was used.

Results: A significant relationship was found between the cardiovascular hospital admissions (percentage increase of 1.24% per 10 $\mu g.m^{-3}$) and values of PM_{10} less than 150 $\mu g.m^{-3}$ in the basic model, although after adjustment for other factors, this relationship was no longer significant. A significant relationship was also observed for respiratory causes of hospital admissions in the basic model. Contrary to cardiovascular hospitalization, the relationship between respiratory hospital admissions and PM_{10} values below 150 $\mu g.m^{-3}$ (percentage increase of 1.52%) remained statistically significant after adjustment for other factors.

Conclusions: The observed significant relationship between hospital admissions for respiratory causes was consistent with the results of large European and American studies.

Key words: particulate matter, hospital admissions, time series, health risk assessment

Address for correspondence: H. Tomášková, Institute of Public Health in Ostrava, Partyzánské nám. 7, 728 00 Ostrava, Czech Republic. E-mail: hana.tomaskova@zuova.cz

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INTRODUCTION

Epidemiological and toxicological studies from around the world demonstrated the adverse effect of suspended particulate matters (PM) on human health. The World Health Organization (WHO) has responded to this fact by an elaboration of the Air Quality Guidelines (AQG) that include recommended standards for health protection against the effects of PM (1). The term PM refers to a diverse mix of particles and aerosols dispersed in the atmosphere. The main sources of PM are industry, transport and household heating. Since the revision of the AQG (2) almost a decade has already passed during that the health risks associated with the exposure to PM have proved much more significant than originally expected.

The PM exposure may have serious health consequences. The long-term and short-term exposure to PM_{10} (a fraction of suspended particulate matter up to 10 µm in a diameter) may lead to premature deaths from cardiovascular and respiratory disease, lung cancer, and increased morbidity and hospital admissions for cardiovascular and respiratory diseases (3).

A new evidence is linking exposure to PM also with a number of other manifestations, such as the development of congenital defects, effects on the development of the nervous system and cognitive function in children, and disorders of the nervous system and diabetes in the adult population (3, 4).

The WHO estimates that approximately 8 million of deaths related to air pollution may occur worldwide in 2012, out of which 4.3 million of deaths could be related to indoor air pollution and 3.7 million to ambient air pollution (88% of them in low- and middle-income countries in the regions of Southeast Asia and Western Pacific) (5, 6). Despite the progress achieved in the past decade the level of PM in ambient air has not been reduced significantly.

According to the WHO, nearly 80% of the population in the European region lives in the cities, where concentrations exceeds the current standards recommended by the WHO. The European Union (EU) has estimated that PM pollution can pose in average a 9 months loss of life expectancy for each European (7). Only a few risks have a greater impact on human health than pollution in the current global world. In response to these findings the WHO has launched the process of the Air Quality Guidelines revision, that should result in further reduction of recommended PM standards, and has urged the global community to take appropriate measures that would reduce health risks.

According to recent findings, the short-term exposure to fractions PM_{10} and $PM_{2.5}$ are associated with an increased mortality and morbidity (PM_{10} exposure is associated with morbidity for respiratory causes, $PM_{2.5}$ exposure is related to cardiovascular morbidity and mortality) (8–10). American studies have evaluated the mortality and morbidity related to $PM_{2.5}$ for more than a decade. In Europe, the effect of fraction PM_{10} has still being assessed in health studies and the transition from fraction PM_{10} to $PM_{2.5}$ is lenghty. The reason is that at most of the monitoring sites in Europe $PM_{2.5}$ has still not been measured and the conversion from PM_{10} to $PM_{2.5}$ using coefficients proves to be inappropriate for this type of analysis (11).

A number of large studies have also passed through several phases over time that resulted in numerous analyses and re-analyses (e.g. APHEA-2, NMMAPS etc.). The results differ according to approaches and methods and also according to involvement of various combinations of cities in different phases of studies. For these reasons, it is possible to compare their results only approximately.

