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Neuroscience and Respiration

Mieczyslaw Pokorski *Editor*

Environment Exposure to Pollutants

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Environment Exposure to Pollutants

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Preface

This is a new book series entitled Neuroscience and Respiration, a subseries of Springer's renowned Advances in Experimental Medicine and Biology. The book volumes present contributions by expert researchers and clinicians in the field of pulmonary disorders. The chapters provide timely overviews of contentious issues or recent advances in the diagnosis, classification, and treatment of the entire range of pulmonary disorders, both acute and chronic. The texts are thought as a merger of basic and clinical research dealing with respiratory medicine, neural and chemical regulation of respiration, and the interactive relationship between respiration and other neurobiological systems such as cardiovascular function or the mind-to-body connection. In detail, topics include lung function, hypoxic lung pathologies, epidemiology of respiratory ailments, sleep-disordered breathing, imaging, and biomarkers. Other needful areas of interest are acute respiratory infections or chronic inflammatory conditions of the respiratory tract, exemplified by asthma and chronic obstructive pulmonary disease (COPD), or those underlain by still unknown factors, such as sarcoidosis, respiratory allergies, lung cancer, and autoimmune disorders involving the respiratory system.

The prominent experts will focus their presentations on the leading-edge therapeutic concepts, methodologies, and innovative treatments. Pharmacotherapy is always in the focus of respiratory research. The action and pharmacology of existing drugs and the development and evaluation of new agents are the heady area of research. Practical, data-driven options to manage patients will be considered. The chapters will present new research regarding older drugs, performed from a modern perspective or from a different pharmacotherapeutic angle. The introduction of new drugs and treatment approaches in both adults and children will be discussed. The problem of drug resistance, its spread, and deleterious consequences will be dealt with as well.

Lung ventilation is ultimately driven by the brain. However, neuropsychological aspects of respiratory disorders are still mostly a matter of conjecture. After decades of misunderstanding and neglect, emotions have been rediscovered as a powerful modifier or even the probable cause of various somatic disorders. Today, the link between stress and respiratory health is undeniable. Scientists accept a powerful psychological connection that can directly affect our quality of life and health span. Psychological approaches, by decreasing stress, can play a major role in the development and course of respiratory disease, and the mind-body techniques can aid in their treatment.

Neuromolecular aspects relating to gene polymorphism and epigenesis, involving both heritable changes in the nucleotide sequence and functionally relevant changes to the genome that do not involve a change in the nucleotide sequence, leading to respiratory disorders will also be tackled. Clinical advances stemming from basic molecular and biochemical research are but possible if the research findings are "translated" into diagnostic tools, therapeutic procedures, and education, effectively reaching physicians and patients. All that cannot be achieved without a multidisciplinary, collaborative, "bench-to-bedside" approach involving both researchers and clinicians, which is the essence of the book series Neuroscience and Respiration.

The societal and economic burden of respiratory ailments has been on the rise worldwide leading to disabilities and shortening of life span. COPD alone causes more than three million deaths globally each year. Concerted efforts are required to improve this situation, and part of those efforts are gaining insights into the underlying mechanisms of disease and staying abreast with the latest developments in diagnosis and treatment regimens. It is hoped that the books published in this series will fulfill such a role by assuming a leading role in the field of respiratory medicine and research and will become a source of reference and inspiration for future research ideas.

Titles appearing in Neuroscience and Respiration will be assembled in a novel way in that chapters will first be published online to enhance their speedy visibility. Once there are enough chapters to form a book, the chapters will be assembled into complete volumes. At the end, I would like to express my deep gratitude to Mr. Martijn Roelandse and Ms. Tanja Koppejan from Springer's Life Sciences Department for their genuine interest in making this scientific endeavor come through and in the expert management of the production of this novel book series.

Opole, Poland Mieczyslaw Pokorski

Volume 3: Environmental Exposure to Pollutants

The impairment of lung function caused by environmental exposure to pollutants and toxicants is a rising health problem, particularly in highly industrialized parts of the world. The problem urgently calls for the development of new methodologies to assess both the level of elemental exposure and the effects for quality of health and longevity. This volume provides state-of-the-art information about the recent advances in occupational and nonoccupational pollutant-related disorders of the respiratory tract and the assessment of a threat they pose for the health span. The detrimental health effects of pollution related to heavy road traffic are described at length.

Contents

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Effects of Exposure to Welding Fume on Lung Function: Results from the German WELDOX Study

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Abstract

The association between exposure to welding fume and chronic obstructive pulmonary disease (COPD) has been insufficiently clarified. In this study we assessed the influence of exposure to welding fume on lung function parameters. We investigated forced expiratory volume in 1 s (FEV_1), forced vital capacity (FVC), FEV_1/FVC, and expiratory flow rates in 219 welders. We measured current exposure to respirable particles and estimated a worker's lifetime exposure considering welding techniques, working conditions and protective measures at current and former workplaces. Multiple regression models were applied to estimate the influence of exposure to welding fume, age, and smoking on lung function. We additionally investigated the duration of working as a welder and the predominant welding technique. The findings were that age- and smoking-adjusted lung function parameters showed no decline with increasing duration, current exposure level, and lifetime exposure to welding fume. However, 15 % of the welders had FEV_1/FVC below the lower limit of normal, but we could not substantiate the presence of an association with the measures of exposure. Adverse effects of cigarette smoking were confirmed. In conclusion, the study did not support the notion of a possible detrimental effect of exposure to welding fume on lung function in welders.

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Keywords
Chronic obstructive lung disease • Cumulative exposure • Occupation • Respirable particle matter • Respiratory impairment

1 Introduction

Welding fume is composed of gases, and particulate matter, mainly consisting of iron and other metals, and depends on the processed material and the welding technique applied (Antonini 2003). Personal sampling in the breathing zone of welders revealed that about 50 % of the particulate matter is respirable and can reach the lung (Lehnert et al. 2012). The individual shift exposure of a welder to respirable particles is mainly influenced by the welding technique, working position, welding in confined space, exhaust ventilation systems, and the use of respiratory protection (Lehnert et al. 2012). Few efforts have been made to assess a welder's lifetime exposure to welding fume, for example in a cohort of European welders (Gerin et al. 1993) and in a cross-sectional study of welders in New Zealand (Fishwick et al. 1997).

Adverse effects of long-term exposure to welding fume on the lung function have been inconclusively reported in the literature, frequently not associated with quantitative measures of lifetime exposure (Szram et al. 2013). Chronic obstructive pulmonary disease (COPD) in welders has been reported, but it was, at least partially, attributed to smoking (Chinn et al. 1990). Szram et al. (2013) recently reviewed seven cohort studies regarding the lung function of welders but concluded that exposure assessment was limited and found no clear impairment of lung function parameters in non-smokers (Szram et al. 2013).

WELDOX has been carried out as a cross-sectional study in more than 200 German welders from various industrial settings, with comprehensive efforts to measure and model determinants of exposure to welding fume and its constituents (Lehnert et al. 2012, 2013; Weiss et al. 2013; Pesch et al. 2012; Hoffmeyer et al. 2009). In the present report we studied the association of exposure to respirable welding fume and lung function based on various exposure metrics.

2 Methods

The study was approved by the Ethics Committee of Ruhr University Bochum and was conducted in accordance with the Helsinki Declaration for Human Experimentation of the World Medical Association.

2.1 Study Population

In total, 243 male welders from 23 companies were enrolled in the WELDOX study between 2007 and 2009 as previously described (Lehnert et al. 2012, 2013; Weiss et al. 2013; Pesch et al. 2012). For the present analysis we included 219 welders with complete data about lung function and exposure to respirable welding fume. In brief, information regarding welding in the past, smoking, and health status, including respiratory symptoms (cough, phlegm, and shortness of breath), was collected by questionnaires in face-to-face interviews. Current smoking was additionally confirmed with cotinine using 100 μg/L as cut-off in post-shift urine.

2.2 Lung Function Measurements

The lung function was measured with a Master Scope (Jaeger, Hoechberg, Germany) after a work shift following the criteria of the American Thoracic Society (1995). We did not conduct post-bronchodilator spirometry. All but eight examinations were performed by the same investigator (HB). Forced expiratory volume in 1 s (FEV_1), forced vital capacity (FVC) and their ratio (FEV_1/FVC), peak expiratory flow (PEF), and mean expiratory flow (MEF) at 75, 50, and 25 % of vital capacity (MEF_{75}, MEF_{50}, MEF_{25}), further referred to as expiratory flow rates, were determined. FEV_1, FVC, and FEV_1/FVC were used as dependent variables in the modelling of welding-fume effects. Predicted values of lung function parameters were derived from the healthy non-smoking Caucasian men collected by the Global Lung Initiative (GLI) (Quanjer et al. 2012). In order to compare our results with previously published studies, we additionally used reference values of the European Coal and Steel Community (ECCS) (Quanjer et al. 1993).

Welders were assessed as low performers regarding their lung function if measures were below the lower limits of normal (LLN) set to the 5th percentile given by GLI. An FEV_1/FVC performance below the LLN was used to identify welders with an airway obstruction suggesting chronic obstructive pulmonary disease (COPD).

2.3 Assessment of Exposure to Welding Fume

We assessed shift exposure to welding fume by the concentration of respirable welding fume measured during a working shift prior to the lung function measurement. Details of sampling and laboratory analyses of welding fume during a working shift have been reported elsewhere (Lehnert et al. 2012). In short, samplers were mounted in the breathing zone inside the welding helmets. Respirable particles were sampled using a cellulose nitrate filter with a pore size of 8 μm and a diameter of 37 mm. Preselection of larger particles was provided by an upstream polyurethane filter. Sampling was performed at a flow rate of 3.5 L/min and for an average duration of 3.4 h. All sampling filters were shipped to the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) in Sankt Augustin, Germany, for particle and metal analysis. Dust concentrations were determined as formerly described (Hebisch et al. 2005). Exposure data and a structured description of the current workplace with regard to welding technique, workplace characteristics and protection measures were gathered within the framework of the measurement system for exposure assessment of the German Social Accident Insurance (MGU) (Gabriel et al. 2010).

The duration of working as welder was retrieved from the questionnaire, along with the information on former workplaces. All participants were asked about predominantly applied welding techniques and processed materials, working conditions, and respiratory protection at the time of the investigation and during former periods. A welder's lifetime exposure to welding fume (LT_e) was calculated as the sum of the products of duration (years) and intensity of exposure to welding fume (mg/m^3) in two time periods (before and after 1990). The intensity was estimated according to the statistical model developed in the WELDOX study to estimate determinants of the shift exposure to welding fume (Lehnert et al. 2012). We implemented the following factors into the model: gas metal arc welding with solid wire (GMAW) as reference (1), welding with flux-cored wire (FCAW) 2.25, tungsten inert gas welding (TIG) 0.18, shielded metal arc welding 0.68, and others with 1.13. Confinement was included with a factor of 1.87, an efficient local exhaust ventilation with 0.43, and the processing of stainless steel with 0.55.

2.4 Statistical Analysis

We present the distribution of continuous variables with median and inter-quartile range (IQR) and associations between two variables with Spearman's correlation coefficients (*r*). Multiple regression analysis was performed to assess exposure to welding fume with different metrics together with other predictors of lung function. Exposure variables were implemented into the model with exposure classes. Lifetime exposure to welding fume was stratified by tertiles of their distribution in the study group. Due to the skewed distribution, the third tertile spans across a wide range and was split into high and substantial exposure.

The selection of potential confounders started with smoking status (never, former, and current), anthropometrical factors (height and weight), age, physical workload, and season. The best model was chosen according to Akaike's Information Criterion and adjusted coefficient of determination. The final model for potential predictors of FEV_1, FVC, and their ratio included smoking status, age, height, and weight in addition to the exposure variable. Sensitivity analyses were performed by excluding low performers. We omitted age and height from the models for predicted lung function parameters. All analyses were calculated with the statistical software SAS version 9.2 (SAS Institute Inc., Cary, NC). Graphs were created with Prism version 5 (Graphpad Software Inc., La Jolla, CA).

3 Results

3.1 Characteristics of Welders

Table 1 presents the characteristics of all welders (n = 219), comprising 115 current, 52 former, and 52 never smokers. The median BMI was 27 kg/m^2 in all welders with minor variation by smoking status. The average shift exposure to respirable welding fume was 0.87 mg/m^3 in all welders and showed no obvious variation by smoking status. Former smokers were slightly older (median 46 years) and performed welding for a longer time (median 24 years) than current smokers (40 years and 14 years, respectively) and never smokers (38 years and 17 years, respectively). This results in a higher lifetime exposure to welding fume of former smokers compared with current or never smokers (median levels 31, 16, and 25 mg × years/m^3, respectively).

3.2 Lung Function of Welders

Table 2 depicts the distribution of lung function measurements in all welders and stratified by smoking status and exposure to welding fume. Overall, welders in the study presented a median of 98,9 % für FEV_1 and a median of 104,8 % for FVC regarding the predicted values of GLI, with slightly lower values for former and current smokers than in never smokers. Current smokers had lower median values for FEV_1 (98.4 %) and FEV_1/FVC ratio (75.6 %) but a higher median FVC (105.2 %) than never or former smokers. Effects of smoking were also visible in expiratory flow rates. For example, median values for MEF_{50} were 89.2, 81.7, and 81.3 % predicted in never, former, and current smokers, respectively. We observed no obvious impairment of the predicted lung function parameters in welders classified into the highest categories of exposure assessed with various metrics. For example, predicted FEV_1 of welders performing high-emission techniques like FCAW was 98.4 % and 98.9 % predicted in TIG welders. The distribution of FEV_1/FVC was presented by a median of 76.3 % with an IQR ranging from 72.6 to 80.2 % in all welders with a slightly lower median of 74.6 % in welders with a shift exposure above 4.88 mg/m^3.

3.3 Associations of Exposure and Lung Function

Figure 1A–C depict lacking statistical associations between the cumulative exposure to respirable welding fume and predicted FEV_1, FVC, and FEV_1/FVC (e.g., lifetime exposure to respirable welding fume and FEV_1/FVC, $r = 0.08$; $p = 0.26$). Figure 1D shows the 33 welders with an impaired lung function with regard to their lifetime exposure, also without a clear indication of an association.

Different regression models did not reveal adverse effects of cumulative exposure to respirable welding fume (Table 3), shift exposure (Table 4), duration of welding or predominant welding technique (data not shown). Increasing age affected FEV_1, FVC, and FEV_1/FVC significantly. Smoking reduced FEV_1 and FEV_1/FVC, but not FVC. Body height had an impact on FEV_1 and FVC, but not on FEV_1/FVC. Weight was not associated with the lung function measures.

Table 1 Characteristics of 219 welders from the WELDOX study

	All (n = 219)		Never smokers (n = 52)		Former smokers (n = 52)		Current smokers (n = 115)	
	Median	IQR	Median	IQR	Median	IQR	Median	IQR
Age (years)	41	33, 49	38	33, 48.5	46	38, 52	40	28, 46
Height (cm)	178	172, 181	178	175, 184	174	171, 179	178	173, 182
Weight (kg)	86	78, 95	86	82, 99	89	81.5, 96.5	85	77, 93
Body mass index (kg/m^2)	27.2	25.2, 30.3	27.5	25.1, 30.3	28.9	26.6, 31.3	26.6	24.9, 28.7
Duration of employment as welder (year)	17	9, 27	17	11, 25	24	13, 31	14	7, 25
Shift exposure to respirable welding fume (mg/m^3)	0.87	<0.41, 3.40	<0.74	<0.41, 2.38	1.17	<0.45, 3.67	0.86	<0.40, 3.40
Lifetime exposure to respirable welding fume (mg × years/m^3)	20.2	7.0, 48.1	25.1	8.7, 49.2	31.1	14.7, 57.5	16.3	5.4, 39.9
Major welding technique	n (%)		n (%)		n (%)		n (%)	
GMAW/FCAW	83 (37.9)		18 (34.6)		19 (36.5)		46 (40.0)	
TIG	35 (16.0)		6 (11.5)		5 (9.6)		24 (20.9)	
SMAW/Miscellaneous	101 (46.1)		28 (53.9)		28 (53.9)		45 (39.1)	
Physical workload								
Low	41 (18.7)		11 (21.2)		6 (11.5)		24 (20.9)	
Medium	135 (61.6)		35 (67.3)		37 (71.2)		63 (54.8)	
High	43 (19.6)		6 (11.5)		9 (17.3)		28 (24.4)	

IQR Interquartile range (25th percentile, 75th percentile), *TIG* Tungsten inert gas welding, *GMAW* Gas metal arc welding, *FCAW* Flux – cored arc welding, *SMAW* Shielded metal arc welding

Table 2 Lung function parameters of 219 welders from the WELDOX study by smoking status and exposure levels to respirable welding fume with regard to reference equations of Global Lung Function Initiative

		FEV1(L)		FEV_1 (% $predicted_{GLI}$)		FVC (L)		FVC (% $predicted_{GLI}$)		FEV_1/FVC (%)		FEV_1/FVC (% $predicted_{GLI}$)	
		Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR	Median	IQR
All	219	4.2	3.7, 4.6	98.9	91.4, 107.3	5.4	4.9, 6.0	104.8	97.1, 111.2	76.3	72.6, 80.2	94.4	89.7, 98.5
Smoking													
Never	52	4.3	3.9, 4.8	99.9	95.6, 110.4	5.6	5.1, 6.0	104.5	99.9, 112.4	77.9	74.3, 80.4	95.0	90.9, 99.5
Former	52	4.0	3.2, 4.4	98.5	88.5, 108.8	5.1	4.3, 5.7	102.4	93.9, 110.7	76.3	72.7, 79.8	94.7	90.2, 99.6
Current	115	4.2	3.8, 4.7	98.4	88.7, 106.8	5.6	5.0, 6.0	105.2	96.4, 109.9	75.6	71.8, 80.3	93.5	88.5, 97.7
Duration of employment as welder (years)													
1–9	59	4.4	4.1, 4.9	96.6	86.9, 105.4	5.8	5.3, 6.4	105.2	96.1, 111.8	77.0	72.0, 80.9	92.1	86.2, 96.5
10–19	62	4.3	3.8, 4.7	98.5	92.7, 106.8	5.4	4.9, 6.0	103.0	98.0, 109.5	77.4	72.6, 80.5	94.7	89.9, 98.6
20–29	63	4.1	3.6, 4.4	99.5	90.1, 109.8	5.4	4.9, 5.9	106.8	98.4, 111.6	75.3	72.7, 78.9	94.7	91.5, 98.5
≥ 30	35	3.8	3.2, 4.1	100.0	90.2, 109.0	4.9	4.5, 5.6	102.1	96.7, 111.2	75.2	70.1, 80.1	94.8	88.3, 102.3
Shift exposure to respirable welding fume (mg/m^3)													
<LOQ	83	4.2	3.4, 4.7	97.1	89.1, 106.2	5.4	4.7, 6.0	102.0	95.0. 108.8	77.0	73.0, 80.7	95.0	89.9, 98.5
≥LOQ and ≤1.18	34	4.1	3.6, 4.4	97.7	85.6, 105.3	5.2	4.7, 6.0	103.4	99.1, 111.2	75.5	73.2, 79.6	94.6	89.6, 98.5
>1.18 and ≤2.36	34	4.2	4.0, 4.6	100.3	96.6, 107.8	5.6	5.2, 6.0	106.5	100.6, 115.1	77.0	72.7, 80.3	94.0	89.7, 98.6
>2.36 and ≤4.88	34	4.2	3.6, 4.7	97.9	86.9, 108.5	5.5	5.0, 5.9	104.5	96.5, 111.3	76.0	72.0, 80.1	92.9	90.0, 98.6
>4.88	33	4.4	4.0, 4.5	100.2	93.6, 109.2	5.6	5.1, 6.0	107.7	102.6, 114.7	74.8	72.0, 80.2	93.1	87.2, 98.0
Lifetime exposure to respirable welding fume ($mg \times years/m^3$)													
Low (0.1–10.1)	73	4.3	3.9, 4.8	98.9	91.6, 107.2	5.7	5.0, 6.3	105.7	98.5, 110.6	77.0	73.0, 81.0	94.5	89.2, 98.6
Medium (>10.1–37.8)	72	4.2	3.7, 4.6	98.3	87.5, 106.0	5.4	5.0, 5.9	103.5	94.5, 111.2	77.3	72.0, 80.1	94.2	89.2, 98.3
High (>37.8–78.9)	55	4.1	3.6, 4.4	98.4	92.0, 109.2	5.3	4.7, 5.7	104.0	97.7, 114.1	75.0	72.5, 78.9	94.3	91.0, 98.5
Substantial (>78.9)	19	4.0	3.5, 4.4	100.7	90.2, 107.9	5.1	4.7, 5.5	107.1	91.0, 109.9	75.3	72.7, 80.3	93.9	93.0, 100.3
Major welding technique													
GMAW/ FCAW	83	4.3	3.8, 4.7	98.4	90.1, 104.8	5.5	5.0, 6.0	105.0	95.7, 109.9	76.3	72.0, 80.3	93.8	89.3, 97.8
TIG	35	4.3	3.9, 4.7	98.9	89.1, 106.7	5.7	5.0, 6.3	103.4	97.6, 108.6	77.3	72.7, 81.0	95.4	87.6, 99.8
SMAW/Miscellaneous	101	4.1	3.5, 4.5	99.5	92.0, 109.2	5.3	4.8, 5.9	106.0	98.8, 114.0	75.7	72.7, 79.6	94.7	90.2, 98.5

FEV_1 Forced expiratory volume in one second, *FVC* Forced vital capacity, *FEV_1/FVC* (%) Tiffeneau index, *IQR* Interquartile range (25th percentile, 75th percentile), *GMAW* gas metal arc welding, *FCAW* Flux-cored arc welding, *TIG* tungsten inert gas welding, *SMAW* shielded metal arc welding, *>LOQ* below the limit the quantitation

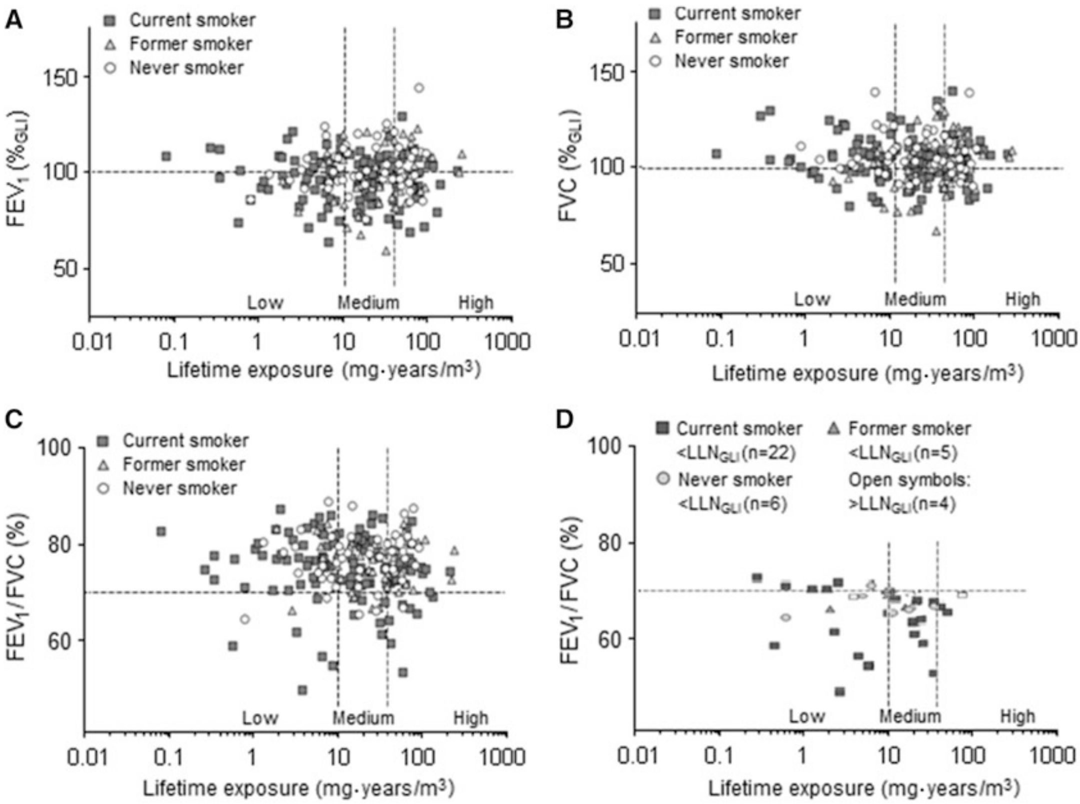

Fig. 1 Forced expiratory volume in 1 s (FEV_1) (*Panel A*), forced vital capacity (FVC) (*Panel B*), and ratio of measured volumes of FEV_1 to FVC (*Panel C*) regarding predictive values by the Global Lung Initiative (GLI) *vs.* cumulative exposure to respirable welding fume (n = 219); *Panel D* – FEV_1/FVC ratio vs. cumulative exposure to respirable welding fume by smoking status in low performers (FEV_1/FVC below LLN_{GLI} (n = 33) and/or FEV_1/FVC below 70 %)

Exclusion of low performers did not change the results (data not shown). Regression models of expiratory flow rates revealed similar results and no impairment due to welding fume exposure.