Older American studies reported an increase in hospitalizations for cardiovascular causes from 0.54 to 7.84% per each 10 $\mu g.m^{-3}$ PM_{10} and increased hospital admissions for respiratory causes from 0.58 to 7.32% per 10 $\mu g.m^{-3}$ PM_{10} (12). More accurate estimates modified this range. The US studies (12–15) found an increase in the number of hospital admissions for cardiovascular reasons from 0.1 to 2.4%, the European studies from 0.3 to 0.9% (16–22), and the Asian studies from 0.15 to 0.6% per 10 $\mu g.m^{-3}$ PM_{10} (23–26). In case of hospitalization for respiratory causes the American studies showed an increase from 0.4 to 2.3% (12), the European studies from 0.6 to 1.1% (16–19, 27), and the Asian studies from 0.12 to 1.6% per each 10 $\mu g.m^{-3}$ PM_{10} (23–26).

The World Health Organization recommends to calculate a theoretical estimate of the increased short-term PM_{10} concentrations effect on hospital admissions for cardiac causes based on 0.6% increase per 10 $\mu g.m^{-3}$ PM_{10} (95% CI: 0.3–0.9) (17), and for respiratory causes based on 1.14% increase (95% CI: 0.62–1.67) (17). The theoretical estimates stated by the WHO represent so called concentration-response (C-R) function, i.e. percentage increase of morbidity per increase of PM_{10} exposure by each 10 $\mu g.m^{-3}$.

Despite a decline of PM concentrations in the recent years, the city of Ostrava and its surroundings belong to the most long-term polluted areas in the Czech Republic and Europe (28).

The aim of the presented study was to verify the proportional increase of morbidity for cardiovascular and respiratory causes, as per WHO guidelines for health risk assessment, in the population of Ostrava.

MATERIALS AND METHODS

The input data include data on PM_{10} air pollution, meteorological data, the absolute number of hospital admissions for acute cardiovascular and respiratory diseases.

Data on PM_{10} Air Pollution

In the city of Ostrava there are located seven stations of immission monitoring and a hot-spot measurement station. The monitoring is provided by the Czech Hydrometeorological Institute and the Institute of Public Health.

In this study we analysed short-term PM_{10} concentrations measured over the period 2010–2012 at four stations: Poruba (S1422-TOPUM), Radvanice (S1650-TOREK, untill 2010 called Bartovice-TOBAK), Zábřeh (S1064-TOZRA), and Fifejdy (S1061-TOFFA). At selected stations in the area Fifejdy, Zábřeh and Radvanice there is running a continuous 24-hour PM_{10} measurement. The measurement in Poruba is a 24-hour measurement at intervals of 3 days. For further processing, it was necessary to fill in missing data at all measurement stations – data was missing due to shortfalls of measurement, measurement mode (every third day in Poruba) or cessation of the measurement at the station Poruba in 2012. The relationships for imputation of data were calculated on the basis of correlation and regression analysis of the measured values for the year 2010 and merged years 2011–2012. For the final analysis the average daily values for Ostrava were calculated based on the values of all four measurement stations. The PM_{10} values were categorized into 10 $\mu g.m^{-3}$ intervals. The first category included the values up to 20 $\mu g.m^{-3}$ – an agreed background level.

Meteorological Data

Information on the meteorological conditions was obtained from the station Mariánské Hory (1649-TOMHK) that is situated roughly in the middle of the area of interest. The meteorological data should illustrate climatic conditions in the individual years. The data on humidity (%), temperature (°C) and wind speed ($m.s^{-1}$) was presented. Wind speed lower than 0.5 $m.s^{-1}$ was defined as calm wind.

Health Outcomes

Morbidity (hospitalization) was evaluated on the basis of data on acute hospital admissions (except of planned ones) that were obtained from the three Ostrava hospitals – the University Hospital Ostrava, the Vítkovice Hospital and the Municipal Hospital Ostrava that serve the entire city. Out of the list of diagnoses of the International Classification of Diseases of the World Health Organization diagnoses I00-I99 – diseases of the circulatory system and diagnoses J00-J99 – diseases of the respiratory system that were the reason for hospital admission were selected. In addition, available data on age, gender and residence address (street, city district) were collected as well.