3.4 Impaired Lung Function

Thirty-three welders (15 %) performed below the lower limit of normal, based on the GLI equation (Fig. 1D). We revealed these 33 welders as impaired regarding lung performance and compared this group with welders classified as low and substantially exposed, based on shift and lifetime exposure. Only 1 of the 33 welders was classified as substantially exposed, based on LT_e. The low performers were younger than welders assessed as substantially exposed during lifetime (40 *vs.* 48 years) and had been working for a shorter time as welders (11 *vs.* 27 years). This difference in age and, hence time-related exposure variables, was reflected in a lower median lifetime exposure of the low performers (16.3 mg × years/m^3) compared with welders with substantial lifetime exposure (100.2 mg × years/m^3), but it was higher than that in the welders with low lifetime exposure (5.8 mg × years/m^3).

However, when considering current smoking, high-emission welding techniques and high physical workload at the time of investigation, low-performers had the highest prevalence values for these variables. For example, 24.2 % were assessed as working under high physical workload compared with 16.7 % in substantially exposed welders and 13.6 % in low-exposed welders.

Table 3 Lifetime exposure to welding fume and other potential determinants of FEV_1, FVC, and FEV_1/FVC in 219 welders of the WELDOX study

		FEV_1 (L)			FVC (L)			FEV_1/FVC (%)		
Factor	n	$\hat{\beta}$	95 % CI	p	$\hat{\beta}$	95 % CI	p	$\hat{\beta}$	95 % CI	p
Intercept	219	−3.29	−5.26,–1.32		−5.71	−8.05,–3.37		91.6	68.5, 114.7	
Lifetime exposure to respirable welding fume (mg × years/m^3)										
Low (0.1–10.1)	73	0			0			0		
Medium (>10.1–37.8)	72	−0.05	−0.23, 0.13	0.56	−0.09	−0.30, 0.13	0.42	0.03	−2.07, 2.13	0.98
High (>37.8–78.9)	55	0.02	−0.18, 0.23	0.85	0.07	−0.18, 0.31	0.59	−0.52	−2.92, 1.89	0.67
Substantial (>78.9)	19	0.05	−0.24, 0.33	0.76	−0.03	−0.38, 0.31	0.84	1.16	−2.21, 4.52	0.50
Smoking										
Never	52	0			0			0		
Former	52	−0.15	−0.37, 0.06	0.17	−0.15	−0.41, 0.10	0.24	−0.82	−3.35, 1.70	0.52
Current	115	−0.21	−0.39, –0.03	0.02	−0.12	−0.33, 0.10	0.28	−2.26	−4.35, –0.18	0.03
Anthropometry										
Weight (per 10 kg)	219	−0.002	−0.06, 0.05	0.94	−0.01	−0.07, 0.05	0.74	0.17	−0.46, 0.79	0.59
Height (per 10 cm)	219	0.49	0.38, 0.60	<.0001	0.70	0.57, 0.84	<0.0001	−0.64	−1.97, 0.69	0.35
Age (per 5 years)	219	−0.14	−0.17, –0.10	<.0001	−0.14	−0.19, –0.10	<0.0001	−0.57	−1.02, –0.11	0.01
r^2		0.46			0.50			0.05		

$\hat{\beta}$ – Regression coefficient in additive model

Table 4 Shift exposure to welding fume and other potential determinants of FEV_1, FVC, and FEV_1/FVC in 219 welders of the WELDOX study

Factor	n	FEV_1 (L) $\hat{\beta}$	FEV_1 (L) 95 % CI	FEV_1 (L) p	FVC (L) $\hat{\beta}$	FVC (L) 95 % CI	FVC (L) p	FEV_1/FVC (%) $\hat{\beta}$	FEV_1/FVC (%) 95 % CI	FEV_1/FVC (%) p
Intercept	219	−3.46	−5.42,–1.51		−5.77	−8.09,–3.44		89.0	65.9, 112.1	
Shift exposure to respirable welding fume (mg/m^3)										
<LOQ	83	0.03	−0.19, 0.24	0.79	−0.13	−0.38, 0.12	0.31	2.22	−0.30, 4.74	0.08
≥LOQ and ≤1.18	34	0			0			0		
>1.18 and ≤2.36	34	0.19	−0.06, 0.45	0.14	0.12	−0.18, 0.42	0.43	1.90	−1.11, 4.91	0.21
>2.36 and ≤4.88	34	0.10	−0.15, 0.36	0.42	−0.03	−0.33, 0.27	0.85	2.00	−1.00, 5.00	0.19
>4.88	33	0.20	−0.06, 0.45	0.13	0.20	−0.11, 0.50	0.20	1.17	−1.85, 4.19	0.45
Smoking										
Never	52	0			0			0		
Former	52	−0.16	−0.38, 0.05	0.14	−0.16	−0.42, 0.09	0.21	−0.80	−3.33, 1.73	0.54
Current	115	−0.20	−0.38, –0.03	0.03	−0.11	−0.32, 0.10	0.29	−2.12	−4.19, –0.05	0.04
Anthropometry										
Weight (per 10 kg)	219	0.01	−0.05, 0.06	0.84	−0.01	−0.07, 0.06	0.86	0.24	−0.39, 0.86	0.46
Height (per 10 cm)	219	0.49	0.37, 0.60	<.0001	0.70	0.57, 0.84	<.0001	−0.64	−1.98, 0.69	0.34
Age (per 5 years)	219	−0.13	−0.17, –0.10	<.0001	−0.14	−0.18, –0.10	<.0001	−0.52	−0.94, –0.11	0.01
r^2		0.47			0.51			0.06		

$\hat{\beta}$ – Regression coefficient in additive model; > *LOQ below the limit the quantitation*

Airflow limitation is the diagnostic hallmark of COPD. However, other reasons for airflow limitation have to be considered. In this respect, an underlying asthmatic disease was most likely present in one welder. In addition, among the low performers, an abnormal shape of the flow volume loop in terms of extra-thoracic and fixed upper airway obstruction could be observed in two welders.

4 Discussion

4.1 Association of Welding and Lung Function

Welders comprise a large workforce with exposure to fumes and gases that are commonly measured in terms of airborne mass concentrations of particulate matter and metals. Various fatal respiratory outcomes in welders, like lung cancer (Kendzia et al. 2013), raise the question of the presence of auguring signs, e.g., an impairment of lung function, as obstruction indicating COPD, and if potential health effects can be associated with quantitative measures of exposure. Here we present the association between respirable particles assessed with different metrics of exposure and lung function in 219 German welders. However, welding fume is a complex mixture, where respirable particles comprise only one of the possible irritative factors. It has to be taken into account that a high concentration of particles is usually associated with the welding of mild steel resulting in a lower content of chromium and nickel (Kendzia et al. 2013; Weiss et al. 2013).

So far, cross-sectional studies reported inconsistent results about an impairment of lung function in welders, and a systematic review of cohort studies point toward an impairment of FEV_1, but mainly in smokers (Szram et al. 2013). We adjusted for smoking and other potential covariates, but observed no quantitative negative associations between welding and lung function, and no obvious deviation from normal values. In addition, we analyzed MEF_{75}, MEF_{50}, and MEF_{25} values to detect obstruction in peripheral small airways. Small airway dysfunction may progress into chronic obstructive pulmonary disease. Again, we could not reveal any association between welding and the impairment of small airway function. However, there was a consistent effect of smoking in all models supporting the idea that cigarette smoking may induce small airways dysfunction.

4.2 Determinants of Lung Function

Although lung function assessment was not a primary issue of the WELDOX study, spirometry was performed in a highly standardized manner by the same investigator and according to the ATS criteria, with three attempts under defined conditions in a separate room. Five welders were excluded from this analysis due to an inappropriate lung function. Predicted values were derived from the up-to-date recommendations by the Global Lung Initiative (GLI) (Quanjer et al. 2012). A discussion of suitable reference values for welders is beyond the scope of this analysis.

We could differentiate between normal or abnormal lung function with respect to FEV_1, FVC, FEV_1/FVC, and expiratory flow rates indicating small airways dysfunction in all welders. Reported accelerated declines in lung function of welders in longitudinal studies refer to changes of FEV_1 that were observed in smokers, but only minor changes were detected in non-smokers (Szram et al. 2013; Thaon et al. 2012). We chose the FEV_1/FVC ratio as a preferable indicator of air-flow limitations. Statistical modelling confirmed an impairment of FEV_1 and FVC by a higher age attained and smoking, and an improvement with taller stature (Chinn et al. 1996).

4.3 Assessment of Exposure to Welding Fume

WELDOX was the first larger field study, where shift exposure to respirable particles was determined in welders performing a variety of techniques in different settings (Lehnert et al. 2012). So far, few studies reported attempts to assess lifetime exposure to welding fume quantitatively. Fishwick et al. (1997) assessed the years working as welder and the hours per day performing welding and Gerin et al. (1993) developed a welding process exposure matrix with estimated shift average for total fume, chromium, and nickel considering the applied welding technique and base metal in order to estimate cumulative exposure in a large cohort of European welders. Our quantitative estimates derived from the WELDOX model are similar to the levels provided for welding fume in Gerin's matrix (Lehnert et al. 2012). However, we did not perform a longitudinal study and had to rely on the information collected retrospectively from the welder about former workplaces. Additional predictors of exposure to welding fume comprise the confinement of the workplace and an efficient ventilation system beside the welding process and materials. However, a precise assessment of the working conditions is hardly feasible in epidemiological studies, due either to a retrospective manner in cross-sectional studies, such as WELDOX, or the lack of information in historical cohorts.

Misclassification of the quantitative level of exposure can attenuate the estimates of an effect toward zero. Facing the observed lack of an association of exposure to welding fume and lung function, we explored different exposure metrics in regression models in combination with age, smoking, and anthropometric measures. Impairment of lung function measurements after a working shift may reflect, at least partially, the working condition at the day of investigation in combination with potential chronic effects (Fishwick et al. 1997). Therefore, we investigated the shift exposure to respirable welding fume, the major welding technique during lifetime, duration of welding, and lifetime exposure to welding fume. All exposure metrics suffer from specific shortcomings. Particularly, duration of welding is associated with the age of a welder and hence, the lifetime exposure as well. Lifetime exposure considers both the time of working as welder and the emission characteristics of the welding process. None of the welders categorized as substantially exposed performed tungsten inert gas (TIG) welding as the predominant technique in contrast to every other welder classified as low exposed during lifetime. Substantially exposed persons worked as welders, on average, for 27 years in contrast to 10 years among low-exposed welders. Combining both time and intensity of exposure results in a 20-fold mean difference of lifetime exposure between low and substantially exposed welders. A comparison of FEV_1/FVC did not show any difference between these groups classified by lifetime exposure.

4.4 Classification of Impairment

Even though there are upcoming biomarkers indicating early inflammatory responses in airways or lungs (Hoffmeyer et al. 2009), spirometry is the most established tool in diagnostics of pulmonary diseases. A total of 33 welders had a post-shift FEV_1/FVC below the 5th percentile of the GLI reference population and were considered as low-performers and potential candidates for COPD. However, when referring to a fixed cut-off of 70 % as commonly proposed by GOLD (2011), an airflow limitation would be rated in 29 welders. As the FEV_1/FVC ratio is decreasing with age, there is a potential over-diagnosis of COPD at older age when using just one fixed cut-off value (Swanney et al. 2008). In this respect, four elderly welders (mean age 55 years) did not meet the LLN definition. On the other hand, eight younger welders (mean age 30 years) passed the 70 % cut-off for FEV_1/FVC.

The demonstration of an airflow limitation raises the question of whether they may suffer from COPD. An abnormal shape of the flow volume loop in terms of extra-thoracic or fixed upper airway obstruction was observed in four welders including two non-smokers. The majority of low performers (81.8 %) had smoked in the past; one welder complained of shortness of breath and another reported asthma. Interestingly, none of the low performers reported cough or phlegm. None of the 11 never smokers presented an elevated level of exhaled nitric oxide (FeNO) which may point to an underlying asthmatic disease in the post-shift measurement (Malinovschi et al. 2012). The impact of chronic bronchitis on COPD was recently evaluated (de Oca et al. 2012). The study indicated a substantial prevalence of COPD without chronic bronchitis. Moreover, welders with COPD and without coexisting chronic bronchitis demonstrated less impaired pulmonary function compared with those with chronic bronchitis. After excluding other obvious causes of air flow limitation, a prevalence of COPD of 13 % (28/219) could be assumed in our study. This prevalence based on the Tiffeneau ratio is in accord with previously published data on occupational causes of COPD (Blanc 2012).

4.5 Limitations

Across-shift or repeated lung function measurements were not available in WELDOX. The rating of an impaired lung function was based on just one measurement after the working shift. This may indicate acute shift effects in combination with chronic effects due to smoking or welding. More welders with impaired lung function had a higher work intensity and were more frequently current smokers. A synergistic relation between exposure to tobacco smoke and welding fume on the lung function had been previously suggested (Erkinjuntti-Pekkanen et al. 1999; Chinn et al. 1995). Workers developing work-related health symptoms or even diseases may leave the job. This points towards the selection of healthy workers for welding with high work intensity. The assessment of healthy worker effects remains challenging in occupational epidemiology and is very limited in cross-sectional studies.

5 Conclusions

The prevalence of an impaired FEV_1/FVC ratio was higher in the group of welders than predicted from the GLI reference population. The lower performance may also indicate shift effects of a high physical intensity of work. The results of our present analysis of data from the German WELDOX study confirmed the role of smoking in the lung function, but they did not point to a lung function impairment by exposure to respirable particles of welding fume. The complex matrix of welding fume and the interactions of exposure with smoking and physical workload can hardly be disentangled when modeling exposure and covariates. Prevention campaigns aiming at respiratory protection at work should cover smoking cessation as well.

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Conflicts of Interest The authors declare no conflicts of interest in relation to this article.

References

American Thoracic Society (1995) Standardization of spirometry. Am J Respir Crit Care Med 152:1107–1136

Antonini JM (2003) Health effects of welding. Crit Rev Toxicol 33:61–103

Blanc PD (2012) Occupation and COPD: a brief review. J Asthma 49:2–4

Chinn DJ, Stevenson IC, Cotes JE (1990) Longitudinal respiratory survey of shipyard workers: effects of trade and atopic status. Br J Ind Med 47:83–90

Chinn DJ, Cotes JE, el Gamal FM, Wollaston JF (1995) Respiratory health of young shipyard welders and other tradesmen studied cross sectionally and longitudinally. J Occup Environ Med 52:33–42

Chinn DJ, Cotes JE, Reed JW (1996) Longitudinal effects of change in body mass on measurements of ventilatory capacity. Thorax 51:699–704

de Oca MM, Halbert RJ, Lopez MV, Perez-Padilla R, Talamo C, Moreno D, Muino A, Jardim JR, Valdivia G, Pertuze J, Menezes AM (2012) The chronic bronchitis phenotype in subjects with and without COPD: the PLATINO study. Eur Respir J 40:28–36

Erkinjuntti-Pekkanen R, Slater T, Cheng S, Fishwick D, Bradshaw L, Kimbell-Dunn M, Dronfield L, Pearce N (1999) Two year follow up of pulmonary function values among welders in New Zealand. J Occup Environ Med 56:328–333

Fishwick D, Bradshaw LM, Slater T, Pearce N (1997) Respiratory symptoms, across-shift lung function changes and lifetime exposures of welders in New Zealand. Scand J Work Environ Health 23:351–358

Gabriel S, Koppisch D, Range D (2010) The MGU – a monitoring system for the collection and documentation of valid workplace exposure data. Gefahrstoffe-Reinhaltung der Luft – Air Qual Control 70:43–49
Gerin M, Fletcher AC, Gray C, Winkelmann R, Boffetta P, Simonato L (1993) Development and use of a welding process exposure matrix in a historical prospective study of lung cancer risk in European welders. Int J Epidemiol 22(Suppl 2):S22–S28
GOLD – Global Initiative for Chronic Obstructive Lung Disease (2011) Global strategy for the diagnosis, management and prevention of COPD. Available from http://www.goldcopd.org/guidelines-global-strategy-for-diagnosis-management.html. Accessed 24 Sept 2013
Hebisch R, Fricke H-H, Hahn J-U, Lahaniatis M, Maschmeier C-P, Mattenklott M (eds) (2005) Sampling and determining aerosols and their chemical compounds. Wiley-VCH, Weinheim, pp 3–40
Hoffmeyer F, Raulf-Heimsoth M, Bruning T (2009) Exhaled breath condensate and airway inflammation. Curr Opin Allergy Clin Immunol 9:16–22
Kendzia B, Kendzia B, Behrens T, Jöckel KH, Siemiatycki J, Kromhout H, Vermeulen R, Peters S, Van Gelder R, Olsson A, Brüske I, Wichmann HE, Stücker I, Guida F, Tardn A, Merletti F et al (2013) Welding and lung cancer in a pooled analysis of case-control studies. Am J Epidemiol 178:1513–1525
Lehnert M, Pesch B, Lotz A, Pelzer J, Kendzia B, Gawrych K, Heinze E, Van GR, Punkenburg E, Weiss T, Mattenklott M, Hahn JU, Mohlmann C, Berges M, Hartwig A, Bruning T (2012) Exposure to inhalable, respirable, and ultrafine particles in welding fume. Ann Occup Hyg 56:557–567
Lehnert M, Weiss T, Pesch B, Lotz A, Zilch-Schöneweis S, Heinze E, Van Gelder R, Hahn JU, Brüning T, The WELDOX Study Group (2013) Reduction in welding fume and metal exposure of stainless steel welders: an example from the WELDOX study. Int Arch Occup Environ Health, Epub ahead of print. doi:10.1007/s00420-013-0884-7
Malinovschi A, Backer V, Harving H, Porsbjerg C (2012) The value of exhaled nitric oxide to identify asthma in smoking patients with asthma-like symptoms. Respir Med 106:794–801
Pesch B, Weiss T, Kendzia B, Henry J, Lehnert M, Lotz A, Heinze E, Kafferlein HU, Van GR, Berges M, Hahn JU, Mattenklott M, Punkenburg E, Hartwig A, Bruning T (2012) Levels and predictors of airborne and internal exposure to manganese and iron among welders. J Expo Sci Environ Epidemiol 22:291–298
Quanjer PH, Tammeling GJ, Cotes JE, Pedersen OF, Peslin R, Yernault JC (1993) Lung volumes and forced ventilatory flows. Report Working Party Standardization of Lung Function Tests, European Community for Steel and Coal. Official Statement of the European Respiratory Society. Eur Respir J Suppl 16:5–40
Quanjer PH, Stanojevic S, Cole TJ, Baur X, Hall GL, Culver BH, Enright PL, Hankinson JL, Ip MS, Zheng J, Stocks J (2012) Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations. Eur Respir J Suppl 40:1324–1343
Swanney MP, Ruppel G, Enright PL, Pedersen OF, Crapo RO, Miller MR, Jensen RL, Falaschetti E, Schouten JP, Hankinson JL, Stocks J, Quanjer PH (2008) Using the lower limit of normal for the FEV1/FVC ratio reduces the misclassification of airway obstruction. Thorax 63:1046–1051
Szram J, Schofield SJ, Cosgrove MP, Cullinan P (2013) Welding, longitudinal lung function decline and chronic respiratory symptoms: a systematic review of cohort studies. Eur Respir J 42:1186–1193
Thaon I, Demange V, Herin F, Touranchet A, Paris C (2012) Increased lung function decline in blue-collar workers exposed to welding fumes. Chest 142:192–199
Weiss T, Pesch B, Lotz A, Gutwinski E, Van GR, Punkenburg E, Kendzia B, Gawrych K, Lehnert M, Heinze E, Hartwig A, Kafferlein HU, Hahn JU, Bruning T (2013) Levels and predictors of airborne and internal exposure to chromium and nickel among welders-results of the WELDOX study. Int J Hyg Environ Health 216:175–183

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Disability-Adjusted Life Years in the Assessment of Health Effects of Traffic-Related Air Pollution

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Abstract

Traffic-related air pollutants have an impact on human health and have been recognized as one of the main stressors that cause mortality and morbidity in urban areas. Research confirms that citizens living in the vicinity of main roads are strongly exposed to high concentrations of numerous air pollutants. In the present study the measurements of traffic-related parameters such as density, velocity, and structure were performed for cross-sections of selected street canyons in Warsaw, the capital city of Poland. In addition, the results of the general traffic measurements were used to describe the number of cars crossing the border of the city. Vehicle emissions of PM_{10} were calculated for the whole city area and changes of the PM_{10} concentration were modeled to present the exposure to this pollutant that could be attributable to traffic. The principles of the environmental burden of disease (EBD) were used. The assessment of the impact of traffic-related air pollutants on human health was made. The results, presented in disability-adjusted life years (DALY), were based on the outcomes of the study conducted in 2008–2012 in Warsaw, one the most congested agglomerations in Europe, and included the health damage effect of the exposure to high concentrations of air pollutants. DALY calculations were performed in accordance to the methodologies used in renowned international scientific research on EBD.

Keywords

Environmental burden of disease • Health damage • Particulate matter • Traffic congestion • Urban air pollution

1 Introduction

Road transport plays a vital role in air pollution emissions, especially in large cities. According to the 2011 data of European Environment Agency (EEA), transport is responsible for emissions of

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17 % of particulate matter PM_{10} and 32 % of nitrogen oxides in the European Union. An adverse influence of high air pollution on human health, especially for the particulate matter PM_{10} and $PM_{2.5}$, is known (Badyda et al. 2013a; Pope et al. 1995, 2002; Krewski et al. 2000). Moreover, the World Health Organization has not determined a safe level of concentrations of particulate matter yet (WHO 2006). This means that an increase of particulate matter concentration by each μg/m^3 causes a specific health effect. According to the research by Lim et al. (2012), approximately 430,000 people died prematurely in Europe due to air pollution in 2010. The assessment of health effects of exposure of a population to particulate matter $PM_{2.5}$ takes into account the upper and lower respiratory infections, lung cancers, ischemic heart disease, cerebrovascular disease, and chronic obstructive pulmonary disease (COPD). Thus, research results suggest that traffic-related emissions are partly responsible for early deaths as a result of the above-mentioned diseases

Pope et al. (2009) have determined that a positive health effect that could be obtained by reducing the concentrations of $PM_{2.5}$. Reductions of $PM_{2.5}$ over 5 years by 10 μg/m^3 increase life expectancy by 3 years. The methodology of the study took into account the change in mortality due to lung cancer and COPD of the whole population.

Symptoms of disease connected with increased air pollution are apparent in the studies on admissions to hospitals due to cardiovascular problems (e.g., imminent myocardial infarction). Daily exposure to high pollution contributes, particularly, to cardiovascular diseases, thereby increasing the risk of anemia, heart failure, or arrhythmia (Autrup 2010). Moreover, there is evidence of a relationship between increased concentration of particulate matter in the outdoor air and a greater risk of myocardial ischemia or infarction, arrhythmia, heart failure, peripheral arterial stroke, and sudden death (Franchini and Mannucci 2012; Nelin et al. 2012; Zanobetti et al. 2011).

To determine the influence of air pollution on human health, numerous studies have been conducted and various models have been elaborated (Laden et al. 2006; Tainio et al. 2005; Hoek et al. 2002), which include the following:

- emission volumes from transportation sources,
- pollution dispersion in the atmosphere,
- impact of pollution increase on human health,
- assessment of health damage in a population.

The Environmental Burden of Disease (EBD) is a methodology that enables to assess the influence of air pollution on health damage on the basis of emission volume. A tool used to conduct the EBD analysis is the GaBi5 software which implements the models of the Life Cycle Impact Assessment (LCIA). In the present paper we use one such LCIA methodology, called ReCiPe, to assess health damage and quality of life of a big city inhabitants living in the vicinity of busy traffic routes.

2 Methods

The study consisted of the measurement and calculation stages. The first one included measurements of traffic parameters and air pollution concentrations in seven chosen locations in Warsaw, the capital city of Poland. The measurement sections with heavy traffic and congestions were selected with the premise that the slowness of traffic allows a more reliable estimation the identification of vehicle types and their ecological structure (engine types, ranges of cubic capacity, emission standards, etc.). Measurements of traffic parameters were made around the clock over 1 week in June and October of 2010.

2.1 Measurements of Traffic Parameters and Pollution Concentration

The measurement of traffic parameters was conducted using an NC-200 analyzer (Vaisala; Vantaa, Finland). The analyzer was placed in the middle of each lane and registered (using magnetic resistance) the passage of each vehicle, including its speed and length. Traffic density was determined taking into consideration the division into four categories of vehicles: passenger cars, light goods vehicles, small buses and vans, and large buses and large goods vehicles.

Measurements of air pollution (carbon monoxide, nitrogen oxides, volatile organic compounds, and particulate matter PM_{10}) were conducted with a mobile monitoring station Airpointer™ (MLU, Wiener Neudorf, Austria). PM_{10} concentration was measured by nephelometry and that of nitrogen oxides by chemiluminescence. Apart from the models linked to particulate matter, other models being part of the ReCiPe methodology were used, according to which 21 % of the emitted nitrogen oxides are created from the particulate matter PM_{10} (Goedkoop et al. 2008).

2.2 Calculations of Traffic Emission and Its Intensity

The results denoting traffic density, average speed, and types of vehicles were used to model emissions of pollution, which allowed determining the emission concentration (Chłopek 1999). A unique model of traffic-related emissions for vehicles in Warsaw was created, taking into consideration the ecological structure of the traffic. The results obtained on the basis of this model were verified by live measurements of PM_{10} at the monitoring stations. Moreover, the 2013 traffic forecast, based on the general traffic measurements conducted in Warsaw, was used as surrogate of the volume of PM_{10} emissions for the whole road network in Warsaw. These results were then employed to assess the impact of the whole stream of traffic-related pollution (PM_{10} and nitrogen oxides emissions over the whole year) on health damage of city inhabitants. Traffic modeling was made using EMME3 software (INRO, Montréal, QC). The results covered the 24-h vehicle traffic in Warsaw expressed in vehicle-kilometres and included:

- four categories of vehicles as outlined above;
- 19 ranges of speed (starting with the 0–10 km/h, followed by 5 km/h increases up to 95 km/h and above);
- 5 time scales: rush hours twice (an hour in the morning and afternoon each), time around the rush hours (when the traffic density remains high), time between the rush hours, and night time.

2.3 Assessment of Health Damage to People Living in the Vicinity of Heavy Traffic

Data from the emission model were used to calculate the volume of health damage in relation to the city population. For this purpose, the GaBi5 software was used, employing so-called models of substance fate, which determine the physical and chemical processes occurring after the substance emission to the atmosphere. The following processes were taken into account: creation, migration, transformations, and absorption of pollution in the atmosphere. On the basis of results of numerous epidemic studies on the impact of pollution on human health, the percentage of population having a given health effect connected with increased concentration of pollutants was determined. The last stage was the assessment of the volume of health damage expressed as the population health index DALY (disability-adjusted life years), which is a sum of potential years of life lost due to early death and the years of life with a specific disability, e.g., COPD.

3 Results and Discussion

Increases in the traffic density during the morning and afternoon rush hours cause a decrease in the average speed of vehicles, thereby generating traffic congestion and contributing to greater emissions of harmful substances. Therefore, specificity of changes of traffic parameters at different times of day was taken into consideration when modeling emissions. During the rush hours (lasting in total 2 h) in the analyzed road network, the number of vehicle-kilometres accounts for ca 25 % of the total 24-h transport activity which stands at ca 12.3 million of vehicle-kilometres over 24 h. Vehicles in the morning rush hour drive at the average speed of 28.7 km/h. The average speed at the time around the rush hours rises to 35.3 km/h and between the rush hours to 36.9 km/h. The highest speed is observed at night (40.9 km/h).

The influence of the average speed on pollution emissions, as assessed from the level of

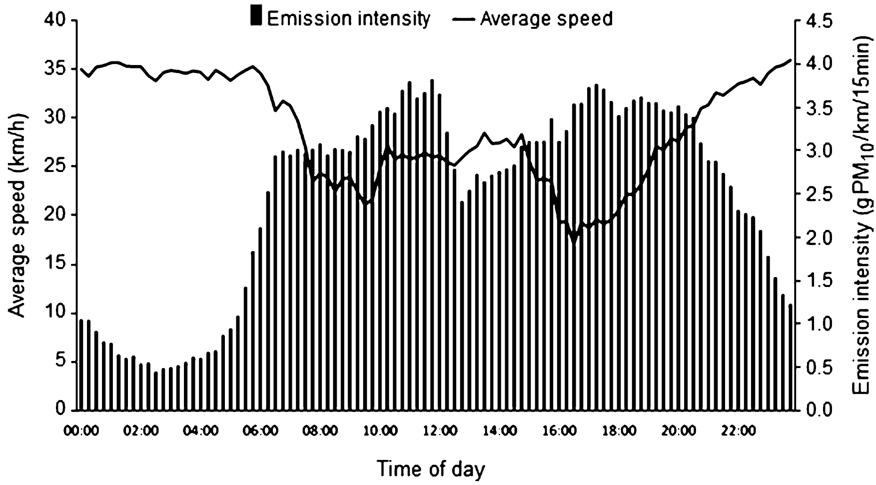

Fig. 1 **Average 24-h characteristics of PM_{10} emission** in a measurement section in Warsaw

Table 1 Emissions of particulate matter PM_{10} in kg per year, calculations for 2013

Time of day	Passenger cars	Light goods vehicles	Small buses and vans	Large buses and trucks
Morning rush hour – 1 h	10,926	3,898	2,457	6,066
Afternoon rush hour – 1 h	10,245	3,718	2,285	5,641
Around the rush hours – 5 h	137,558	46,566	25,909	63,959
Between the rush hours – 8 h	217,074	72,697	39,374	97,198
Night – 9 h	54,986	18,311	9,157	22,604

Table 2 Emissions of nitrogen oxides in kg per year, calculations for 2013

Time of day	Passenger cars	Light foods vehicles	Small buses and vans	Large buses and trucks
Morning rush hour – 1 h	410,489	57,603	62,535	154,374
Afternoon rush hour – 1 h	378,622	54,766	58,136	143,515
Around the rush hours – 5 h	4,783,864	666,407	683,050	1,686,184
Between the rush hours – 8 h	7,424,412	1,032,443	1,048,146	2,587,463
Night – 9 h	1,802,020	252,714	254,819	629,050

PM_{10}, is illustrated in Fig. 1. An increase in vehicle traffic in the streets generates a decrease in the traffic speed, resulting in a greater consumption of fuel and thereby greater air pollution emission.

The modeling of pollution emission was made for particular times of day and types of vehicles (Tables 1 and 2). The results show that, assuming that the forecast data of traffic streams for 2013 are true, road traffic emitted approximately 850 Mg of PM_{10} and 24 Gg of nitrogen oxides in the whole road network in Warsaw. The largest share in the emissions belongs to passenger cars which emitted 50.6 % of the total volume of PM_{10} and 61.2 % of the total volume of nitrogen oxides. The emission was calculated only for the combustion of the fuel phase, which is a part of the life cycle of vehicles. However, in this process the biggest part of harmful to health pollutions are emitted (Chłopek and Lasocki 2013). Calculations show that the emission is greatest during the 8-h time between the rush hours. It is also worth noting that between the rush hours and around them the speed of vehicles increases only by ca 6–7 km/h, so that vehicles still do not drive optimal conditions, which contributes to the relatively significant emission of pollution.

The calculations described above were employed to assess the volume of health damage to the population using the ReCiPe model of LCIA methodology. The assumed index of health effects is the DALY index, which determines the number of years of life adjusted with disability. Results in the DALY unit should be interpreted as a total loss of a given number of years of life in full health due to a given population.

The ReCiPe model shows that the emission of 1 kg of PM_{10} causes a loss of health of 0.00026 DALY, while that of 1 kg of nitrogen oxides is connected with a deterioration of life quality at the level of 0.000057 DALY. Assuming the level of PM_{10} emission from the transport sector in Warsaw at the above mentioned level of 850 Mg per year, there is a loss of life years adjusted with disability of 221 DALY. In turn, annual emission of 24 Gg NO_x is connected with a loss of 1383 DALY. Therefore, annual loss for the whole population of 1.7 million citizens of Warsaw due to exposure to traffic-related emissions of PM_{10} and NO_x would approximate 1604 DALY. A limitation of the vehicle speed in the road network, which contributes to the creation of traffic congestion, has a significant bearing on the emission level. It also needs to be pointed out that the greatest impact on the emissions of both particulate matter (49 %) and nitrogen oxides (61 %) have to passenger cars, whose share in the total traffic density stands at almost 89 %. A significant part of emissions (34 % for PM_{10} and 31 % for NO_x) is caused by buses, which however have only a 3 % share in the whole road traffic in the road network of the city.

4 Conclusions

The presented results of the volume of health damage in the population of Warsaw show that traffic-related air pollution with PM_{10} and nitrogen oxides contributes to the annual loss of more than 1600 DALY. Health damage is caused mostly by higher morbidity due to chronic respiratory diseases (Badyda et al. 2013b). It is worth noting that the 2009 WHO estimates for all urban areas in Poland showed that all particulate matter emission sources result in the annual loss of 86400 DALY. Thus, the share of pollution emitted from transportation in Warsaw alone accounts for almost 2 % of the health damage calculated for the whole country and all emission sources. The calculated health damage comes only from local road transport emission, but air pollution can travel long distance, so that the total DALY including other sources of pollution (energy, industry, and road transport in other urban areas) would be higher (Juda-Rezler et al. 2011).

The estimation of volumes of health damage caused by traffic-related pollution, conducted with the methodology being widely employed to analyze life cycle, yielded satisfactory results. However, the models used in the present study do not allow determining the exact kind of health damage. That is a limitation of the LCIA method, which requires making numerous assumptions and simplifications due to imperfection of input data to the model. Nevertheless, the results seemed to assess well the influence of traffic-related air pollution on the health condition of the analyzed population. It is estimated that one per 10,000 Warsaw's citizens loses 9.5 years of healthy life over his entire life due to traffic-related emissions, as a result of chronic diseases and potentially early death.

Conflicts of Interest The authors declare no conflicts of interest in relation to this article.

References

Autrup H (2010) Ambient air pollution and adverse health effects. Proced Social Behav Sci 2:7333–7338

Badyda A, Dąbrowiecki P, Lubiński W, Czechowski PO, Majewski G, Chciałowski A, Kraszewski A (2013a) Influence of traffic-related air pollutants on lung function: Warsaw study. Adv Exp Med Biol 788:229–235

Badyda A, Dąbrowiecki P, Lubiński W, Czechowski PO, Majewski G (2013b) Exposure to traffic-related air pollutants as a risk of airway obstruction. Adv Exp Med Biol 755:35–45

Chłopek Z (1999) Badania modelu globalnej emisji spalin z silników pojazdów drogowych. Chemia i Inżynieria Ekologiczna 6:65–76 (Article in Polish)

Chłopek Z, Lasocki J (2013) Comprehensive environmental impact assessment of the process of preparation of bioethanol fuels of the first and second generation. Maint Reliab 15:44–50

Franchini M, Mannucci PM (2012) Air pollution and cardiovascular disease. Thromb Res 129:230–234

Goedkoop MJ, Heijungs R, Huijbregts M, De Schryver A, Struijs J, Van Zelm R, ReCiPe (2008) A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition Report I: characterisation; 6 January 2009. http://www.lcia-recipe.net. Accessed on 27 Dec 2013

Hoek G, Brunekreef B, Goldbohm S, Fischer P, van den Brandt PA (2002) Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. Lancet 360:1203–1209

Juda-Rezler K, Reizer M, Oudinet JP (2011) Determination and analysis of PM10 source apportionment during episodes of air pollution in Central Eastern European urban areas: the case of wintertime 2006. Atmos Environ 45:6557–6566

Krewski D, Burnett RT, Goldberg MS, Hoover K, Siemiatycki J, Jerrett M, Abrahamowicz M, White WH (2000) Reanalysis of the Harvard Six Cities study and the American Cancer Society study of particulate air pollution and mortality. A Special Report of the Institute's Particle Epidemiology Reanalysis Project. Health Effects Institute, Cambridge, MA

Laden F, Schwartz J, Speizer FE, Dockery DW (2006) Reduction in fine particulate air pollution and mortality – extended follow-up of the Harvard Six Cities study. Am J Respir Crit Care Med 173:667–672

Lim SS, Vose T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, AlMazroa MA, Amann M, Anderson HR, Andrews KG, Aryee M, Atkinson C, Bacchus LJ, Bahalim AN et al (2012) A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet 380:2224–2260

Nelin TD, Joseph AM, Gorr MW, Wold LE (2012) Direct and indirect effects of particulate matter on the cardiovascular system. Toxicol Lett 208:293–299

Pope CA, Thun MJ, Namboodiri MM, Dockery DW, Evans JS, Speizer FE, Heath CW (1995) Particulate air-pollution as a predictor of mortality in a prospective-study of US adults. Am J Respir Crit Care Med 151:669–674

Pope CA, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, Thurston GD (2002) Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287:1132–1141

Pope CA, Ezzati M, Dockery DW (2009) Fine-particulate air pollution and life expectancy in the United States. New Engl J Med 360:376–386

Tainio M, Tuomisto JT, Hänninen O, Aarnio P, Koistinen KJ, Jantunen MJ, Pekkanen J (2005) Health effects caused by primary fine particulate matter (PM2.5) emitted from buses in the Helsinki Metropolitan Area, Finland. Risk Anal 25:151–160

WHO (2006) World Health Organization: air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment. Copenhagen, Denmark

Zanobetti A, Baccarelli A, Schwartz J (2011) Gene-air pollution interaction and cardiovascular disease: a review. Prog Cardiovasc Dis 53:344–352

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Impact of Traffic-Related Air Pollution on Health

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Abstract

Road transport contributes significantly to air quality problems through vehicle emissions, which have various detrimental impacts on public health and the environment. The aim of this study was to assess the impact of traffic-related air pollution on health of Warsaw citizens, following the basics of the Health Impact Assessment (HIA) method, and evaluate its social cost. PM_{10} was chosen as an indicator of traffic-related air pollution. Exposure-response functions between air pollution and health impacts were employed. The value of statistical life (VSL) approach was used for the estimation of the cost of mortality attributable to traffic-related air pollution. Costs of hospitalizations and restricted activity days were assessed basing on the cost of illness (COI) method. According to the calculations, about 827 Warsaw citizens die in a year as a result of traffic-related air pollution. Also, about 566 and 250 hospital admissions due to cardiovascular and respiratory diseases, respectively, and more than 128,453 restricted activity days can be attributed to the traffic emissions. From the social perspective, these losses generate the cost of 1,604 million PLN (1 EUR-approx. 4.2 PLN). This cost is very high and, therefore, more attention should be paid for the integrated environmental health policy.

Keywords

Air pollution • Health Impact Assessment • Particulate matter • Road transport • Social costs

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1 Introduction

Automobile use has strongly increased during the last few decades. The number of passenger kilometers increased, on average, by 260 % in the member countries of the Organization for Economic Co-operation and Development (OECD) between 1970 and 2008, and in Poland by 385 %. Transport contributes significantly to economic growth, providing access to markets, creating new jobs and supporting additional investments. However, transport affects society not only in a positive way. When the impact of motor vehicles is considered, the statistics on road accidents are most often mentioned. According to the WHO estimates, every year the lives of almost 1.3 million people are cut short as a result of a road traffic crash. Twenty to 50 million people suffer from non-fatal injuries, with many incurring a disability as a result of their injury. In Poland, in 2011 these numbers amounted to 4,189 fatalities and 49,501 causalities as a result of car accidents. It is worth emphasizing that transport side effects include also congestion, air pollution (responsible for health problems, such as increased hospitalization due to cardiovascular and respiratory diseases, premature mortality or restricted activity days, or buildings and material damages), noise, and impact on climate and ecosystem changes. These effects are often neglected and thus called a 'hidden toll' of motor vehicles. What is more, they generate costs which are borne by the whole society, not just by the transport users. Therefore, the transport policy aiming at internalization of these costs is crucial and one of the first steps consists in identifying of all their components.