Statistical Analysis

To examine the association between air pollution and health outcomes the time series Poisson regression adjusted for covariates was used. The models were fitted in generalized linear models (GLM) procedure in the software package Stata v. 13 (29). Model building strategy was carried out in a similar way as in other relevant studies (30). The decisive factors like temperature, humidity, calm wind, days off (weekends and holidays) were included into the models. Initially, the models were tested for individual factors and then they were included in the final model. The Akaike's Information Criterion (AIC) was used for evaluation of models that were tested based on residues.

The exponential model was used for the expression of regression coefficients in the form of rate ratio (RR). The results are presented in the form of percentage increase/change (%), expressed for RR: percentage increase = (RR – 1) * 100% with 95% confidence intervals (95% CI). The results are presented only for the lag = 0.

Statistical tests used a significance level of 5%. The statistical program Stata version 13 (29) was used for the statistical analysis.

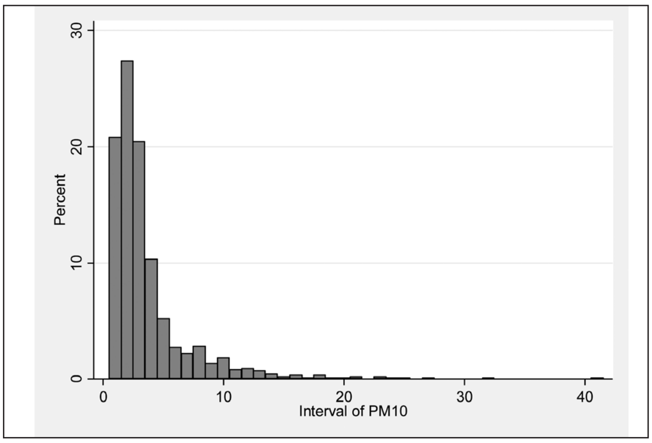

Fig. 1. *Frequency of days in PM_{10} concentrations intervals in Ostrava in the period from 2010–2012.*

(The first concentration interval presents the values PM_{10} < 20 μg.m^{-3}, the second one the values 20.0–29.9 μg.m^{-3}, etc.)

RESULTS

PM_{10} Concentrations

The descriptive data on the PM_{10} concentrations in the years 2010–2012 is introduced in Table 1. Daily values exceeded the value 150 μg.m^{-3} in 22 days. The average PM_{10} values ranged between 39.1 and 46.4 μg.m^{-3}. Daily concentrations were divided into concentrations intervals by 10 μg.m^{-3} from concentrations exceeding 20 μg.m^{-3} and up to a maximum of daily measured values (Fig. 1). The number of days was indicated in the first three concentration intervals (up to 40 μg.m^{-3}) (Fig. 1). As seen in Fig. 2, the highest values were observed during the winter months.

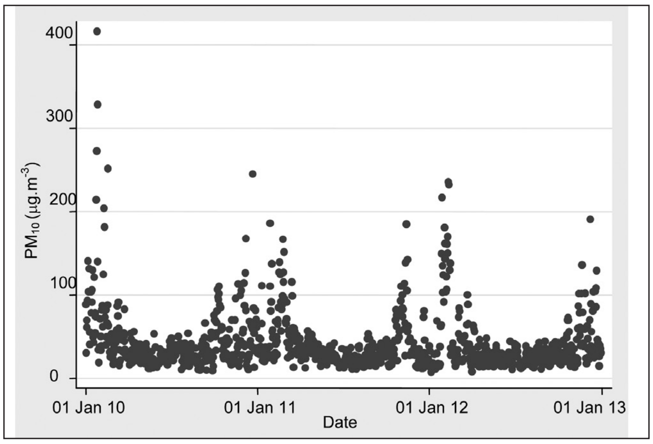

Fig. 2. *Time series of particulate matters PM_{10} for the study period from 2010–2012.*

Meteorological Conditions

In the analyses, the average daily temperature, humidity of air and the number of days with calm wind were taken into account (Table 2). These calm wind days reached from 15 to 23% during the years 2010–2012. The correlation between PM_{10} and meteorological variables is described in the Table 3.

Table 1. *Descriptive statistics of PM_{10} concentrations in Ostrava*

Year	N	PM_{10} (μg.m^{-3})						N PM_{10} ≥ 150 μg.m^{-3}
		Mean	Min.	25th percentile	Median	75th percentile	Max.	
2010	365	46.4	8.9	23.4	34.1	53.4	416.1	9
2011	365	39.3	10.8	21.5	30.5	44.2	185.6	4
2012	366	39.1	7.7	19.5	28.2	40.4	235.6	9

N – number of days

Table 2. *Description of the average daily temperatures and humidity of air in individual years*

Condition	Year	N days	Average	Min.	25th percentile	Median	75th percentile	Max.
Average daily temperature (°C)	2010	363	8.9	−16.1	1.5	9.9	16.0	26.9
	2011	364	10.2	−9.3	3.4	10.3	17.3	26.8
	2012	362	10.3	−15.5	3.6	10.4	17.9	27.9
Humidity of air (%)	2010	363	78.7	50.6	69.6	79.5	88.2	99.8
	2011	364	76.0	41.5	67.6	75.6	85.5	99.6
	2012	362	75.1	32.1	63.9	76.3	85.9	99.8

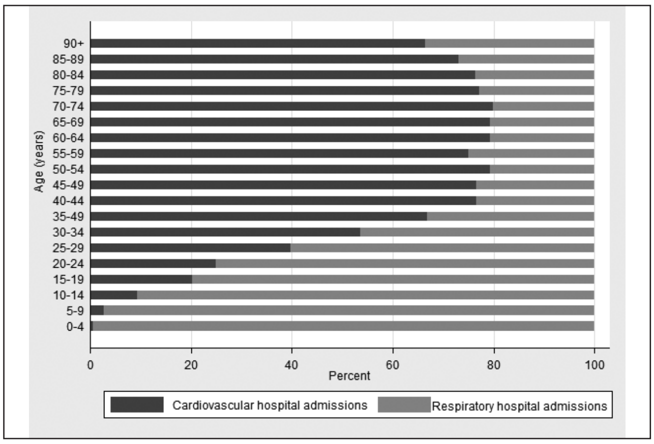

Fig. 3. *Proportions of cardiovascular and respiratory hospital admissions by age groups.*

Health Outcomes

During the 2010–2012 period there were registered 15,310 cases of acute hospital admissions for cardiovascular causes (N = 10,300) and respiratory causes (N = 5010) in inhabitants of Ostrava. The hospitalization due to cardiovascular causes was about twice as high as due to respiratory causes. Up to the age of 30 years the hospital admissions for acute respiratory disease dominated, above this age the most frequent cause of hospitalization were cardiovascular reasons (Fig. 3). The average age of people admitted to hospital was 57 years in men (SD = 24.6) and 64 years in women (SD = 24.1).

Mean values of daily number of hospital admissions for cardiovascular causes varied from 9–10 cases, a number of hospital admissions due to respiratory causes was lower (4–5 cases) (Table 4).

Relationship between PM_{10} and Health Indicators

The average daily numbers of hospital admissions were calculated for the PM_{10} concentration intervals (1–14) in the range from 0–150 $\mu g.m^{-3}$.

Table 3. *Spearman rank correlation coefficients between the particulate matters PM_{10} and meteorological variables*

	PM_{10} ($\mu g.m^{-3}$)	Ambient temperature (°C)
PM_{10} ($\mu g.m^{-3}$)	1.0000	
Ambient temperature (°C)	−0.4101	1.0000
Relative humidity (%)	0.1296	−0.4894

The PM_{10} values ≥ 150 $\mu g.m^{-3}$ (concentration intervals 15 to 41) occurred in only 22 days during the whole study period which corresponds with the substantial variability of numbers of hospital admissions (Fig. 4). A linear trend was indicated in both causes of hospital admissions for the intervals of PM_{10} < 150 $\mu g.m^{-3}$. Based on this finding, corresponding with the findings from meta-analyses, the final analysis was performed for PM_{10} < 150 $\mu g.m^{-3}$.