The problem of transport-related air pollution is particularly significant in large urban areas. Warsaw is the capital of Poland and its biggest city with around 1.7 million inhabitants. The city has undergone rapid economic growth since the early 1990s, and this shift has had a major impact on the vehicle fleet. According to Central Statistical Office, the total number of registered vehicles in Warsaw increased by nearly 58 % from 1995 to 2011 and now amounts to around 1.2 million. Due to its central location, the city is considered the key regional transport hub. On the other hand, the development of road infrastructure is very slow and the capacity of many urban traffic routes in Warsaw is not enough to meet the requirements of increased road traffic. Inefficient transportation system of the city has a number of negative effects, including increased pollution and fuel consumption. Another problem of road transport in Warsaw is aging of the vehicle fleet, which is caused by an increased import of used cars, mainly from Western Europe. Almost half of all passenger cars registered in Poland (43.5 %) are from 6 to 15 years old and 36.5 % are from 16 to 30 years old. In 2011, the number of cars aged 30 and over outnumbered cars aged 3 years and under by 1.5 times (CSO 2012). Old vehicles do not apply to today's strict emission standards and their worn out engines emit more pollution than new engines do. According to the Regional Inspectorate of Environmental Protection in Warsaw (2012) about 94 % of the total emission of carbon monoxide in the city comes from line sources (i.e., traffic). Transport is also responsible for almost 60 % of total emission of particulate matter up to 10 μm in aerodynamic diameter (PM_{10}) and 50 % of nitrogen oxides, whereas in central parts of the city it contributes up to 90 % of their emission (Badyda and Kraszewski 2010). The study conducted on Warsaw population (Badyda et al. 2013) has shown that living in the proximity of urban roads, in comparison to rural areas, increases fourfold the risk of bronchoconstriction, particularly among non-smoking persons.

The most important air pollutants are the following: particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO_2), ozone (O_3), and volatile organic compounds (VOC). The effects of these pollutants on health are correlated, i.e., epidemiological studies cannot strictly allocate observed effects to a single pollutant. A pollutant-by-pollutant assessment would grossly overestimate the impact. Therefore, usually one pollutant – typically PM_{10} or $PM_{2.5}$ – serves as an indicator of outdoor air pollution to derive the attributing cases (Künzli et al. 2000). PM is an air pollutant consisting of a mixture of particles that can be solid, liquid or both, suspended in the air, and representing a complex mixture of organic and inorganic substances. Particles vary in size, composition, origin, and their properties are usually determined by their aerodynamic diameter.

The evidence that particle exposures cause a range of adverse health effects has primarily emerged from the findings of American epidemiological studies (Kelly and Fussell 2012), which comprised both time-series and prospective cohort studies. They showed a significant increase in respiratory and cardiovascular mortality associated with acute and chronic exposures to particulate air pollution (Pope et al. 1995; Dockery et al. 1993). Also, the impact of particulate air pollution on morbidity endpoints has been subject to intense studies, resulting in strong evidence of detrimental effects on respiratory and cardiovascular conditions following either short-term or chronic exposures (Pope et al. 2008).

The aim of this study was to assess the impact of traffic-related air pollution on health of Warsaw citizens, following the basics of the Health Impact Assessment (HIA) method. The method generally consists of four steps: hazard identification, exposure analysis, dose-effect relationships, and the risk assessment. As a result, we expected to obtain the number of premature mortality cases, excessive hospitalizations due to both respiratory and cardiovascular diseases, and the number of restricted activity days. In the end, we tried to put an economic value on the obtained results to assess a social cost of traffic-related air pollution in Warsaw. Several similar studies have been conducted throughout Europe and worldwide, mostly but not exclusively, for whole countries (Dhondt et al. 2011; Fisher et al. 2002; Künzli et al. 2000). However, some of them focused on air pollution from all sources (HAPINZ 2012; Orru et al. 2011). The present study is to our knowledge the first such attempt concerning Warsaw.

2 Methods

The study consists of three main parts. The first one is concerned with air pollution, the second with epidemiology, and the third deals with the economic evaluation. Generally, we followed the recognized methodology presented by Künzli et al. (2000), which has been applied in the majority of studies assessing the impact of air pollution on health, with some adjustment for Warsaw conditions. Figure 1 presents the sequential steps of our calculations; described further on in detail.

2.1 Traffic-Related Air Pollution

Firstly, we evaluated the annual exposure of Warsaw citizens to PM_{10}, assuming this pollutant to be the best available indicator. As our study concerns only one city (and not the whole country or region), we abandoned the idea of modeling the concentration of PM_{10} in Warsaw and decided to use the average annual concentration of PM_{10} (μg/m^3) from six monitoring stations in Warsaw. All the results were similar (except for one site, located directly in the center of Warsaw, with higher concentrations), which confirms that our simplifying assumption should not have a significant effect on the results.

Secondly, the total concentration of air pollutants is affected not only by the emission from the considered area (point, line, and area sources), but also by the transfer of pollutants from the outside. According to the study conducted in Warsaw (Badyda and Kraszewski 2010), the dominant source of PM_{10} emission in the area of Warsaw are line sources (58 %), identified primarily with the transport activity. The outside emission fraction of the total emissions of PM_{10} is 42 %, of which approx. 6.5 % comprises transportation. Taking into account the above data, we assumed the proportion of traffic-related PM_{10} concentration in the air in Warsaw is approx. 36.5 %.

Having determined the traffic-related PM_{10} concentration, we assumed that the whole population of Warsaw citizens is exposed to it. This simplifying assumption has been discussed and criticized in many papers (e.g., Fisher et al. 2002), as there is evidence that people spend little time outdoors (e.g., Jenkins et al. 1992) (cf. conclusions). However, all the conducted studies adopted it as well.

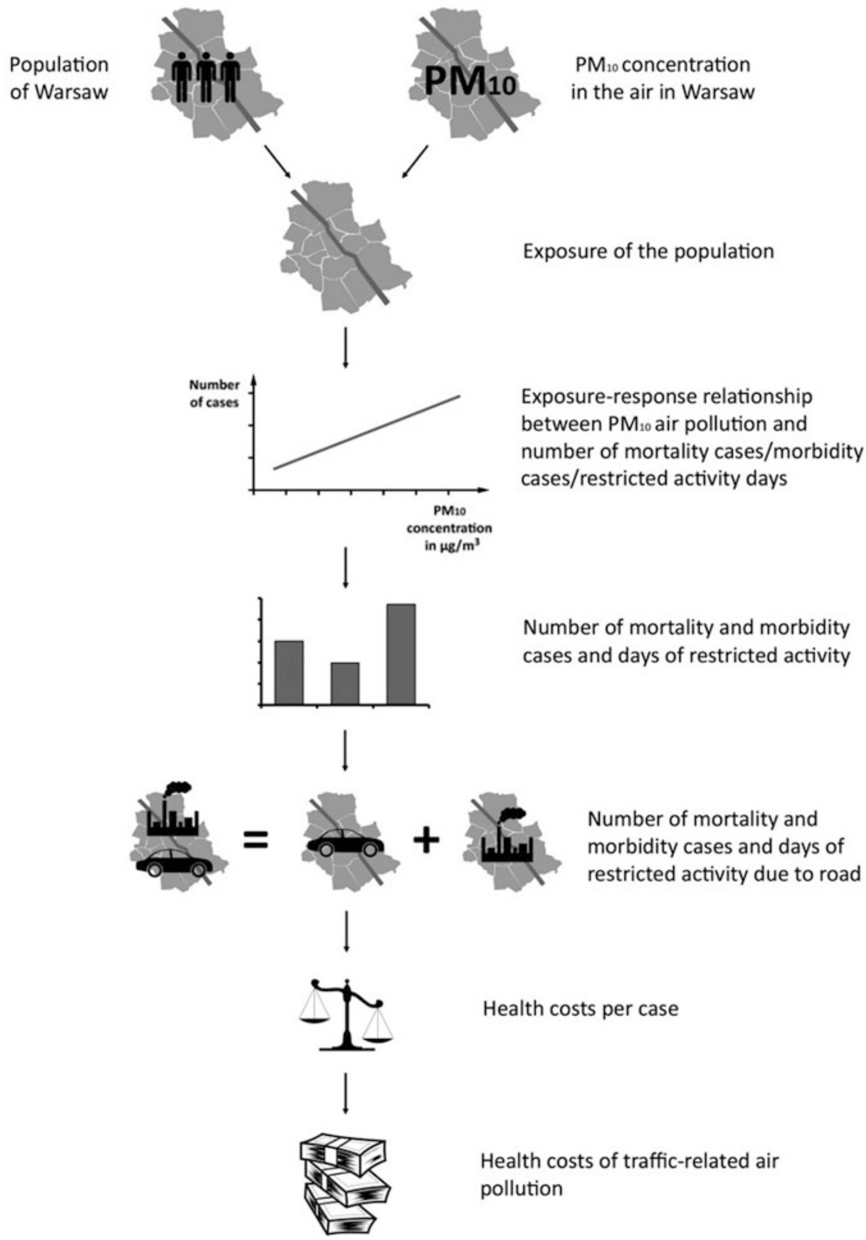

Fig. 1 The methodology scheme

2.2 Quantifying the Impact of Traffic-Related Air Pollution on Health

Although there are several lines of studies indicating the relationship between concentration levels of PM_{10} and different endpoints, we decided to consider in particular mortality (age $\geq$30 years), respiratory (e.g., due to asthma, chronic obstructive lung disease, and cancer) and cardiovascular (e.g., myocardial infarction and stroke) hospitalizations as well as restricted-activity days (RADs; age 18–65 years). To be more conservative, in our calculations we preferred to underestimate the magnitude of those effects rather than overestimate it (we followed

Table 1 Relative risks per 10 $\mu g/m^3$ of PM_{10} for selected health effects

Health effect	Relative risk (95 % CI)	Source of exposure-response function
Long-term mortality (age ≥30 years; from non-external causes)	1.043 (1.026–1.061)	Pope et al. (1995) and Dockery et al. (1993)
Respiratory hospital admissions (all ages)	1.013 (1.001–1.025)	Zmirou et al. (1998), Prescott et al. (1998), and Wordley et al. (1997)
Cardiovascular hospital admissions (all ages)	1.013 (1.007–1.019)	Prescott et al. (1998), Wordley et al. (1997), Poloniecki et al. (1997), and Medina et al. (1997)
Restricted activity days (age 18–65 years)[a]	1.094 (1.079–1.109)	Ostro (1990)

[a]Total person-days per year

the 'at least' approach), and so we restricted ourselves only to those non-overlapping endpoints, for which appropriate data for Warsaw population are available.

In order to assess the traffic-related number of mortality and morbidity cases as well as RADs, we used exposure-response functions between air pollution and health impacts, which describe quantitatively how much a specified health effect changes when exposure to the specified agent changes by a given amount. As this relationship in case of PM_{10} seems to have a linear correlation without the threshold value below which there is no health effect (WHO 2006), we used the gradient derived from the meta-analysis presented by Künzli et al. (2000). Table 1 shows this relationship in terms of relative risks per 10 $\mu g/m^3$ of PM_{10}.

We applied the following formula to obtain the number of cases due to air pollution (n):

$$n = \frac{N}{1 + \frac{1}{(RR-1)\cdot\frac{E}{10}}}$$

where:

N – the total number of cases observed in the population of Warsaw citizens,

E – the exposure for Warsaw population ($\mu g/m^3$),

RR – relative risk selected from epidemiological studies.

The endpoints: mortality, respiratory, and cardiovascular hospital admissions seem to be comprehensible. However, it is essential to define RADs, as there is no one common definition in the literature. Usually, RADs are understood as days when a person needs to change their normal activities because of illness; often regardless of age or employment status. In our study we based on the research of Ostro (1990), who focused on currently working adults aged 18–65 years and their days off work as well as minor restrictions of daily life due to respiratory disease. In the study of Künzli et al. (1999), which based on Austrian and Swiss data, it was indicated that 'nearly all of the RAD burden reported by Ostro (1990) should relate to days off'. Therefore, as a source of RADs we used the Polish data on annual work absenteeism for respiratory reasons (deducted by the number of respiratory hospitalizations in this group) among Warsaw citizens insured by the Social Insurance Institution, assuming that a major part of RADs leads to absence from work. It must, however, be emphasized that there may be a pressure on workers not to take a sick-leave, which can significantly underestimate the total number of RADs. This suspicion is based on the fact that for Mazovian Voivodeship the number of days of absence due to disease per insured by Social Insurance Institution is among the lowest in Poland.

2.3 Economic Evaluation of Traffic-Related Air Pollution Impact on Health

The idea of associating monetary value with human life and health seems to be very controversial. However, policy makers are regularly facing decisions that affect people risk of death or illness and therefore require methods for comparing the costs of reducing risk with the expected benefits in terms of lives saved or other positive health effects.

In our study we tried to assess the costs of traffic-related air pollution health effects from the societal perspective. In the calculations we included costs of loss of life, medical treatment, and productivity loss as a result of PM_{10} emitted by motor vehicles in Warsaw. To assess the costs of mortality, the value of statistical life (VSL) approach was used, which bases on individual willingness to pay (WTP) for safety improvement. This approach, firmly rooted in the economic theory, requires measuring of people preferences for safety, which at the same time is its major difficulty. VSL is also known as a value of preventing a statistical fatality (VPF), which represents the value a given population places *ex ante* on avoiding the death of an unidentified individual. There are two main approaches to estimate WTP: stated preference (SP) methods, which typically employ survey techniques to ask respondents what they would pay for a risk reduction of a particular type, and revealed preference methods, which estimate the value of non-marketed goods based on observed behaviors or prices and preferences for related marketed goods (Robinson 2008).

The problem with the VSL approach consists in performing a reliable study on the population WTP for risk reduction in mortality due to air pollution. Obviously, VSL may vary between countries due to differences in income or cultural norms, so it is essential to find the assessment of VSL for as close population to the target one as possible. The design of the study also plays a huge role in the results obtained. We searched through many studies and finally decided to use the latest study conducted in Warsaw (Giergiczny 2006), eliciting the VSL with the use of the SP method, based on the mean WTP and consequently adjusting the value to the current 2012 Consumer Price Index.

To assess the costs of additional hospitalizations, the best approach – as in the case of mortality costs – would be the use of WTP for avoiding hospitalization, which reflects the individuals' utility of a risk reduction in air pollution related morbidity. This method comprises all implications that a person expects in case of a disease, such as loss of earnings, costs of averting behavior, or intangible costs. However, the literature on the WTP air pollution-related morbidity costs is very rare in Europe. That is why we decided to use the cost of illness (COI) method, which incorporates direct and indirect costs, in the form of medical treatment costs (perceived as a waste of resources) and productivity loss due to illness, ignoring thereby intangible costs. In our study we multiplied the number of all excessive hospital admissions due to respiratory and cardiovascular diseases by the average weighted medical cost per hospitalization due to these diseases (basing on National Health Fund data on diagnosis-related groups in 2011) and the average loss of output per day in hospital (estimated as the average daily gross income in Warsaw). The costs of RADs were assessed assuming that each RAD equals the productivity loss, measured by the average daily gross income in Warsaw.

2.4 Data Treatment

All the necessary data was obtained from the sources published or available on-line. We used data primarily from the Polish Statistical Yearbooks (Central Statistical Office), Social Insurance Institution, Regional Inspectorate of Environmental Protection in Warsaw, reports on health of Warsaw and Mazovian Voivodeship citizens (Mazovian Province Office in Warsaw) and diagnosis-related group statistics provided by the National Health Fund (NFZ). As we were trying to use as up-to-date data as possible, we chose the latest editions of these sources. That means that our 'annual' data comes from the years 2005–2012. Such an approach in our opinion should not lead to a serious distortion of the final results.

3 Results

The average concentration of PM_{10} in Warsaw in 2011 amounted to 37.2 μg/m^3, of which 13.6 μg/m^3 was attributed to motor vehicles. According to our calculations, annually approx. 2,264 people die as a result of air pollution (Table 2) and about 827 cases could have been avoided, if there was no emission from motor vehicles. It is worth emphasizing that according to Polish Regulation of the Minister of Environment of 3 March 2008 on the levels of certain substances in the air, the acceptable annual mean level of PM_{10} concentration cannot exceed 40.0 μg/m^3. WHO, on the other hand, in its air quality guidelines (WHO 2006) stresses that there is little evidence to suggest a threshold below which no adverse health effects would be anticipated and sets the level of 20.0 μg/m^3 as a limit for annual mean of PM_{10}. If the WHO guideline were respected in Warsaw, almost 1,000 mortality cases would have been prevented. 1,551 and 684 cardiovascular and respiratory hospital admissions, respectively, were air pollution attributable, of which 566 and 250 due to motor vehicle emission. There were 351,839 RADs, of which 128,453 were caused by traffic.

We assessed the average cost of hospitalization due to respiratory problems for 4,038 PLN and cardiovascular diseases for 5,493 PLN per case, including direct costs of hospitalization and the productivity loss for the average number of days spent in the hospital. For RADs the cost per case amounted to 167 PLN. The VSL for the estimation of traffic-related air pollution attributable mortality cost, equals approx. 1.9 million PLN per case.

The total costs of traffic-related air pollution health effects in Warsaw amount to approx. 1,604.1 million PLN (Table 2). Premature mortality accounts for the majority of these costs (98.4 %), which is not surprising taking into account the height of its cost per case.

4 Discussion

Our aim was to assess the annual traffic-related air pollution impact on health of Warsaw citizens and its attributable cost. According to our calculations, about 827 Warsaw citizens die in a year as a result of traffic-related air pollution. Moreover, about 566 and 250 hospital admissions due to cardiovascular and respiratory diseases, respectively, and about 128,453 restricted activity days can be attributed to the traffic emissions. From the social perspective, these losses generate costs which add up to 1,604 million PLN. To fully understand the magnitude of this number, it is worth emphasizing that the air pollution traffic-related mortality accounts for about 5 % of all deaths (≥30 years old people) from external reasons among Warsaw citizens annually.

Table 2 Air pollution and traffic-related air pollution effects on Warsaw citizens' health, the cost per case/day and the annual total costs of traffic-related air pollution effects from a social perspective

Health effect	Total air pollution attributable number of cases/days	Traffic-related air pollution attributable number of cases/days	Cost per case/day – PLN 2012	Traffic-related air pollution costs – million PLN 2012
Mortality	2,264	827	1,909,471	1,579
Respiratory hospital admissions	684	250	4,038	1.0
Cardiovascular hospital admissions	1,551	566	5,493	3.1
Restricted activity days	351,839	128,453	167	21.5
Total				1,604

We compared these results with the estimates obtained by Orru et al. (2011) for Tallinn, the capital of Estonia, which is a country of comparable gross income product (GDP) to Poland. In Tallinn, the number of premature deaths for the total air-pollution, not just traffic-related, amounted to 296 (around 76 per 100,000 inhabitants). This is less than in Warsaw with its estimate of 2,264 (132 per 100,000 inhabitants). The reasons for such differences may be speculated. For instance, Tallinn is much smaller than Warsaw (390,107 vs. 1,711, 324 citizens), the structure of emission sources differs, there are fewer cars in Estonia than in Poland (according to OECD, in 2010 there were 451 cars per 1,000 inhabitants in Poland vs. 412 in Estonia). It is difficult to compare our results with those from other studies, as the methodology differs and the results encompass different components. One reason for this is the necessity to adjust the calculations to the characteristics of an area which is the subject of interest. Another reason is that in spite of the growing number of such studies and international projects (e.g., ExternE, CAFE CBA, HEATCO), the methodology of quantifying and valuing the impact of air pollution on health is still developing and hence it is not yet standardized or unified.

Our study has limitations. First of all, we chose PM_{10} as an indicator of traffic-related air pollution. Such an approach may be subject to criticism as PM_{10} is not a typical traffic-related air pollutant (such as NO_x or CO). However, there are many advantages of such choice. PM_{10} is generally considered a good air pollution indicator and is widely used to assess the impact of air pollution on human health. The reason for that is the credibility and recognition of the epidemiological studies which the dose-response functions are based on. Moreover, PM_{10} has been widely used in other studies and projects, so this choice allows to make some comparisons between regions. Another limitation is the assumption that the annual average concentration of PM_{10} is the exposure all Warsaw citizens face. Many people spend the majority of their time indoors, where the PM_{10} concentration is lower, whereas some spend a considerable amount of time outdoor, near major traffic routes. Nonetheless, the epidemiological studies, mainly cross-sectional, time-series, and cohort prospective studies have also been conducted among citizens whose ‘outdoor activity’ differed.

Another issue to consider is the transferability of the exposure-response functions derived from epidemiological studies, in which population, its lifestyle, and other factors differed significantly from the Polish conditions. Being aware of this problem and due to lack of such studies for Poland, we decided to use the best recognized, studies that were used by other European scientists in their calculations. This enables comparisons with other countries, which is also highly informative and should be the topic of the future analysis. To this point there is also a problem with the site-specific chemical composition of particulate matter. However, we believe that thanks to the use of meta-analysis of different studies for deriving the relative risks, we included various compositions and their health effects on humans.

Despite these limitations, the estimated cost is significant and can be much higher in reality, as we only focused on some of the effects and assumed the PM_{10} as an indicator for the total effect of air pollutants on health. Further research is needed to clarify the impact of other factors related with motor vehicles on health of Warsaw citizens, e.g., noise (associated with annoyance, sleep disturbance, and impairment of learning functions) or sedentary lifestyle (which increases the risk of cardiovascular problems, diabetes and obesity).

In conclusion, the cost of the influence of traffic-related air pollution on human health, constituting part of external cost of motor vehicles, is very high. Therefore, more attention should be paid for the integrated environmental health policy, with the focus on cities as a priority.