Crude percentage changes for all values of PM_{10} and PM_{10} < 150 $\mu g.m^{-3}$ are listed in Table 5. Possible influential factors used in the models were the average daily temperature, humidity of air, calm wind, and days off (weekends and public holidays). A significant relationship was found between the cardiovascular hospital admissions (percentage increase of 1.24%) and values of PM_{10} less than 150 $\mu g.m^{-3}$ in the basic model, but after adjustment for other factors, this relationship was not significant (Table 5).

A significant relationship was also observed for respiratory causes of hospital admissions in the basic model. Contrary to cardiovascular hospitalization, the relationship between the respiratory hospital admissions and PM_{10} values less than 150 $\mu g.m^{-3}$ (percentage increase of 1.52%) remained statistically significant after adjustment for other factors (Table 5).

Of studied factors, temperature, humidity and days off were in statistically significant inverse relationship with the percentage of change of both indicators.

DISCUSSION

The impact of air pollution on health in Ostrava has been observed for a long time. The approach of a simple comparison of routinely collected data on population health status with concentrations of air pollutants used in the past does not meet current requirements for the evaluation of air pollution impacts on health and was replaced by the methods of health risk assessment that is based on qualitative or quantitative estimates of the impact of air pollution on health. As demonstrated by numerous studies this quantification is biased by relatively large uncertainties regarding the level of specific estimates of air pollution impacts on health (12–26). Theoretically estimated numbers of deaths and hospitalizations of persons cannot in fact correspond with real numbers of deceased or hospitalized persons with respect to a simplification that represents a theoretical calculation. The real mortality and morbidity is affected by many factors that cannot be taken into account in the theoretical estimate. As a result, the theoretical estimates can be successfully used rather for the comparison of different situations than for the estimation of the real consequences. A more appropriate methods

Table 4. *The summary of daily numbers of hospital admissions for I and J diagnosis during the study period in Ostrava*

Indicator	Year	Min.	Median	Max.	Total in the year
Hospital admission for cardiovascular causes (I diagnosis)	2010	1	10	23	3691
	2011	1	9	23	3285
	2012	0	9	25	3324
Hospital admissions for respiratory causes (J diagnosis)	2010	0	4	11	1676
	2011	0	5	17	1751
	2012	0	4	14	1583

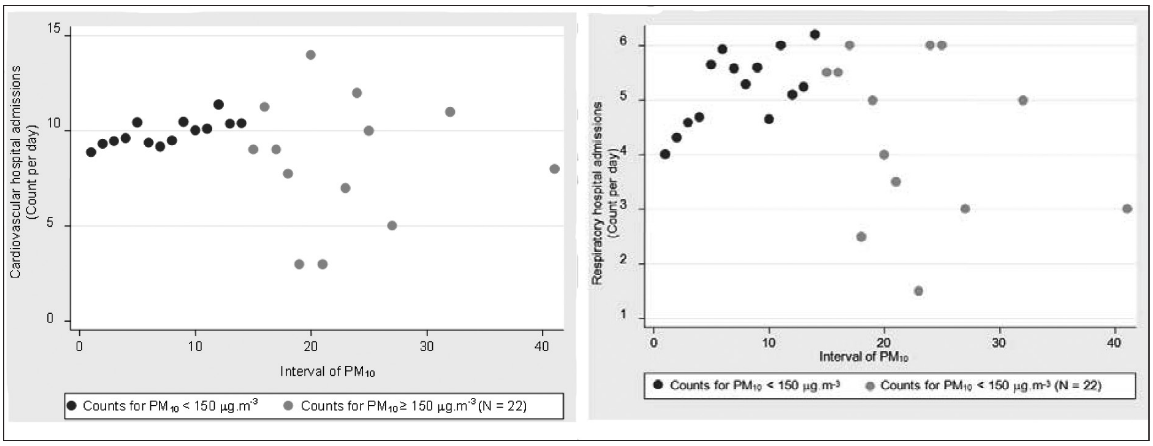

Fig. 4. *Average daily numbers of hospital admissions in the concentrations intervals of PM_{10} (Daily PM_{10} concentrations were divided into concentrations intervals by 10 µg.m^{-3} from concentrations higher than 20 µg.m^{-3}; the first concentration interval presents the values PM_{10} < 20 µg.m^{-3}, concentration intervals 15 to 41 presents the values above 150 µg.m^{-3}.)*

for determining the impacts of air pollution on health are provided by epidemiological studies. Until now, no more accurate analysis of mortality and hospitalization in relation to PM_{10} exposures of residents in Ostrava has been made. The presented analysis based on real numbers of hospitalized persons represents the first evaluation of the direct impact of air pollution on health.

The study found an association between the short-term PM_{10} exposures and increased numbers of hospitalizations due to cardiovascular and respiratory causes. In case of cardiovascular hospitalization it is not possible to clearly determine whether the incidence has increased or not. The cardiovascular hospitalization was considerably affected by other confounding factors that reduced the effect of short-term PM_{10} exposure. The observed percentage increase was smaller compared to the most recent two meta-analyses (4, 10) that found a significant relationship between short-term PM_{10} exposure and hospitalization for cardiovascular reasons.

The observed significant relationship for hospitalization due to respiratory causes is consistent with the results of the large European and American studies (12, 16–19, 27).

The analysis presented here indicates that PM_{10} exposure in Ostrava is more significantly associated with respiratory morbidity than cardiovascular one. This is in compliance with recent findings associating the respiratory morbidity rather with the exposure to PM_{10} and cardiovascular morbidity with the $PM_{2.5}$ exposures (10).

The heterogeneity of results of the studies on the relationship between hospital admissions on one hand and exposures to PM on the other hand is not reliably explained. One of the possible explanations is that the effect of PM depends on its composition (10). This might explain the different effect of PM in various areas with approximately equal exposure values. At the moment, however, there is not sufficient evidence and further research is therefore required.

In compliance with the current knowledge the linear relationship between the exposure and effect (C-R function) of a range of PM concentrations in ambient air, common in European cities, was confirmed.

In the areas with low concentrations, the C-R function is rather steeper i.e. supra-linear with greater health effects than in the case of higher concentrations, where the C-R function flattens and health effects decrease. If the linear C-R function is used for such high concentrations it could lead to an overestimation of the risk. Some sources indicate borderline concentrations of PM_{10} > 150 µg.m^{-3} (31), others PM_{10} > 200 µg.m^{-3} (1).

In case of the study in Ostrava the entire period included 22 values of PM ≥ 150 µg.m^{-3} and the number of hospital admissions showed a high variability in those days thus the final model included only days with concentrations of PM_{10} < 150 µg.m^{-3}.

Most of the world studies currently evaluate the morbidity in relationship with the $PM_{2.5}$exposure (10). This is based on evidence about the harmful effects of fine particles on the cardiovascular system. Initially the conversion from PM_{10} to $PM_{2.5}$ was applied using the coefficient obtained from long-term measurements.

However, since that time this approach has been retreated due to the fact that the conversion coefficient blurs the variation in daily concentrations depending on the composition of PM from the currently prevailing sources. At present, directly measured

Table 5. *The relationship between PM_{10} and hospital admissions adjusted for the interacting factors*

	Cardiovascular hospital admission			Respiratory hospital admission		
PM_{10}	% change	95% CI	p value	% change	95% CI	p value
PM_{10} (per 10 µg.m^{-3})[1]	0.32	−0.20–0.85	0.227	1.45	0.74–2.17	< 0.001
PM_{10} (per 10 µg.m^{-3})[2]	1.24	0.50–1.99	0.001	3.19	2.16–4.24	< 0.001
PM_{10} (per 10 µg.m^{-3})[3]	0.01	−0.78–0.80	0.986	1.52	0.42–2.63	0.007

[1]Crude % change for all values of PM_{10}
[2]Crude % change for PM_{10} < 150 µg.m^{-3}
[3]Model – % change adjusted for average daily temperature, humidity of air, calm wind days and days off

values are used. In case of the study in Ostrava there was not possible to use $PM_{2.5}$ values because the measurement has been carried out only in the most polluted municipal district of Ostrava (Bartovice) and these values cannot be considered representative for the whole city.