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References

Badyda AJ, Kraszewski A (2010) Public transport – chances and threats for environment. Urban Reg Transp 7(8):19–25

Badyda A, Dąbrowiecki P, Lubiński W, Czechowski PO, Majewski G (2013) Exposure to traffic-related air pollutants as a risk of airway obstruction. Adv Exp Med Biol 755:35–45

CSO. Transport – activity results in 2011 Central Statistical Office (CSO) (2012). Available from: http://www.stat.gov.pl. Accessed on 28 Oct 2013

Dhondt S, Le Xuan Q, Vu Van H, Hens L (2011) Environmental health impacts of mobility and transport in Hai Phong, Vietnam. Stoch Environ Res Risk Assess 25:363–376

Dockery DW, Pope CA III, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG Jr, Speizer FE (1993) An association between air pollution and mortality in six U.S. cities. New Engl J Med 329:1753–1759

Fisher GW, Rolfe KA, Kjellstrom T, Woodward A, Hales S, Sturman AP, Kingham S, Petersen J, Shrestha R, King D (2002) Health effects due to motor vehicle air pollution in New Zealand. Report to the Ministry of Transport. Available from: http://www.transport.govt.nz. Accessed 28 Oct 2013

Giergiczny M (2006) Value of a statistical life – the case of Poland. In: The 3rd Annual Congress of Association of Environmental and Resource Economics (AERE), Kyoto, 4–7 July, 2006. Available from: http://www.webmeets.com/files/papers/ERE/WC3/919/ATT00007.pdf. Accessed 28 Oct 2013

HAPINZ. Updated Health and Air Pollution in New Zealand Study, vol 1, Summary report. Health and Air Pollution in New Zealand (HAPINZ) (2012). Available from: http://www.hapinz.org.nz. Accessed 28 Oct 2013

Jenkins PL, Phillips TJ, Mulberg EJ, Hui SP (1992) Activity patterns of Californians: use of and proximity to indoor air pollutant sources. Atmos Environ 26A:2141–2148

Kelly FJ, Fussell JC (2012) Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter. Atmos Environ 60:504–526

Künzli N, Kaiser R, Medina S, Studnicka M, Oberfeld G, Horak F (1999) Health costs due to road traffic-related air pollution: air pollution attributable cases – technical report on epidemiology. Available from: http://www.salzburg.gv.at. Accessed 28 Oct 2013

Künzli N, Kaiser R, Medina S, Studnicka M, Chanel O, Filliger P, Herry M, Horak F Jr, Puybonnieux-Texier V, Quénel P, Schneider J, Seethaler R, Vergnaud JC, Sommer H (2000) Public-health impact of outdoor and traffic-related air pollution: a European assessment. Lancet 356:795–801

Medina S, Le Terte A, Dusseux E (1997) Evaluation des risques de la pollution urbaine sur lar santé (ERPURS). Analyse des liens à court terme entre pollution atmoshérique et santé: resultats 1991–95. Conseil Regional d'lle de France, Paris

Orru H, Maasikmets M, Lai T, Tamm T, Kaasik M, Kimmel V, Orru K, Merisalu E, Forsberg B (2011) Health impacts of particulate matter in five major Estonian towns: main sources of exposure and local differences. Air Qual Atmos Health 4:247–258

Ostro B (1990) Associations between morbidity and alternative measures of particulate matter. Risk Anal 10:421–427

Poloniecki J, Atkinson R, Ponce de Leon A, Anderson H (1997) Daily time series for cardiovascular hospital admissions and previous day's air pollution in London, UK. Occup Environ Med 54:535–540

Pope CA III, Thun MJ, Namboodiri MM, Dockery DW, Evans JS, Speizer FE, Heath CW Jr (1995) Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. Am J Respir Crit Care Med 151:669–674

Pope CA III, Renlund DG, Kfoury AG, May HT, Horne BD (2008) Relation of heart failure hospitalization to exposure to fine particulate air pollution. Am J Cardiol 102:1230–1234

Prescott GJ, Cohen GR, Elton RA, Fowkes FG, Agium RM (1998) Urban air pollution and cardiopulmonary ill health: a 14.5 year time series study. Occup Environ Med 55:697–704

Robinson LA (2008) Valuing the health impacts of air emissions. Available from: http://www.regulatory-analysis.com. Accessed 28 Oct 2013

WHO (2006) Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005. Summary of risk assessment. World Health Organization (WHO). WHO Press, Geneva, pp 9–13

Wordley J, Walters S, Ayres J (1997) Short term variations in hospital admissions and mortality and particulate air pollution. Occup Environ Med 54:108–116

Zmirou D, Schawartz J, Saez M, Zanobetti A, Wojtyniak B, Touloumi G, Spix C, Ponce de Leon A, Le Moullec Y, Bacharova L, Schouten J, Ponka A, Katsouyanni K (1998) Time-series analysis of air pollution and cause-specific mortality. Epidemiology 9:495–503

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Traffic-Related Air Pollution and Respiratory Tract Efficiency

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Abstract

High concentrations of air pollutants are characteristic of the vicinity of urban busy roads. Numerous studies have shown that these concentrations are significantly higher in comparison with areas located in a certain distance from roads and especially those in rural areas. Inhabitants living in the proximity of roads are, therefore, likely to be more exposed to adverse effects of air pollutants. On the basis of a study realized in 2008–2012 among nearly 5,000 residents of Warsaw and non-urbanized areas, we used generalized linear regression models (GRM) to identify factors that most significantly influence the variability of respiratory function variables. GRMs combine multiple classes of models and estimation methods such as simple, multiple, or factorial regression, ANOVA, ANCOVA, etc. Therefore, they allow receiving results based also on interactions between the independent variables. This paper presents the results of GRM for the forced expiratory volume in 1 s (FEV_1) distribution. They indicate that the variation of FEV_1 is associated with personal factors such as age, height, weight, BMI, or gender, as well as with factors related to the place of residence: traffic density, duration, and the floor of residence. The results clearly show that living in the proximity of busy roads in the city is linked with a significant decrease in FEV_1 values.

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Keywords
Air pollution • Bronchial obstruction • Generalized regression model • Health • Pulmonary function • Traffic congestion

1 Introduction

The implementation of air quality standards has contributed to a considerable reduction in emissions (mainly from industry and energy sector) and thus in improvement of air quality. Nevertheless, in many parts of Europe (especially in cities) air pollutants such as ozone, particulate matter, nitrogen dioxide, or polycyclic aromatic hydrocarbons still remain at high concentrations. To the greatest extent, the problem concerns the countries of Eastern Europe (Sauer et al. 2013), which was confirmed in a recent report on air quality in Europe (EEA 2013). Particularly, important contribution in this field have the emissions from the municipal sector as well as road traffic; the areas located in the immediate proximity of urban roads with high traffic density are characterized by elevated concentrations of various air pollutants such as CO, NO_2, PM, PAHs, and others (Majewski et al. 2013; Rogula-Kozlowska et al. 2013; Juda-Rezler et al. 2011; Brugge et al. 2007). There is a substantial number of studies from the last decade presenting the influence of vehicular traffic-originated air pollutants on health outcomes (e.g., Jedrychowski et al. 2005; Schikowski et al. 2005). Evidence of the health hazard of air pollutants arises, however, from much earlier work carried out even in the late 1970s (Pope et al. 2002).

At present, one of the most important air quality problems in Europe to be urgently addressed in terms of health is still high exposure of inhabitants to particulate matter pollution. It is estimated that in Europe 430,000 premature deaths could be attributed to exposure to ambient $PM_{2.5}$ (EEA 2013). Estimates made for the Polish conditions indicated that in the year 2000 almost 40,000 people died prematurely due to the exposure to $PM_{2.5}$ (Tainio et al. 2012). Both the size and chemical composition of particulates determine the health risk. PM smaller than 10 μm get through the throat and nose to lower parts of the respiratory tract, and especially those smaller than 3 μm are easily deposited in the pulmonary alveoli. Particles of even smaller diameters, through the lower parts of the respiratory system, may almost freely move to other organs (including the brain) around the circulation system (Nemmar et al. 2002). An increase in the concentration of fine particles in the air determines an increased incidence of hospital admissions due to respiratory diseases, most notable chronic obstructive pulmonary disease (COPD) (Dominici et al. 2006), a higher mortality rate due to cardiovascular diseases, and lung cancer (Pope et al. 2002). Infants seem particularly endangered (Anderson et al. 2011). Increasing concentrations of ultrafine particles (smaller than 0.1 μm), observed in the vicinity of roads during morning and evening traffic rush hours (Mishra et al. 2012), can even enhance the occurrence of hypertensive crisis (Franck et al. 2011). It has also been observed that exposure to urban traffic-related PM significantly increases cytotoxicity, oxidative stress, and pro-inflammatory response of lung epithelial cells and macrophages in comparison with PM from rural areas (Michael et al. 2013).

Results of a Swedish study indicate that living in a 100-m distance from a busy road (traffic intensity of over 10 cars per min), in comparison with a road of small traffic intensity, is connected with the incidence of the following diseases: bronchial asthma (OR = 1.40, 95 % CI, 1.04–1.89) and COPD (OR = 1.64, 95 % CI, 1.11–2.40) (Lindgren et al. 2009). Long-term exposure to air pollutants in urban environments, as a Norwegian study shows (Nafstad et al. 2004), may lead to increased mortality due to respiratory diseases. It may be inferred that the mortality risk factor due to respiratory diseases, other than cancer, amounts to 1.16 (95 % CI, 1.06–1.26), pulmonary cancer – 1.11 (95 % CI, 1.03–1.19), ischemic heart disease – 1.08 (95 % CI, 1.03–1.12), and cerebrovascular diseases – 1.04 (95 % CI, 0.94–1.15). Results of a cohort study conducted in Canada in a group of over 450,000 people has confirmed that long-term exposure to air pollution increases the incidence of ischemic heart disease – OR 1.29 (95 % CI, 1.18–1.41) among residents of buildings located 150 m away from a motorway or over 50 m away from a main road in comparison with other people (Gan et al. 2011). A Dutch study shows that even a short-term exposure to high concentrations of particles in the air is a detriment to pulmonary function, reduces airway resistance, and increases the possibility of inflammation (Zuurbier et al. 2010). A similar finding has been provided by an English study, where a short-term exposure to air pollution (NO_2, O_3, SO_2, or PM_{10}) contributed to aggravation of COPD symptoms (Peacock et al. 2011).

Lowering of the concentration of air pollutants in urban areas should be a priority in an effort to reduce the scale of health problems resulting from pollution. Legitimacy of such activity is demonstrated by the results of implementation of traffic restricted access zones in cities, such as in Milan, Italy (Invernizzi et al. 2011) or increasing the share of public transport and cycling in the modal split, such as in Barcelona, Spain (Rojas-Rueda et al. 2013).

2 Methods

2.1 Subjects

The study was approved by the Ethics Committee of the Military Institute of Medicine in Warsaw, Poland. Pulmonary function tests were conducted in 4,725 people living in the vicinity of 7 selected busy roads in the capital city of Warsaw, Poland and in rural areas isolated from a direct impact of air pollutant emissions, including traffic-related emissions (control group). Tests were performed from April to June and from September to October in the years 2008–2011. The selection of the study time took into account the avoidance of a potential influence of short-term effects of air pollutants from sources other than traffic (especially municipal and domestic sources) and holiday breaks, which could affect the representativeness of results. The subjects under treatment for COPD or asthma, and those who failed to cooperate with the experimenters were discarded from further analysis.

In Warsaw, 3,834 examinations were performed, including 1,608 women and 2,226 men aged 9–91 (mean 50.9 ± 19.7 years). The proportion of non-smokers was 50.5 % (1,938 people). The control (rural) group consisted of 891 individuals, including 471 women and 420 men aged 9–91 (mean 50.1 ± 19.1 years); 49.6 % of them (449 people) were non-smokers. The presentation of results was limited to the non-smoking people only, due to the general aim of this study, which was the assessment of the impact of traffic-related air pollution on spirometric variables.

2.2 Tests

The examination was conducted according to the following scheme:

- A testee was informed about the aim of the examination and that it has no harmful effect on the organism;
- Questionnaire-based interview, taking into consideration anthropometric features, characteristics of the place of residence, smoking habit burden, exposure to harmful factors in the workplace and the place of living, information about pulmonary diseases, presence of symptoms that might prove respiratory system disease, allergies, etc.;
- Pulmonary function tests carried out in a sitting position (EasyOne spirometers; ndd Medizintechnik AG, Zürich, Switzerland), preceded by a few-minute adaptation time. Several flow-volume curves were recorded until the repeatability criterion was achieved, in accordance with the American Thoracic

Society (Miller et al. 2005). The test included the following:

– FVC (forced vital capacity);
– FEV_1 (forced expiratory volume in 1 s);
– PEF (peak expiratory flow);
– MEF_{50} (maximum expiratory flow at 50 % of FVC);
– FEV_1/FVC ratio (pseudo-Tiffeneau factor).

According to the ATS guidelines (Miller et al. 2005), the study was carried out until at least 3 repeatable results of FVC and FEV_1 were obtained, i.e., differences between the measurements were less than 0.15 dm^3, total expiratory time was at least 6 s, and the time to reach the peak flow (PEF) was less than 300 ms. Values expressed in liters were converted into predicted values according to commonly used ERS/ECCS standards (Quanjer et al. 1993).

2.3 Statistical Analysis

Data are means ± SD, unless otherwise indicated. The Shapiro-Wilk test was used to test for the normality of data distributions. Differences were compared with a parametric (ANOVA) or non-parametric (Kruskal-Wallis) test, as required. Statistical significance was defined as $p < 0.05$. The assessment of factors determining the variability of spirometric variables was done with a generalized linear regression (GRM path). GRM is a kind of estimation path with a wide range of regression methods and models, prepared for the estimation of variables in all measurement scales and interactions between endogenous variables. Initial data analysis, based on the robust estimators and GRM results (Dffits ratio, Cook distance, and others), was made before GRM models and logistic regression identification. Among others, Kruskal-Wallis tests, ANOVA, cluster analysis, classical regression, and PCA were made to achieve partial aims and regulators before model identification. The GRM was used to assess the significance of external factors determining the variability of key spirometric variables. The analysis presented herein concerns the FEV_1 only. Statistical analyses were conducted using Statistica ver. 10 Software (StatSoft Inc., Tulsa, OK).

3 Results and Discussion

3.1 General Results

Among both the city and rural residents the mean predicted values for spirometric variables were generally in the normal range. In most cases, however, especially those in which bronchial patency was determined, significant differences between the groups have been observed. In city residents, FEV_1, MEF_{50}, and (FEV_1/FVC) were significantly lower than those in the rural inhabitants (*t*-test and Kruskal-Wallis test, $p < 0.001$). Significant differences were also noted for PEF. The FVC, on the other hand, did not differ significantly between the two groups. That implies that a higher exposure to air pollution does not much affect the FVC, although it should be noted that this parameter has a limited relevance from the clinical point of view. The results of spirometry are presented in Table 1.

Since there were differences in spirometric indices between the city and rural inhabitants, we calculated the percentage of people with airflow obstruction in each group. Figure 1 presents the results of this calculation as broken down by the levels of FEV_1/FVC and FEV_1

Table 1 Predicted values of spirometric indices among non-smoking inhabitants of Warsaw and the control group of rural residents

	Warsaw group		
	Percentage of predicted values (%)	Rural group	p
FEV_1	95.3 ± 19.3	100.3 ± 17.2	$p < 0.001$
FVC	107.5 ± 24.9	108.1 ± 18.9	$p = 0.64$
PEF	96.2 ± 24.2	100.5 ± 22.8	$p < 0.001$
MEF_{50}	75.0 ± 32.8	86.0 ± 31.3	$p < 0.001$
FEV_1/FVC	94.5 ± 14.4	98.6 ± 10.6	$p < 0.001$

Data are means ± SD

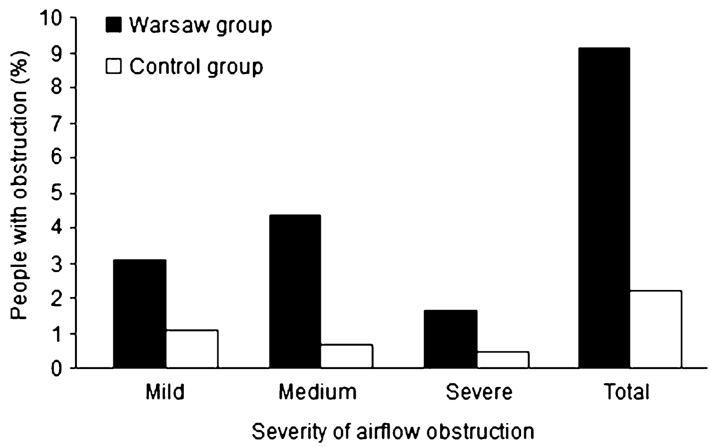

Fig. 1 Prevalence of airflow obstruction in urban and rural areas

corresponding to obstruction severity: mild – $FEV_1 \geq 80$ %, moderate – FEV_1 50–79 %, and severe – $FEV_1 < 50$ %.

The conducted observations show that among non-smokers:

- there is a significant decrease of values of the most important spirometric variables which reflect bronchial patency and possible adverse changes in the city residents compared with the control group of rural residents (Table 1);
- there are visible differences in the percentage of people with diagnosed obstruction between Warsaw and rural residents; relative risk of bronchial obstruction is 4.1-fold greater in city inhabitants (Fig. 1);
- Warsaw residents clearly have a moderate form of bronchial stricture, with FEV_1 lowered to 50–79 %. This is rather typical for smokers suffering from chronic obstructive pulmonary disease and not for people exposed to mainly environmental factors. The observation definitely needs further monitoring, also for economic reasons – with more advanced obstruction, treatment costs would be growing and quality of life would dramatically decrease, especially that the individuals examined were professional active.

3.2 Generalized Linear Regression Models (GRM) Results

In general, as indicated by the results of principal component analysis (PCA), spirometric indicators are close to each other in pairs, i.e., a specific parameter (e.g., MEF_{50}) and its equivalent in the percentage of predicted values (e.g., MEF_{50}%). This is illustrated in the principal component 2D projection (Fig. 2). It is assumed that a finding of similarities between pairs of spirometric indicators may be helpful in reducing the dimensions of multidimensional models and analysis, which will considerably simplify the calculations.

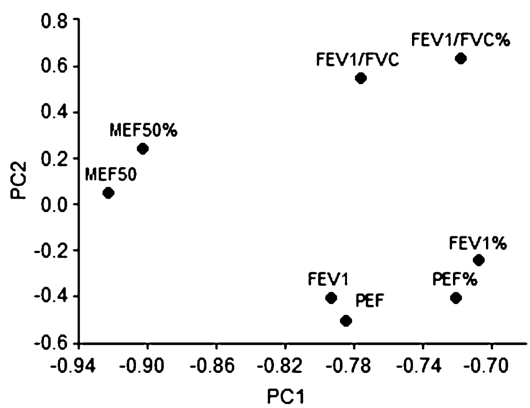

Fig. 2 Results of principal component (PC; without rotation) two-dimensional projection

However, regardless of the presumption of a connection between the variables in pairs, separate models for each variable were made. The model presented herein exemplifies FEV_1 and concerns the results of non-smoking patients only. The significant ($p < 0.05$) effects and their interactions are specified in Table 2. The results indicate that FEV_1 variability mostly depends on the demographic parameters, age or gender, duration of residence at a particular

Table 2 Generalized linear regression model (GRM) for FEV_1 distribution

	SS	Degrees of freedom	MS	F-value	P-value
Intercept	21.81	1	21.81	86.84	<0.0001
Age (years)	276.09	1	276.09	1,099.52	<0.0001
Height (cm)	69.13	1	69.13	275.29	<0.0001
Weight (kg)	4.10	1	4.10	16.34	0.0001
BMI (kg/m^2)	7.25	1	7.25	28.86	<0.0001
Duration of residence (years)	2.62	1	2.62	10.43	0.0013
Traffic (cars/day)	2.40	1	2.40	9.54	0.0020
Gender	57.96	1	57.96	230.84	<0.0001
Sports	2.97	1	2.97	11.82	0.0006
Gender*Passive smoking	2.10	1	2.01	8.35	0.0039
Sports*Place of residence	4.21	8	0.53	2.09	0.0333
Gender*Sports*Place of residence	6.34	8	0.79	3.16	0.0015

Traffic – daily average traffic density in the vicinity of residence, gender – (0-man, 1-woman), sports – physical activity (0-no, 1-yes), passive smoking exposure (0-no, 1-yes), place of residence – different locations of residence of city and rural area inhabitants (1–9), *interaction between variables
SS sum of squares, *MS* mean square

Table 3 SS-test results for the full model relative to SS for the residues

		Multiple R		Multiple R^2		Adjusted R^2
Dependent variable FEV_1		0.886		0.786		0.781
SS Model	df Model	MS Model	SS Rest	df Rest	MS Rest	F
2,102.78	25	84.11	574.52	2,288	0.25	334.97

place, traffic volume at the intersection of the nearest heavy traffic road, and on physical activity. Some interactions between variables were also significant. The SS-test for the presented complete model in relation to SS-test for the residues indicates that the model describes well the dependent variable (FEV_1), as it is evidenced by a relatively high value of the determination coefficient ($R^2 = 0.786$) (Table 3). The determination coefficient of 0.786 indicates that the 78.6 % of the variance of the dependent variable FEV_1 is explained by this model. Therefore, the remaining 21.4 % of the variation is explained by other unidentified factors. A good fit of the model is confirmed by the scatter plot of predicted *vs*. observed values (Fig. 3).

In addition to the standard evaluation of goodness of model fit to the empirical data, the residues were also evaluated. The calculated DFFITS values do not exceed ±1. It is, therefore, reasonable to conclude that there were no outliers observed among the remaining identified models, which would require further analysis.

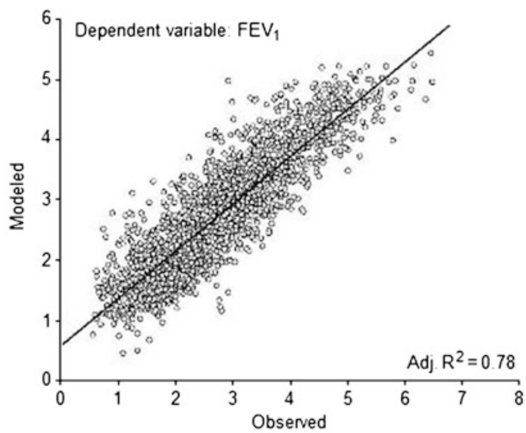

Fig. 3 FEV_1 observed *vs*. FEV_1 modeled (predicted)

4 Conclusions

The present study demonstrates that relative risk of bronchial obstruction is more than fourfold greater among non-smoking inhabitants of the vicinity of heavy traffic roads in a large city

(Warsaw), compared with that among inhabitants of rural areas, who are much less exposed to the influence of traffic-related air pollution. This conclusion stems from the analysis of key spirometric variables (FEV_1, FEV_1/FVC, and MEF_{50}) which are appreciably ($p < 0.001$) lower in city residents than in the rural group. This indicates an increased percentage of people who exhibit respiratory tract inflammatory reactions due to greater exposure to air pollution, which is in rapport with previous work in which multiple regression models also indicate decreasing values of FEV_1 and pseudo-Tiffeneau index among Warsaw residents (Badyda et al. 2013a, b). Lower values of these variables are linked with a shorter lifespan, particularly of city inhabitants and of those living on lower floors, which involves being in contact for prolonged periods of time stay with higher air pollution. A concentration of pollutants usually falls with increasing altitude (distance from emissions sources), with the exception of non-standard meteorological conditions.

The generalized regression model used in the present study for FEV_1 and the changeability of FEV_1 depend mostly on demographic factors, but also on such determinants as the place of residence, the vehicle traffic at the closest intersection of a busy street, and duration of residence. A decline of FEV_1 was increasing with increasing duration of residence in a particular place, which was partly related to the age of individuals, although the decline was stronger among city than in rural inhabitants.

To wrap it up, despite the complexity of the environmental factors influencing spirometric variables, the points to significant impact of road traffic and air pollutants on the respiratory health of inhabitants of big cities.

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Conflicts of Interest The authors declare no conflicts of interest in relation to this article.

References

Anderson HR, Favarato G, Atkinson RW (2011) Long-term exposure to outdoor air pollution and the prevalence of asthma: meta-analysis of multi-community prevalence studies. Air Qual Atmos Health 6:57–68

Badyda A, Dąbrowiecki P, Lubiński W, Czechowski PO, Majewski G (2013a) Exposure to traffic-related air pollutants as a risk of airway obstruction. Adv Exp Med Biol 755:35–45

Badyda A, Dąbrowiecki P, Lubiński W, Czechowski PO, Majewski G, Chcialowski A, Kraszewski A (2013b) Influence of traffic-related air pollutants on lung function: Warsaw study. Adv Exp Med Biol 788:229–235

Brugge D, Durant JL, Rioux C (2007) Near-highway pollutants in motor vehicle exhaust: a review of epidemiologic evidence of cardiac and pulmonary health risks. Environ Health 6:23

Dominici F, Peng RD, Bell ML, Pham L, McDermott A, Zeger SL, Samet JM (2006) Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. JAMA 295:1127–1134

EEA (2013) European Environment Agency: air quality in Europe – 2013 report. Publications Office of the European Union, Luxembourg. ISBN 978-92-9213-406-8; ISSN 1725-9177

Franck U, Odeh S, Wiedensohler A, Wehner B, Herbarth O (2011) The effect of particle size on cardiovascular disorders – the smaller the worse. Sci Total Environ 409:4217–4221

Gan WQ, Koehoorn M, Davies H, Demers PA, Tamburic L, Brauer M (2011) Long-term exposure to traffic-related air pollution and the risk of coronary heart disease hospitalization and mortality. Environ Health Perspect 119:501–507

Invernizzi G, Ruprecht A, Mazza R, de Marco C, Mocnik G, Sioutas C, Westerdahl D (2011) Measurement of black carbon concentration as an indicator of air quality benefits of traffic restriction policies within the ecopass zone in Milan, Italy. Atmos Environ 45:3522–3527

Jedrychowski WA, Galas A, Pac A, Flak E, Camman D, Raugh V, Perera F (2005) Prenatal ambient air exposure to polycyclic aromatic hydrocarbons and the occurrence of respiratory symptoms over the first year of life. Eur J Epidemiol 20:775–782

Juda Rezler K, Reizer M, Oudinet JP (2011) Determination and analysis of PM_{10} source apportionment during episodes of air pollution in Central Eastern European urban areas: the case of wintertime 2006. Atmos Environ 45:6557–6566

Lindgren A, Stroh E, Montnemery P, Nihlen U, Jakobsson K, Axmon A (2009) Traffic-related air pollution associated with prevalence of asthma and COPD/chronic bronchitis. A cross-sectional study in Southern Sweden. Int J Health Geogr 8:2

Majewski G, Czechowski PO, Badyda A, Kleniewska M, Brandyk A (2013) Emission of total gaseous mercury (TGM) at the regional background station in Granica-KPN (Mazovia Province, Poland), 2010–11. Annu Set Environ Prot 15:1302–1317. ISSN: 1506-218X

Michael S, Montag M, Dott W (2013) Pro-inflammatory effects and oxidative stress in lung macrophages and epithelial cells induced by ambient particulate matter. Environ Pollut 183:19–29

Miller MR, Hankinson J, Brusasco V, Burgos F, Casaburi R, Coates A, Crapo R, Enright P, van der Grinten CP, Gustafsson P, Jensen R, Johnson DC, MacIntyre N, McKay R, Navajas D, Pedersen OF, Pellegrino R, Viegi G, Wanger J (2005) Standardisation of spirometry. Eur Respir J 26:319–338

Mishra VK, Kumar P, Van Poppel M, Bleux N, Frijns E, Reggente M, Berghmans P, Int Panis L, Samson R (2012) Wintertime spatio-temporal variation of ultrafine particles in a Belgian city. Sci Total Environ 431:307–313

Nafstad P, Haheim LL, Wisloff T, Gram F, Oftedal B, Holme I, Hjermann I, Leren P (2004) Urban air pollution and mortality in a cohort of Norwegian men. Environ Health Perspect 112:610–615

Nemmar A, Hoet PH, Vanquickenborne B, Dinsdale D, Thomeer M, Hoylaerts F, Vanbilloen H, Mortelmans L, Nemery B (2002) Passage of inhaled particles into the blood circulation in humans. Circulation 105:411–414

Peacock JL, Anderson HR, Bremner SA, Marston L, Seemungal TA, Strachan DP, Wedzicha JA (2011) Outdoor air pollution and respiratory health in patients with COPD. Thorax 66:591–596

Pope CA, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K, Thurston GD (2002) Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287:1132–1141

Quanjer PH, Tammeling GJ, Cotes JE, Pedersen OF, Peslin R, Yernault JC (1993) Lung volumes and forced ventilatory flows. Report working party: standardization of lung function tests. European Community for Steel and Coal. Official statement of the European Respiratory Society. Eur Respir J 16:5–40

Rogula-Kozlowska W, Kozielska B, Klejnowski K (2013) Concentration, origin and health hazard from fine particle-bound path at three characteristic sites in southern Poland. Bull Environ Contam Toxicol 91:349–355

Rojas-Rueda D, de Nazelle A, Teixidó O, Nieuwenhuijsen MJ (2013) Health impact assessment of increasing public transport and cycling use in Barcelona: a morbidity and burden of disease approach. Prev Med 57:573–579

Sauer P, Svihlova D, Dvorak A, Lisa A, et al (2013) Visegrad countries: environmental problems and policies. Cenia, Prague, 272 pp. ISBN: 978-80-85087-16-1

Schikowski T, Sugiri D, Ranft U, Gehring U, Heinrich J, Wichmann EH, Kraemer U (2005) Long-term air pollution and living close to busy roads are associated with COPD in women. Respir Res 6:152–177

Tainio M, Juda Rezler K, Reizer M, Warchałowski A, Trapp W, Skotak K (2012) Future climate and adverse health effects caused by fine particulate matter air pollution: case study for Poland. Reg Environ Change 13:705–715

Zuurbier M, Hoek G, Oldenwening M, Lenters V, Meliefste K, van den Hazel P, Brunekreef B (2010) Commuters' exposure to particulate matter air pollution is affected by mode of transport, fuel type and route. Environ Health Perspect 118:783–789

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Different Patterns in Changes of Exhaled Breath Condensate pH and Exhaled Nitric Oxide After Ozone Exposure

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Abstract

Study objective was the evaluation of pH in exhaled breath condensate (EBC-pH) and nitric oxide in exhaled breath (FeNO) as biomarkers of ozone induced inflammation. We recently demonstrated that an ozone exposure of 240 ppb is sufficient to reduce lung function indices. We enrolled ten healthy subjects exposed in an intermittent exercise protocol to ozone concentrations of 240 ppb and 40 ppb (sham exposure). EBC-pH and FeNO were assessed before (pre), immediately post (post), and 16 h after exposure (16 h). Findings are that compared to baseline, EBC-pH was significantly higher immediately after sham and ozone exposures, but not 16 h later. There was a negative net change in EBC-pH after adjusting for effects after sham exposure (net-ΔpH_{post} -0.38 %, net-ΔpH_{16h} -0.23 %). Concerning FeNO, we observed no changes of values after sham exposure compared to baseline, but measured a significant lower net response at the end of exposure (net-$\Delta FeNO_{post}$ -17.5 %) which was transient within 16 h (net-$\Delta FeNO_{16h}$ -9.4 %). We conclude that exercise known to enhance EBC-pH may compensate for EBC acidification associated with inflammation resulting in diminished change of this biomarker. Ozone imposes an oxidative burden and reactions between reactive oxygen species and NO might be an explanation for reduced FeNO levels.

Keywords

Acid-base balance • Exercise • Exhaled breath • Inflammation • Nitric oxide • Ozone

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1 Introduction

Ozone, an important environmental and occupational pollutant, is a strong oxidant, triggers toxic effects, and acute exposure to ozone can result in airway inflammation as well as decrements in lung function (Lippmann 1989). However, no specific correlations between ozone-induced acute decrements in FEV_1 or FVC with measures of airway inflammation could be revealed in healthy subjects (Blomberg et al. 1999; Balmes et al. 1996). The magnitude of inflammatory responses and ozone-induced lung function impairment appear to present individual intrinsic characteristics. Recent reports point to underlying differences in sensory nervous mechanisms (Hoffmeyer et al. 2013a). At the target site, ozone makes first contact with the airway lining fluid (ALF) (Pryor et al. 1995), where chemical events as well as reaction products promote toxic effects and determine biological responses (Kafoury et al. 1999). Ozone imposes an oxidative burden and is capable of directly damaging epithelial cells by its oxidizing properties resulting in disruption of epithelial barrier. Stimulation of epithelial cells and the recruitment of inflammatory cells can impose lung injury due to release of reactive oxygen species, proteolytic enzymes, and inflammatory mediators. The magnitude of inflammation and time at which the response peaks varies with species under evaluation, exposure conditions (ozone concentration, duration, exercise) and effect parameter analyzed. A comprehensive review is given by Bhalla (1999).

More or less invasive techniques are applied for characterization of inflammation based on cellular or biochemical markers of inflammatory responses. Inflammation in the context of several diseases is linked to acidification of the airways (Kostikas et al. 2002). Information about the ALF composition regarding inflammation, including pH, can be safely provided by exhaled breath condensate (EBC) (Hoffmeyer et al. 2009). The EBC-pH is a robust and reproducible EBC parameter especially when considering influence of CO_2 in analytic (Kullmann et al. 2007).

Another widely used non-invasive biomarker is FeNO. FeNO reflects the activity of NO synthase induced by various inflammatory responses, e.g., allergic diseases. Apart from changes of pH and FeNO due to inflammatory processes, measured biomarker levels might be modulated by composition of inhaled air. In this respect, smoking is a known confounder for detected levels of both EBC-pH (Koczulla et al. 2010) as well as FeNO (Kharitonov et al. 1995). Therefore, subjects in our study were healthy non-smoker. A previous human challenge study assessed acute effects of low dose sulphur dioxide exposure on the airways using non-invasive methods and suggested modulation of EBC-pH by exercise (Raulf-Heimsoth et al. 2010).

The objective of this study was to evaluate the potential of EBC-pH and FeNO as biochemical markers of ozone exposure. These biomarkers were analyzed in changes over time and association to lung function responses. Data were collected within the frame of a recently published challenge study on the role of neural sensitivity in determining physiological responses and susceptibility upon ozone exposure (Hoffmeyer et al. 2013a).

2 Methods

The study was confirmed by the local ethics committee of the Ruhr University, all subjects gave written consent, and received financial compensation for participation.

2.1 Subjects

In 10 out of the 16 participants of our recently published ozone study (Hoffmeyer et al. 2013a), we also evaluated EBC-pH and FeNO. All subjects were healthy non-smokers. Smoking habits were assessed by face-to-face interview and validated by quantification of the nicotine metabolite cotinine in urine. For this additional preliminary evaluation of the biomarkers, the ten subjects were selected before undergoing chamber exposures according to capsaicin sensibility (C2 threshold). The study characteristics including functional results (see below) are summarized in Table 1.

Table 1 Characteristics of the subjects studied

C2	Gender	Age (years)	Height (cm)	Weight (kg)	BSA (m^2)	FVC (%pred)	FEV_1 (%pred)	FEV_1/FVC (%pred)	EL (Watt)	MV/BSA (L/m^2)	Ozone R/NR
4	F	25	167	67	1.76	100.1	99.4	99.3	70	14.8	R
5	M	21	190	70	1.92	112.5	111.4	99.6	75	14.6	NR
5	F	22	182	82	2.04	127.2	118.8	95.5	60	13.8	R
5	F	28	174	69	1.83	99.9	103.1	104.6	70	14.9	R
6	F	25	170	73	1.86	83.6	81.4	97.3	50	14.5	R
7	M	29	173	71	1.85	111.6	113.5	100.4	75	15.2	NR
7	M	27	182	104	2.29	108.7	107.1	97.0	75	14.8	R
8	F	25	165	74	1.84	123.0	120.4	99.5	65	14.7	NR
11	M	27	174	79	1.95	116.1	115.9	101.5	50	14.3	NR
12	M	27	178	77	1.95	106.0	107.6	103.0	75	14.4	NR

C2 capsaicin cough threshold, *F* female, *M* male, *EL* exercise load, *BSA* body surface area, *R* responsive, *NR* non-responsive, *MV* minute ventilation

2.2 Lung Function, Methacholine, and Capsaicin Challenge Test

Details on the methods used for functional characterization of subjects were previously reported (Hoffmeyer et al. 2013a). Briefly, a constant-volume body plethysmograph (MasterScreen®Body, Jaeger GmbH, Germany) was used to determine specific airway resistance (sRaw) and spirometry according the recommendations of the American Thoracic Society (ATS 1995).

We used methacholine dissolved in phosphate-buffered saline (3.3 mg methacholine/mL; Provokit, Lindopharm GmbH, Germany) as a provocative substance and applied the four-step-one-concentration reservoir test method described by Baur et al. (1998). A PD_{20} could not be calculated because no subject reached a drop of at least 20 % within the four concentration steps. General methodological recommendations were followed for capsaicin challenge (Morice et al. 2007) and a single breath dose-response method was applied (Hoffmeyer et al. 2013b). Test concentrations inducing respectively two (C2) or more coughs were determined.

2.3 Exposure

Details of the exposure chamber have been described elsewhere (Monsé et al. 2012). Subjects were exposed to either a constant ozone concentration of 240 ppb or to 40 ppb for 4 h, respectively, in a randomly blind cross-over design as previously reported (Hoffmeyer et al. 2013a). At 40 ppb, ozone brought about an odor perception, but a negligible irritative response (McDonnell et al. 2010). Therefore, this concentration was chosen for sham exposure instead of filtered air. Ozone was generated with the help of an UV-C-lamp (wavelength 195 nm) and was diluted with the air flow of the air conditioning of the exposure chamber. Target concentrations were monitored every 30 s by an UV-detector (ML 9810B; MS4 GmbH, Germany). The exposure protocols included intermittent exercise intervals of 20 min on a cycle ergometer (bike). The activity level selected to produce a minute ventilation of 15 L/min/m^2 body surface area (BSA), corresponding to moderate exercise, was determined during a training session. A decrease of more than 5 % in FEV_1 compared with the decrease after sham exposure was used as criterion to consider a subject as ozone responder.

2.4 Biomarkers

The biomarkers EBC-pH and FeNO were assessed before ($_{pre}$), immediately post ($_{post}$), and 16 h after exposure ($_{16h}$).

2.4.1 EBC-pH

EBC was collected according to general methodological recommendations (Horváth et al. 2005) with the commercially available temperature-controlled device Turbo DECCS (Medivac, Italy). Briefly, subjects used a nose clip during tidal breathing through a mouthpiece. They were instructed to swallow excess of saliva after its coming off the mouthpiece. The Turbo DECCS device directly condensed and collected the EBC in disposable tubes. The collection time was exactly 10 min at a maintained temperature of −5 °C.

A blood gas analyzer (ABL800, Radiometer GmbH, Germany) was used to determine the pH and the partial pressure of carbon dioxide. For the quality assessment, calibration solutions pH5, pH6, pH7, and pH8 were analyzed. All EBC-pH measurements were done in repeat determination revealing a bias of 0.0009. The pH was analyzed after gas standardization of the sample with argon for 10 min yielding a pCO_2 below 2.5 mmHg.

2.4.2 FeNO Measurement

Fractional exhaled nitric oxide was measured using a chemiluminescence analyzer (NIOX system; Aerocrine, Sweden) according to published European Respiratory Society (ERS) and American Thoracic Society (ATS) guidelines (2005). Exhaled FeNO measurements were always performed before spirometry.

2.5 Statistics

Data were assessed before and after each exposure (sham, 240 ppb). pH and FeNO were calculated as the percent change after exposure compared to start of exposure [(post-pre/pre) *100; (16 h-pre/pre)*100] and reported as $\Delta pH_{(post,\ 16h)}$ and $\Delta FeNO_{(post,\ 16h)}$, respectively. In order to determine net responses, the responses immediately and 16 h after 240 ppb were corrected by subtraction for those after sham exposure and respective values were reported as net-$\Delta pH_{(post,\ 16h)}$ and net-$\Delta FeNO_{(post,\ 16h)}$. Differences in lung function and biomarkers after exposure to 240 ppb were compared with those after sham exposure using the Wilcoxon matched-pairs signed-rank test or paired *t*-test as appropriate and a significance of <0.05. Comparison of ozone responder and non-responder was based on Mann Whitney U test or unpaired *t*-test as appropriate and a significance of <0.05. The D'Agostino and Person omnibus normality test were used to assess value distribution. Data are expressed as mean with range or median with interquartile range (25th; 75th percentile). Results for capsaicin cough thresholds (C2) were Log_2 transformed for analysis. Data were analyzed and visualized by using GraphPad Prism version 5.01 for Windows (GraphPad Software, San Diego, California, USA).

3 Results

3.1 Biomarker and Ozone Challenge

Initial level of each biomarker, pH and FeNO, did not differ before challenge with 40 ppb (sham) and 240 ppb ozone. In detail, EBC-pH was 7.467 ± 0.028 and 7.469 ± 0.049, respectively; p = 0.903. FeNO value was 12.8 ± 3.6 ppb and 12.7 ± 3.7 ppb, respectively; p = 0.879. After exposure, there were significant changes in the biomarkers. EBC-pH determined immediately after ozone exposure was increased to 7.528 ± 0.053 and dropped 16 h after end of ozone challenge to 7.448 ± 0.041. We observed a similar pattern after sham exposure with pH values of 7.566 ± 0.085 and 7.482 ± 0.051, respectively (Fig. 1a, b). The increase in EBC-pH (ΔpH_{post}) measured immediately after exposure was higher in case of shame exposure (sham 1.10 (0.61; 1.78)% vs. ozone 0.75 (0.55; 1.02)%; p = 0.16). The sham-adjusted ozone effect on EBC-pH (net-ΔpH_{post}) was a 0.38 % decrease immediately after exposure. Sixteen hours after challenge, changes from baseline (ΔpH_{16h}) were positive after sham and negative after ozone exposure, respectively (sham 0.07 (−0.23; 0.49)% vs. ozone −0.21 (−0.44;

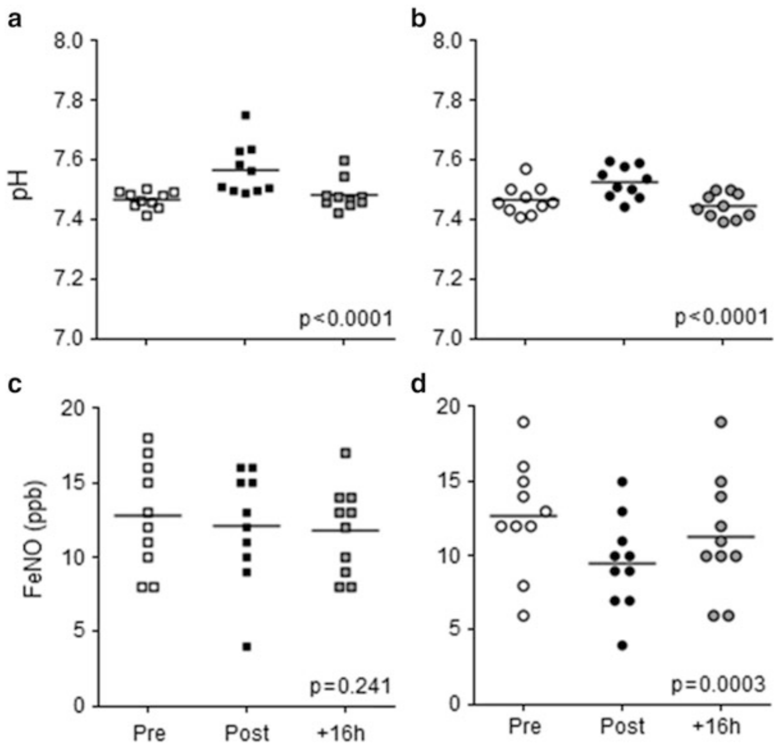

Fig. 1 Changes of pH in exhaled breath condensate (EBC-pH) and nitric oxide in exhaled breath (FeNO) after sham exposure (*Panels A & C*) and ozone (240 ppb; *Panels B & D*). Biomarkers were assessed before (pre), immediately after (post) and 16 h after exposure (+16 h)

−0.03)%; p = 0.049). Thus, the net-ΔpH_{16h} (−0.23 %) was significantly different from zero (p = 0.049).