Other factors that affect the heterogeneity of results of the published studies are statistical methods used. The models using time-series analysis allow shifting of the impact of PM_{10} on health indicators. In different studies there are numerous combinations trying to identify PM_{10} impact on health indicators in the same day, but also in the following days (from the 1st to 7th day) or from the PM_{10} average concentration for several days. Also various confounding factors that make the comparison of results difficult entered the models. In the study in Ostrava, there were taken into account commonly used factors (meteorological data and days off) except of occurrence of the days with the flu epidemic. That approach enabled to determine a current relationship that can be used as a basis for more detailed analysis (study of time-series with adjustment for other factors).

A number of studies were focused on cardiac hospitalization (e.g. CAFE) (17) or hospital admission for cardio-respiratory causes (32). The cardiac diagnoses are only a part of the cardiovascular diagnoses. Then cardio-respiratory causes of hospitalization include cardiac and respiratory causes. Even in this case again the comparison of results of the studies focused on different diagnoses was not ideal. This applies in particular to cardio-respiratory diagnoses. Generally, greater effects were indicated for short-term PM_{10} exposure to cardiac than cardiovascular hospitalization. For example, a study involving 14 Spanish cities found an increase in hospitalizations for cardiovascular reasons of 0.91% (from 0.35 to 1.47%), and for cardiac causes of 1.56% (from 0.82 to 2.31%) per 10 $\mu g.m^{-3}$ PM_{10} (22). The heterogeneity of study results was considerable. According to recent knowledge assigning effects on the whole cardiovascular system to PM exposures there have been analysed all diagnoses I (diseases of the circulatory system) in the Ostrava study.

At present, the optimal size of the population for a similar type of study is considered one million people and more (33). In the literature, however, we can find a number of studies in the cities which population is smaller. This is also the case of the present study. It would be possible to get closer to the recommended value by enlargement of the area of interest from the city of Ostrava to the entire Ostrava-Karviná region.

Another factor that might influence the results is the period for which the study is processed. In case of the study in Ostrava it was a three-year period. This meets the general requirements that state one year as the minimum time period for a similar type of study (33). However, a longer period is an advantage and allows more accurate determination of the relationship.

CONCLUSION

In this study, we found significant proportional increase for both types of hospital admissions (from cardiovascular and respiratory causes) in the relationship (regardless of other factors) with the concentrations of PM_{10} <150 $\mu g.m^{-3}$. After adjusting for other factors the cardiovascular hospitalization in Ostrava showed only a slight, statistically not significant, percentage increase (0.01%) in relation to PM_{10} exposure compared to C-R function used for theoretical calculations that assume a statistically significant increase in hospital admissions due to cardiac causes (0.6% per 10 $\mu g.m^{-3}$).

In case of hospitalization due to respiratory causes the study found a significant relationship with the PM_{10} exposure. The observed percentage increase (1.52%) was higher compared with the C-R function (1.14%) used for theoretical calculations.

The presented study is the first study in the city of Ostrava that explores the relationship between acute hospital admissions and daily values of PM_{10}. The study has a number of limits that are mentioned in the discussion. As for time and financial reasons the study was designed as a pilot study. One of its goals was to verify the availability of data on hospital admissions and it was successfully achieved. In the future, a more detailed analysis should be carried out for a longer time period with the extension to a wider area of the Ostrava-Karviná region that would take into account other possible influential factors and that will be used as the basis for further refinement of the relationship between exposure and effect (namely hospitalization due to respiratory and cardiovascular causes) for residents of the Ostrava-Karvina region. Furthermore, in accordance with current findings and recommendations the $PM_{2.5}$ measurements should be started at the air pollution monitoring stations that would enable to evaluate the effect of this fraction on health in the future.

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