FeNO was transiently reduced post-ozone challenge (9.5 ± 3.1 ppb) reaching nearly baseline values 16 h after challenge (11.3 ± 4.0 ppb). No significant changes of FeNO occurred after sham exposure (p = 0.241). Respective responses of the biomarkers after sham and ozone exposure at a concentration of 240 ppb are shown in Fig. 1c, d. Changes in FeNO levels ($\Delta FeNO_{post}$) were significantly greater immediately after ozone exposure compared to shame exposure [−23.1 (−33.9; −14.0)% vs. 0.0 (−12.2; 3.1)%, respectively; p = 0.02]. Thus, the net-$\Delta FeNO_{post}$ (−17.5 %) was significantly different from zero (p = 0.02). After 16 h ($\Delta FeNO_{16h}$), changes from baseline were no longer different for ozone and shame exposure [−14.0 (−25.9; 0.0)% vs. −4.6 (−20.8; 2.1)%, respectively; p = 0.82]. The adjusted ozone effect on FeNO (net-ΔFeNO) was a decrease of 9.4 % and not significant different from zero (0.82).

3.2 Biomarker and Ozone Responsiveness

For further investigation, subjects were categorized according to individual FEV_1 changes using a decrement >5 % as cut-off. Referring to this stratification, 5 out of the 10 subjects could be identified as ozone responsive. Changes in pH immediately after (ΔpH_{post}) and 16 h after (ΔpH_{16h}) exposure stratified for ozone responsiveness are depicted in Fig. 2a, b, respectively. Immediately after exposure, ΔpH_{post} changes were positive for all exposure conditions and independent of ozone responsiveness. In the ozone non-responsive subjects, changes for ΔpH_{post} were highest after sham exposure compared to ozone exposure (p = 0.06) as well as compared to ozone-responsive subjects (p = 0.03). After 16 h, ΔpH tended to be highest for non-responders across sham conditions, again. In addition, non-responders consistently demonstrated a negative ΔpH_{16h} which was significantly different

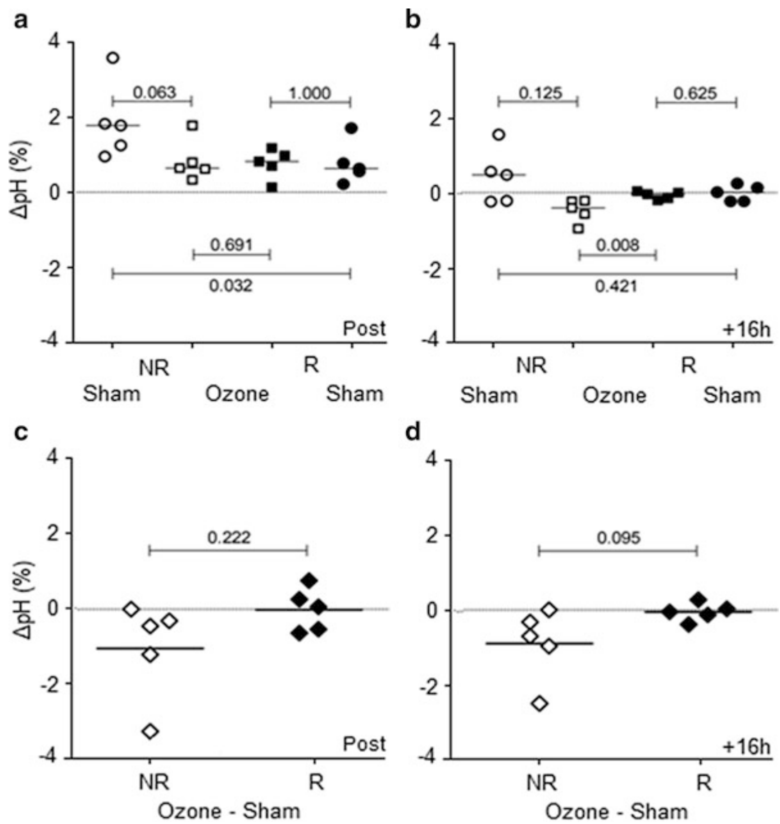

Fig. 2 Changes in pH immediately after (*Panels A & C*; post) and 16 h after (*Panels B & D*; +16 h) exposure stratified for ozone responsiveness (*NR* non-responder, *R* responder). Percent change after exposure compared with the start of exposure for sham (**a**) and ozone (**b**), respectively. Net-response adjusted by subtraction for those after sham exposure immediately after (**c**, post) and 16 h after exposure (**d**, +16 h)

from responders ($p = 0.01$). The overall net responses for EBC-pH after ozone challenge and adjusted for sham condition are shown in Fig. 2c (net-ΔpH_{post}) and Fig. 2d (net-ΔpH_{16h}).

The estimated adjusted ozone effects on EBC-pH were a slight decrement at the end of exposure and significant lower values after 16 h. These net changes mainly resulted from changes in non-responders. Sixteen hours after exposure, net responses for ozone responders and non-responders were visibly different (Fig. 2d, $p = 0.10$). We did not observe significant differences in the pattern of FeNO change when subjects were analyzed with respect to their ozone responsiveness (data not shown).

4 Discussion

Recently, we could substantiate a correlation between sensitivity to capsaicin and magnitude of changes in lung function responses across ozone exposure at 240 ppb (Hoffmeyer et al. 2013a). Within the frame of that study, non-invasive diagnostic of biomarkers was performed in a subgroup of ten participants with known capsaicin responsiveness. As hypothesized, these subjects demonstrated corresponding differences in lung function impairment after ozone exposure with 5 out of the 10 subjects being ozone responsive as based on their magnitude of FEV_1 (>5 %) decrement (Balmes et al. 1996). Regarding the results on FeNO and EBC-pH discussed below, it is to stress that the challenge protocol provided equal ozone inhalation doses. Moreover, results were derived from healthy non-smoking subjects in order to exclude known confounding by smoking on FeNO (Kharitonov et al. 1995) or EBC-pH (Koczulla et al. 2010). Finally, sham and ozone exposure were carried out at the same time of day to account for possible circadian variations of biomarkers under study (Antosova et al. 2009). Notably, we could demonstrate equal baseline levels of FeNO as well as EBC-pH before the two challenge conditions (sham and ozone exposure at 240 ppb).

Determination of pH was performed in accordance to published guidelines (Horváth et al. 2005) and effectiveness of deaeration with argon was confirmed by pCO_2 assessment. EBC-pH and pCO_2 were measured with a reliable blood gas analyzer demonstrating excellent reproducibility. Thus, even though pH changes across challenge were rather small, our results are reasonable. We observed a significantly EBC-pH increase immediately after the exposure to ozone and also after sham exposure. At first glance, this is surprising as inflammation in the context of several diseases is linked to EBC-pH decrease or acidification of the airways (Kostikas et al. 2002). However, exercise has been shown to result in an increase of EBC-pH (Riediker and Danuser 2007) and was suggested to oppose inflammation-induced acidification (Raulf-Heimsoth et al. 2010). Exercise is included in challenge exposure studies as it is part of many working conditions and is a factor that enables an increase of administered effective dose. The magnitude of EBC-pH increase after sham challenge compared to the baseline level in our study is in agreement with Riediker and Danuser (2007), who noted a pH difference of 0.07. Moreover, the magnitude of change after ozone (240 ppb) was also in a range previously reported after exposure to hyperbaric hyperoxia (Taraldsøy et al. 2007) or sulfur dioxide (Raulf-Heimsoth et al. 2010). Ozone can deposit on ALF, mediating its action by generation of reactive oxygen species and ozonation products, followed by induction of inflammatory mediators (Bhalla 1999; Pryor et al. 1995). Alterations of EBC-pH, e.g., acid to bases ratio, can also result of mere physicochemical mechanisms between ozone and ALF constituents. This early effects might contribute to differences, e.g., attenuation of exercise induced increase of EBC-pH observed in our study under ozone conditions. After adjusting for sham exposure, and thereby likewise exercise, net-ΔpH_{post} tended to be negative, although this observation was not statistically significant.

The pattern for pH changes after sham and ozone exposures was obviously different at the two time points chosen (immediately after and 16 h after exposure). The time points chosen were in accordance to previous reports investigating biomarkers of inflammation or oxidative stress after ozone exposure (Corradi et al. 2002). Immediately after exposure, the overall negative net response in pH was based on different magnitudes of increase in pH. Sixteen hours later, we revealed an acidification which is in line with a pathophysiologic model of time-dependent increase and acceleration of inflammation (Kafoury et al. 1999). Accordingly, recent reports indicate a prolonged rise in measurable levels of biomarkers in EBC, sputum, or BAL after ozone exposure (Bhalla 1999). There is evidence that inflammatory markers would appear after the onset of lung function impairments, which do not correlate with the measures of inflammation (Blomberg et al. 1999; Balmes et al. 1996). For investigations of relationships between acute ozone exposure and physiological responses, subjects had been classified according their lung function response (Hoffmeyer et al. 2013a; Balmes et al. 1996). Referring to this stratification, net changes in pH across ozone exposure were less apparent in ozone responders. In our opinion, this resulted from a visible EBC-pH decrease already after sham exposure. A similar result with respect to malondialdehyde (MDA), a marker of oxidative stress, was recently reported by Vagaggini et al. (2010). Even though the levels of MDA were comparable after ozone exposure, they observed significant differences between sham and ozone exposure (300 ppb for 2 h, while exercising on a cycloergometer) for non-responders, but not for responders. In contrast to the early reflex triggered, lung function decrements defining ozone responders and non-responders, changes in pH might be modulated by exercise, physicochemical mechanisms, inflammatory responses, and last but not least by the activation of anti-inflammatory means (Bartoli et al. 2013).

Interdependence of different processes might be an explanation for observed FeNO kinetics. In this respect, NO measured in exhaled breath integrates the processes of its production and scavenge. Alterations of FeNO due to exercise were inconsistently reported. In our study in case of sham condition, FeNO was not altered by the challenge protocol. Notably, we could demonstrate a significant reduction in FeNO immediately after ozone exposure which was transient and recovered within 16 h. This might be explained by chemical reactions between reactive oxygen species (ROS) and NO. Reduction of FeNO was also reported after hyperbaric oxygen therapy known to go along with an increased production of ROS (Taraldsøy et al. 2007; Freeman and Crapo 1981). Moreover, cigarette smoke contains high amounts of ROS, and FeNO is reduced in smokers compared with non-smokers (Kharitonov et al. 1995). Nowadays, different FeNO reference values are recommended according to smoking habits (Malinovschi et al. 2012). No major effects of FeNO after exposure to 200 ppb ozone for 2 h, and adjusted for changes after air filtering, were reported (Olin et al. 2001). However, in that study, FeNO was measured at a flow rate of 150 ml/s resulting in median concentrations of 7–8 ppb. In addition, the authors described a tendency towards decreased FeNO directly after ozone exposure. No differences in kinetics for total NO metabolites after ozone challenge (350 ppb) were reported by Alfaro et al. (2007) when subjects were stratified according to ozone-induced lung function decrements.

In summary, a net decrease of EBC-pH we observed in the present study resembles an acidification of the ALF due to acute ozone exposure. Interestingly, ozone responsive subjects demonstrated no differences in EBC-pH (ΔpH_{post}, ΔpH_{16h}) when comparing sham and ozone challenge conditions. FeNO was transiently reduced by acute exposure, which was independent of ozone-responsiveness. Ozone imposes an oxidative burden and reactions between reactive oxygen species and NO might be an explanation for the reduced FeNO levels.

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Conflicts of Interest The authors declare no competing interests that might be perceived to influence the results and discussion reported in this study.

References

Alfaro MF, Walby WF, Adams WC, Schelegle ES (2007) Breath condensate levels of 8-isoprostane and leukotriene B4 after ozone inhalation are greater in sensitive versus nonsensitive subjects. Exp Lung Res 33:115–133

American Thoracic Society (1995) Standardization of spirometry, 1994 update. Am J Respir Crit Care Med 152:1107–1136

American Thoracic Society, European Respiratory Society (2005) ATS/ERS recommendations for standardized procedures for the online and offline measurement of exhaled lower respiratory nitric oxide and nasal nitric oxide. Am J Respir Crit Care Med 171:912–930

Antosova M, Bencova A, Psenkova A, Herle D, Rozborilova E (2009) Exhaled nitric oxide – circadian variations in healthy subjects. Eur J Med Res 14:6–8

Balmes JR, Chen LL, Scannell C, Tager I, Christian D, Hearne PQ, Kelly T, Aris RM (1996) Ozone-induced decrements in FEV_1 and FVC do not correlate with measures of inflammation. Am J Respir Crit Care Med 15:904–909

Bartoli ML, Vagaggini B, Malagrinò L, Bacci E, Cianchetti S, Dente FL, Novelli F, Costa F, Paggiaro P (2013) Baseline airway inflammation may be a determinant of the response to ozone exposure in asthmatic patients. Inhal Toxicol 25:127–133

Baur X, Huber H, Degens PO, Allmers H, Ammon J (1998) Relation between occupational asthma case history, bronchial methacholine challenge, and specific challenge test in patients with suspected occupational asthma. Am J Ind Med 33:114–122

Bhalla DK (1999) Ozone-induced lung inflammation and mucosal barrier disruption: toxicology, mechanisms, and implications. J Toxicol Environ Health Part B Crit Rev 2:31–86

Blomberg A, Mudway IS, Nordenhäll C, Hedenström H, Kelly FJ, Frew AJ, Holgate ST, Sandström T (1999) Ozone-induced lung function decrements do not correlate with early airway inflammatory or antioxidant responses. Eur Respir J 13:1418–1428

Corradi M, Alinovi R, Goldoni M, Vettori M, Folesani G, Mozzoni P, Cavazzini S, Bergamaschi E, Rossi L, Mutti A (2002) Biomarkers of oxidative stress after controlled human exposure to ozone. Toxicol Lett 134:219–225

Freeman BA, Crapo JD (1981) Hyperoxia increases oxygen radical production in rat lungs and lung mitochondria. J Biol Chem 256:10986–10992

Hoffmeyer F, Raulf-Heimsoth M, Brüning T (2009) Exhaled breath condensate and airway inflammation. Curr Opin Allergy Clin Immunol 9:16–22

Hoffmeyer F, Sucker K, Monsé C, Berresheim H, Rosenkranz N, Jettkant B, Beine A, Brüning T, Bünger J (2013a) Relationship of pulmonary function response to ozone exposure and capsaicin cough sensitivity. Inhal Toxicol 25:569–576

Hoffmeyer F, Sucker K, Rosenkranz N, Berresheim H, Monse C, Brüning T, Bünger J (2013b) Reproducibility of sensitivity to capsaicin assessed by single breath inhalation methodology. Adv Exp Med Biol 755:71–78

Horváth I, Hunt J, Barnes PJ, Alving K, Antczak A, Baraldi E, Becher G, van Beurden WJ, Corradi M, Dekhuijzen R, Dweik RA, Dwyer T, Effros R, Erzurum S, Gaston B, Gessner C, Greening A, Ho LP, Hohlfeld J, Jöbsis Q, Laskowski D, Loukides S, Marlin D, Montuschi P, Olin AC, Redington AE, Reinhold P, van Rensen EL, Rubinstein I, Silkoff P, Toren K, Vass G, Vogelberg C, Wirtz H, ATS/ERS Task Force on Exhaled Breath Condensate (2005) Exhaled breath condensate: methodological recommendations and unresolved questions. Eur Respir J 26:523–548

Kafoury RM, Pryor WA, Squadrito GL, Salgo MG, Zou X, Friedman M (1999) Induction of inflammatory mediators in human airway epithelial cells by lipid ozonation products. Am J Respir Crit Care Med 160:1934–1942

Kharitonov SA, Robbins RA, Yates D, Keatings V, Barnes PJ (1995) Acute and chronic effects of cigarette smoking on exhaled nitric oxide. Am J Respir Crit Care Med 152:609–612

Koczulla AR, Noeske S, Herr C, Jörres RA, Römmelt H, Vogelmeier C, Bals R (2010) Acute and chronic effects of smoking on inflammation markers in exhaled breath condensate in current smokers. Respiration 79:61–67

Kostikas K, Papatheodorou G, Ganas K, Psathakis K, Panagou P, Loukides S (2002) pH in expired breath condensate of patients with inflammatory airway diseases. Am J Respir Crit Care Med 165:1364–1370

Kullmann T, Barta I, Lázár Z, Szili B, Barát E, Valyon M, Kollai M, Horváth I (2007) Exhaled breath condensate pH standardised for CO2 partial pressure. Eur Respir J 29:496–501

Lippmann M (1989) Health effects of ozone. A critical review. J Air Pollut Control Assoc 39:672–695

Malinovschi A, Backer V, Harving H, Porsbjerg C (2012) The value of exhaled nitric oxide to identify asthma in smoking patients with asthma-like symptoms. Respir Med 106:794–801

McDonnell WF, Stewart PW, Smith MV (2010) Prediction of ozone-induced lung function responses in humans. Inhal Toxicol 22:160–168

Monsé C, Sucker K, van Thriel C, Broding HC, Jettkant B, Berresheim H, Wiethege T, Käfferlein H, Merget R, Bünger J, Brüning T (2012) Considerations for the design and technical setup of a human whole-body exposure chamber. Inhal Toxicol 24:99–108

Morice AH, Fontana GA, Belvisi MG, Birring SS, Chung KF, Dicpinigaitis PV, Kastelik JA, McGarvey LP, Smith JA, Tatar M, Widdicombe J, European Respiratory Society (ERS) (2007) ERS guidelines on the assessment of cough. Eur Respir J 29:1256–1276

Olin AC, Stenfors N, Torén K, Blomberg A, Helleday R, Ledin MC, Ljungkvist G, Ekman A, Sandström T (2001) Nitric oxide (NO) in exhaled air after experimental ozone exposure in humans. Respir Med 95:491–495

Pryor WA, Squadrito GL, Friedman M (1995) The cascade mechanism to explain ozone toxicity: the role of lipid ozonation products. Free Radic Biol Med 19:935–941

Raulf-Heimsoth M, Hoffmeyer F, van Thriel C, Blaszkewicz M, Bünger J, Brüning T (2010) Assessment of low dose effects of acute sulphur dioxide exposure on the airways using non-invasive methods. Arch Toxicol 84:121–127

Riediker M, Danuser B (2007) Exhaled breath condensate pH is increased after moderate exercise. J Aerosol Med 20:13–18

Taraldsøy T, Bolann BJ, Thorsen E (2007) Reduced nitric oxide concentration in exhaled gas after exposure to hyperbaric hyperoxia. Undersea Hyperb Med 34:321–327

Vagaggini B, Bartoli ML, Cianchetti S, Costa F, Bacci E, Dente FL, Di Franco A, Malagrinò L, Paggiaro P (2010) Increase in markers of airway inflammation after ozone exposure can be observed also in stable treated asthmatics with minimal functional response to ozone. Respir Res 11:5

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Serial Measurements of Exhaled Nitric Oxide at Work and at Home: A New Tool for the Diagnosis of Occupational Asthma

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Abstract

Whereas serial measurements of lung function at work and at home are a well-known diagnostic tool for the diagnosis of occupational asthma (OA), little is known about the serial measurements of non-invasive parameters such as exhaled nitric oxide (eNO). A 51-year-old baker with variable shortness of breath without relation to work was examined for suspected OA. Skin prick test showed weak sensitizations to wheat and rye flour (without sensitizations to environmental allergens) that were corroborated by *in vitro* testing (CAP class 3). Baseline FEV_1 of 58 % predicted and a decrease of forced expiratory volume in 1 s (FEV_1) after placebo (sugar powder) of 17 % did not allow inhalational challenge testing. The patient performed daily measurements of FEV_1 and eNO for about a month during a holiday at home and at work. Whereas symptoms and FEV_1 did not show differences between holidays and work periods, eNO showed a clear increase from below 10 ppb to a maximum of 75 ppb. A diagnosis of baker's asthma was made, and the patient quit his job immediately after medical advice. A year afterwards, the patient was still taking asthma medication, but his symptoms had improved, FEV_1 had increased to 73 %predicted, and eNO was 25 ppb. We conclude that serial measurements of eNO at home and at work may be a useful tool for the diagnosis of OA.

Keywords

Baker's asthma • Diagnosis • Exhaled nitric oxide • Occupational asthma

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1 Introduction

One of the main criteria to distinguish occupational from non-occupational asthma is the demonstration of work-relatedness of airways obstruction (European Academy of Allergology and Clinical Immunology 1992). This criterion is of special importance if sensitization is not clearly demonstrated, inhalational challenge in the laboratory cannot be performed due to severe airways obstruction, or if complex workplace conditions cannot be simulated in the laboratory. In general, peak expiratory flow (PEF) or FEV_1 are monitored during work and periods off work. This method has disadvantages as the maneuvers are effort-dependent (Moscato et al. 1995). Depending on the purpose of testing, patients may even falsify the measurements (Malo et al. 1995). The use of further non-invasive objective tools to diagnose occupational asthma (OA) has been reviewed recently (Quirce et al. 2010). Induced sputum including eosinophil counts, serial measurements of bronchial hyperresponsiveness, exhaled nitric oxide (eNO), and the examination of exhaled breath condensate (EBC) are the most frequent outcome measures. Whereas there are a number of studies that describe the usefulness of these tools before and after challenge tests in the laboratory, only limited data is available about serial measurements during work periods and at home.

2 Case History

The 51-old male smoker was working as a baker since his adolescence, since 3 years he was dough maker in a large bakery. He described his job as dusty, but measurements of airborne dust concentrations at his workplace were not available. He complained of chronic rhinitis since age 17 after a cranial trauma. He had an obstructive sleep apnea syndrome since a few years and was treated with continuous positive airway pressure (CPAP) during sleep. About a year after starting his job as a dough maker he noticed chronic cough and phlegm production, as well as dyspnoea on exertion. He denied work-related symptoms, but stated that dusty environments were generally poorly tolerated. Symptoms were slightly better on weekends and holidays. He was admitted for a medical opinion after his pneumologist had measured elevated wheat and rye flour specific IgE-antibodies in the serum of CAP class 2. Skin prick tests with bakery allergens were reported completely negative.

When the patient was diagnosed in our institute, he was on medication with long- and short-acting beta-agonists and topical steroids in a stable phase, but medication had been withheld on the day of the examination. Physical examination showed wheezing over both lungs, but was otherwise normal. Lung function showed mild airway obstruction with FEV_1 variations between 58 and 65 % predicted without medication on this day. A bicycle exercise with 50 Watts for 6 min showed an increase of oxygen partial pressure from 91 to 98 mmHg. Skin prick testing (SPT) with a battery of environmental and occupational allergens (various manufacturers) was negative, with the exception of small wheal and flare reactions with wheat and rye flour extract (4 and 3 mm wheal; Bencard Allergie GmbH, Munich, Germany). Total IgE was 96 kU/L (Phadezym; ThermoFisher Scientific, Freiburg, Germany). Increased specific IgE was measured to wheat and rye flour (CAP class 3; ImmunoCAP, ThermoFisher Scientific), but not to various baking enzymes.

A multiple-step workplace simulation in an inhalation chamber with commercial sugar powder (Diamant, Pfeifer & Langen, Cologne, Germany) was terminated after the second step (after 25 min up to a concentration of 50 mg/m^3) due to airway symptoms and a decrease of FEV_1 of 17 % from baseline. An inhalational challenge with flour in the laboratory was not considered due to severe airways obstruction and the placebo reaction. Instead, serial measurements of FEV_1 and eNO were initiated.

3 Serial Measurements of FEV_1 and eNO

The patient performed spirometry (SpiroPro, CareFusion, Würzburg, Germany) and eNO measurements (NioxMino, Aerocrine, Solna, Sweden) once daily during a 2-week holiday

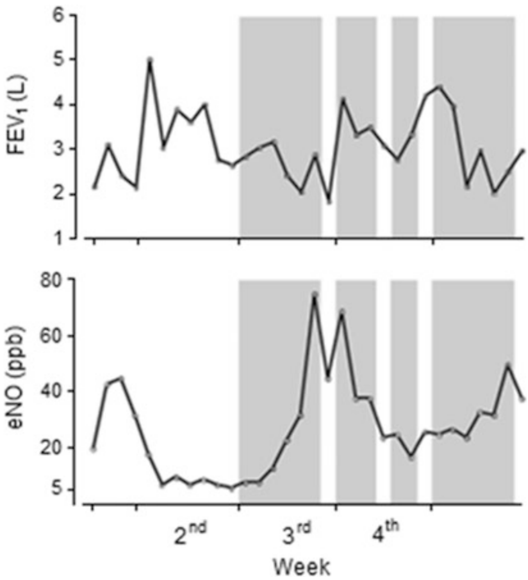

Fig. 1 **Time course of forced expiratory volume** in 1 s (FEV_1; *upper part*; best of 4 FEV_1 measurements) and exhaled nitric oxide (eNO; *lower part*) during a holiday (*open areas*) and at work (*shaded areas*), both measured once daily. Medication was kept constant during the whole assessment

and a 3-week work period. Measurements were done around 1 p.m., i.e., after work in the working period. All data were of excellent quality and recorded electronically. Spirometry was obtained from four maneuvers by choosing the highest FEV_1 for final analysis. Medication was constant during the whole period. Whereas FEV_1 showed some variation, but no clear decrease during work (Fig. 1a), eNO decreased to normal soon after the start of the holidays and showed a clear increase after resuming work (Fig. 1b). Due to these results the patient was advised to quit his job as a baker, to stop smoking, and to continue medication. It was recommended to accept his asthma as an occupational disease (baker's asthma).

4 Follow-Up a Year After Complete Exposure Cessation

The patient was seen again about a year after the initial examination. He had quit his job as a baker about a month after the first examination and worked as a security guard without any exposure to hazardous substances. He reported amelioration of his dyspnea, but continued to take the same asthma medication. He still smoked ten cigarettes per day. Lung function was better than at diagnosis with a FEV_1 of 73 %predicted (post-bronchodilator FEV_1 80 %predicted). Spiroergometry demonstrated minor pulmonary limitation with a maximal oxygen uptake of 58 %predicted, a maximal ventilation of 80 %predicted and a slightly increased ventilatory equivalent (ratio of ventilation to oxygen intake; V_E/V_{O_2}) of 39 at the end of the exercise. Whereas sensitizations to flours as assessed by SPT were more pronounced (wheal reactions to wheat and rye flour 5 and 9 mm, respectively), IgE antibody concentrations to flours were lower (CAP class 2 with both allergens) and total IgE had fallen to 58 kU/L.

5 Discussion

This baker did not report clear work-related asthma symptoms and was a smoker for many years. Thus, chronic obstructive pulmonary disease (COPD) was a reasonable alternative diagnosis to OA. In a previous study we demonstrated a high predictive value of high degree sensitization to flours for a positive inhalational challenge (van Kampen et al. 2008). Thus COPD and OA were both probable diagnoses. As cessation of exposure is superior to exposure reduction (Vandenplas et al. 2011), we decided to include additional testing in view of the important social consequences for this patient. As inhalational challenge testing in the laboratory was not feasible due to severe airway obstruction and an asthmatic reaction after placebo, we initiated serial measurements of FEV_1 with an electronic mini-spirometer and serial measurements of eNO, i.e., daily measurements during 2 weeks of holidays and 3 weeks of work.

Whereas a deterioration of FEV_1 during the work period could not be documented, the increase in eNO suggested OA. Also, a high variability of FEV_1 argued against COPD. Elevated eNO concentrations at the beginning of the patient's holidays were explained by prior exposure to flours at work and a well-known delay of an eNO-increase after allergen challenge (Ferrazzoni et al. 2009). The follow-up examination about a year after exposure cessation with subjective and objective improvement corroborated the diagnosis of OA.

In this patient we did not include serial measurements of induced sputum or exhaled breath condensate. Methacholine testing was not possible due to severe airways obstruction. As serial measurements of eNO are easy to obtain and cannot be manipulated, this parameter remains the most interesting tool for the diagnosis of OA if symptoms, the degree of sensitization and challenge testing do not allow an unequivocal diagnosis of OA.

A similar case of a laboratory animal allergic worker with increasing eNO at work has been reported earlier by others, but the observation time was shorter, and eNO measurements were performed twice per day (Hewitt et al. 2008). Further studies have to define the optimal duration and frequency of eNO measurements for the diagnosis of OA.

Conflicts of Interest The authors declare that they have no conflict of interest.

References

European Academy of Allergology and Clinical Immunology (1992) Guidelines for the diagnosis of occupational asthma. Subcommittee on 'Occupational Allergy' of the European Academy of Allergology and Clinical Immunology. Clin Exp Allergy 22:103–108

Ferrazzoni S, Scarpa MC, Guarnieri G, Corradi M, Mutti A, Maestrelli P (2009) Exhaled nitric oxide and breath condensate ph in asthmatic reactions induced by isocyanates. Chest 136:155–162

Hewitt RS, Smith AD, Cowan JO, Schofield JC, Herbison GP, Taylor DR (2008) Serial exhaled nitric oxide measurements in the assessment of laboratory animal allergy. J Asthma 45:101–107

Malo JL, Trudeau C, Ghezzo H, L'Archevêque J, Cartier A (1995) Do subjects investigated for occupational asthma through serial peak expiratory flow measurements falsify their results? J Allergy Clin Immunol 96:601–607

Moscato G, Godnic-Cvar J, Maestrelli P, Malo JL, Burge PS, Coifman R (1995) Statement on self-monitoring of peak expiratory flows in the investigation of occupational asthma. Eur Respir J 8:1605–1610

Quirce S, Lemière C, de Blay F, del Pozo V, Gerth Van Wijk R, Maestrelli P, Pauli G, Pignatti P, Raulf-Heimsoth M, Sastre J, Storaas T, Moscato G (2010) Noninvasive methods for assessment of airway inflammation in occupational settings. Allergy 65:445–458

van Kampen V, Rabstein S, Sander I, Merget R, Brüning T, Broding HC, Keller C, Müsken H, Overlack A, Schultze-Werninghaus G, Walusiak J, Raulf-Heimsoth M (2008) Prediction of challenge test results by flour-specific IgE and skin prick test in symptomatic bakers. Allergy 63:897–902

Vandenplas O, Dressel H, Wilken D, Jamart J, Heederik D, Maestrelli P, Sigsgaard T, Henneberger P, Baur X (2011) Management of occupational asthma: cessation or reduction of exposure? A systematic review of available evidence. Eur Respir J 38:804–811

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Prevalence of Work-Related Rhino-Conjunctivitis and Respiratory Symptoms Among Domestic Waste Collectors

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Abstract

Waste collectors may suffer from acute and chronic health effects caused by organic dust (bioaerosols). Pathophysiological symptoms may originate either from allergic or irritative pathomechanisms, but an explicit distinction of the etiology is often complicated although crucial for proper risk assessment and workplace prevention. In this cross-sectional study, a total of 69 male waste collectors from the Ruhr area in Germany underwent a customized testing protocol including a modified questionnaire, basic clinical examination, spirometry, and immunologic parameters. Subjects were classified according to their work tasks into loaders (n = 27), floaters (n = 29), and drivers (n = 13). We found that a high percentage of the workers had complaints (eyes 29.0 %, nose 39.1 %, and cough 34.8 %) which were strongly work-related. Multiple logistic regression analyses indicated that duration of employment in waste collection (per 10 years) was associated with an increased prevalence of cough (OR = 1.64, 95 %CI 0.81; 3.35) and chronic bronchitis (OR = 2.18, 95 %CI 0.80; 5.92). An association between rhinitis and cough (OR = 2.62, 95 %CI 0.94; 7.27) was found, which supports the association between the prevalence of upper and lower airway disease. Furthermore, when adjusting for smoking status, atopic subjects suffered more frequently from irritation of the lower airways as indicated by cough (OR = 2.71, 95 %CI 0.91; 8.08). In conclusion, the study demonstrates

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associations between the prevalence of upper and lower airway disease in waste collectors. Notably, an underlying allergic disease in waste collectors could be suspected more commonly than previously reported.

Keywords
Atopy • Bioaerosols • Occupational exposure • Risk assessment • Waste management

1 Introduction

In municipal solid waste collection, workers are inevitably confronted with fluctuating bioaerosol emissions from domestic waste. Associations between occupational bioaerosol exposure and adverse health effects have been demonstrated in several studies (van Kampen et al. 2012; Bünger et al. 2000; Ivens et al. 1999). Subjects exposed to biologic agents often state nonspecific complaints concerning upper and lower airways, skin conditions and digestive disorders (Ivens et al. 1999). While many investigations focus on compost workers or specific exposure assessment, research discussing adverse health effects in municipal solid waste collection is limited (Kuijer et al. 2010; Wouters et al. 2002; Yang et al. 2001).

Apart from temporary peaks during the loading process, emission levels detected outdoors in waste collection are, on average, lower than levels measured indoors, e.g., at composting plants (Wouters et al. 2006). Instead, external factors may have a bigger impact on the outcome. Different types of waste picked up by municipal solid waste collectors are residual and biological waste as well as recyclables. Up to now, investigations could not confirm a significant difference in bioaerosol emissions according to the type of waste (Neumann et al. 2002). Domestic waste is usually contaminated with fluctuating levels of microorganisms, predominantly bacteria and moulds. Conditions for cell growth in waste containers vary depending on duration of collection cycles and weather conditions. With rising cell counts, levels of harmful metabolites (e.g., endotoxins and beta-glucans) also rise in proportion to duration of storage (Wouters et al. 2006). Depending on the responsible municipal waste management company, collection cycles in the investigated area may vary from 7 to 28 days. In this context, there is no evidence for longer storage durations to bear significantly higher emission rates (Neumann et al. 2001).

When waste containers are moved or jolted, cellular particles are released into the air. Especially during the loading process of waste material, suspended solids may soar through the air in a short range around the loading area, affecting loaders standing close by (Poulsen et al. 1995). All these airborne particles may enter the human body in different ways including ingestion and skin contact, but most relevant are health effects triggered by inhalation (Kuijer et al. 2010; Wouters et al. 2002).

Sensitizing, irritative, or inflammatory pathomechanisms may cause adverse health effects depending on transmission path, atopic state, and lifestyle habits (i.e., smoking) of the affected individual. Rhino-conjunctivitis is a commonly observed effect of exposure to aerosolised biological agents. The defining complaints are burning and/or itching of the eyes, wheezing, runny nose, or nasal obstruction. Rhino-conjunctivitis is either a non-allergic reaction in terms of infection or mucous membrane irritation (MMI), but may also be modulated by atopy or result from an allergic response. Moulds may possibly cause a type I allergic disease, but environmental allergens are more likely (Bünger et al. 2007). In general, non-allergic reactions are assumed to overtake instead of beat allergy as a cause of rhino-conjunctivitis in bioaerosol-exposed workers (Eduard et al. 2001).

The purpose of this study was to examine irritative and allergic reactions in waste collectors with different work tasks, exemplified by rhino-conjunctivitis and cough. We investigated the following topics in detail: (1) prevalence of irritation of the eyes, nose and lower airways; (2) contribution of allergy as the underlying pathomechanism of rhino-conjunctivitis in waste collectors; and (3) relation of upper and lower airway impairment.

2 Methods

In May 2012, the Ethics Committee of the Ruhr-University Medical School approved the implementation of all necessary examinations. All participants gave written informed consent and the study was performed in accordance to the Declaration of Helsinki.

2.1 General Study Design and Collection of Data

In this cross-sectional study, 69 current waste collectors (mean weekly working time: 39 h) were divided according to their work task into drivers and loaders. Drivers (n = 13) were workers exclusively occupied as drivers. Subjects exclusively involved in the loading process were referred to as loaders (n = 27). Subjects fulfilling both work tasks during employment were addressed as floaters (n = 29). All subjects were male. During 1 year of data collection from May 2012 to May 2013 (most interviews from May to September 2012), subjects from six municipal solid waste management companies of the Ruhr area in North Rhine-Westphalia, Germany, visited the Institute for Prevention and Occupational Medicine of the German Social Accident Insurance (IPA) for data assessment. To ensure realistic measurements, all workers were invited for testing on an afternoon during a working week after their shift.

The study protocol included a questionnaire, basic clinical examination, which was always performed by the same occupational health physician, spirometry and blood tests for immunologic parameters. The questionnaire was adapted from a previous study, which was performed in cooperation with the same companies under comparable conditions (Neumann et al. 2001). It contained items assessing personal data, working conditions, smoking habits, regular drug use, and perceived symptoms. Complementing items on the respiratory status of the study population (Pekkanen et al. 2005) were added for pulmonary disease assessment.

A full-body plethysmograph (Master Screen Body; Jaeger, Germany) was used for lung-function testing. Examination results were analyzed with the equations of the Global Lung Initiative (GLI 2012). Blood tests included specific immunoglobulin E (IgE) screening against multiple environmental allergens. The screening tool sx1 (Phadiatop; ThermoFisher Scientific, Uppsala, Sweden) contained house dust mite, cat dander/hair, dog dander, *Cladosporium herbarum*, pollen of timothy, rye grass, birch, and mugwort. Allergen-specific IgE values $\geq$0.35 kUA/L were considered positive and used to assess the subjects' atopy status.

2.2 Investigation of Health Effects

Work-related symptoms of eye and airway irritation in terms of conjunctivitis, rhinitis, cough, and chronic bronchitis (CB) were assessed for confirmation of irritative effects due to bioaerosol exposure. Common complaints, indicating an irritation of the eyes, were watering, itching and foreign body sensation (nose: congestion, runny nose, and dysfunction of olfactory sense). These symptoms were assumed according to the answers to the respective questionnaire items. CB was diagnosed in subjects stating cough with phlegm on most days during at least 3 months in two consecutive years (GOLD 2013). For eye and nose complaints, an allergic etiology was suspected in subjects with positive atopic status. A work-relation of symptoms was likely when at least two of the three following criteria were met: (1) absence of symptoms before employment, (2) cumulative occurrence when working, and (3) remission during vacation.

2.3 Data Analysis

Median and inter-quartile range (IQR) were used to describe the characteristics of the study population. The groups were compared using the non-parametric Kruskal-Wallis test for continuous variables and Fisher's exact test for categorical variables. Unconditional logistic regression models were used to analyse the associations between occupational exposure and health effects.

To estimate the actual degree of occupational exposure of the study population, we considered two main factors. We took the work task (i.e., classification into drivers, floaters, and loaders) as a crude measurement of the magnitude of exposure. We then studied the impact on the outcome of the duration of employment as a continuous variable. Besides, the smoking status was considered as a confounding factor in the analyses.

3 Results

Drivers demonstrated the lowest percentage of current smokers compared to floaters and loaders (23.1 %, 51.7 %, and 55.6 %, respectively; $p = 0.134$). General anthropometric, occupational and immunologic data of the study population stratified by smoking status are shown in Table 1. No significant differences were observed concerning the anthropometric measures of employment. The duration of employment was similar in all groups with a median of 22 years. The number of workers with positive atopic status was comparable in never, former, and current smokers.

The spirometric results for forced expiratory volume in 1 s (FEV_1), forced vital capacity (FVC) and the Tiffeneau-index (FEV_1/FVC) adjusted with the GLI equations are depicted in Table 2. Adjusted FEV_1 and FEV_1/FVC, were both highest for never smokers ($p = 0.025$; $p = 0.001$, respectively). An airflow limitation defined by GLI's age dependent lower limits of normal (LLN_{GLI}) could be found in seven current smokers (data not shown).

A high percentage of all workers reported health complaints (eyes 29 %, nose 39 %, and cough 35 %). A description of the stated complaints is shown in Table 3. Almost two thirds of all symptoms were work-related. Besides, one half of workers with eye complaints had an atopic status (nose: 41 %). In general, symptoms in atopic subjects were stronger associated with working conditions (eye: 70 %, nose: 82 %) compared with symptoms associated with MMI (eyes: 60 %, nose: 50 %). Furthermore, symptoms in atopic loaders and floaters were stronger associated with working conditions (eyes 78 %, nose 89 %) than in atopic drivers (eyes 0 %, nose 50 %). In contrast to this, the work-relation of rhino-conjunctivitis symptoms in non-atopic subjects showed an inverse gradient between drivers and loading workers (drivers: eyes 100 %, nose 75 %; loaders and floaters: eyes 50 %, nose 42 %). All subjects reporting cough and coexisting phlegm also suffered from these symptoms in terms of CB.

Univariate logistic regression was used to estimate the association of occupational exposure and conjunctivitis, rhinitis, cough, and CB (data not shown). Neither work task nor duration of employment showed a significant impact on these symptoms. With age, the risk of cough and CB was increased (OR = 1.51, 95 %CI 0.72; 3.19; OR = 2.69, 95 %CI 0.94; 7.68) and the risk of rhinitis was decreased (OR = 0.46, 95 %CI 0.21; 0.998). A significantly lower prevalence of conjunctivitis was seen in current smokers (OR = 0.25, 95 %CI 0.07; 0.87). Atopic subjects had a higher prevalence of cough (OR = 2.62, 95 %CI 0.91; 7.49), rhinitis (OR = 1.94, 95 %CI 0.69; 5.43), and conjunctivitis; the latter demonstrating statistical significance (OR = 3.08, 95 %CI 1.04; 9.19).

A multiple logistic regression model was applied to adjust for occupational exposure (Table 4). After adjustment, current smoking remained negatively associated with conjunctivitis,

Table 1 Characteristics of 69 waste workers stratified by smoking status

	All (n = 69)		Never smoker (n = 19)		Former smoker (n = 17)		Current smoker (n = 33)	
	Median	IQR	Median	IQR	Median	IQR	Median	IQR
Age (years)	48	43; 51	48	44; 51	48	44; 56	47	42; 50
Height (cm)	178	173; 184	176	173; 180	178	171; 180	182	174; 187
Weight (kg)	90	82; 102	89	78; 102	85	82; 92	95	86; 104
BMI (kg/m^2)	28.1	25.9; 30.6	27.8	24.8; 31.2	29.4	24.9; 31.3	28.1	26.3; 30.2
Employment (year)	22	15; 25	22	14; 26	23	21; 27	21	15; 23
	n	%	n	%	n	%	n	%
Driver	13	18.8	4	30.8	6	46.1	3	23.1
Floater	29	42.0	7	24.1	7	24.1	15	51.7
Loader	27	39.1	8	29.6	4	14.8	15	55.6
Atopic (sx1 >0.35 kUA/L)	22	31.9	6	31.6	5	29.4	11	33.3

IQR Interquartile range, *BMI* Body mass index, *sx1* Specific environmental allergen screening

Table 2 Lung function of the waste collectors by smoking status, work task, and duration of employment in waste collection, regarding the reference values of the Global Lung Function Initiative (*GLI*)

		FEV_1 (%predicted$_{GLI}$)		FVC (%predicted$_{GLI}$)		FEV_1/FVC (%predicted$_{GLI}$)	
	n	Median	IQR	Median	IQR	Median	IQR
All	69	99.6	93.5; 106.9	101.1	93.8; 110.1	98.9	93.4; 102.7
Smoking status							
Never	19	106.5	97.0; 112.9	101.9	94.7; 108.6	103.0	98.7; 107.1
Former	17	97.3	91.6; 106.9	100.0	98.6; 106.4	97.0	93.7; 101.3
Current	33	97.8	89.4; 102.6	95.7	92.2; 111.1	95.1	89.2; 101.3
Work task							
Driver	13	102.3	91.2; 112.9	105.3	92.7; 111.3	93.0	86.2; 101.6
Floater	29	97.3	95.8; 104.4	101.1	94.6; 110.1	95.6	93.4; 101.5
Loader	27	99.6	91.6; 110.4	99.7	92.5; 109.8	101.4	94.5; 106.5
Employment							
≤20 years	28	102.1	95.1; 108.8	103.8	94.8; 112.1	97.1	92.6; 102.1
>20 years	41	98.1	91.2; 106.1	99.7	92.5; 107.6	99.4	93.9; 103.4

FEV_1 Forced expiratory volume in 1 s, *FVC* forced vital capacity, *FEV1/FVC* Tiffeneau index, *IQR* Interquartile range

Table 3 Stated complaints of the waste collectors stratified by work task

	Driver (n = 13)		Floater (n = 29)		Loader (n = 27)		All (n = 69)	
	n	%	n	%	n	%	n	%
Eyes								
Watering, itching, FBS	3	23.1	7	24.1	10	37.0	20	29.0
Thereof work-related	2	66.7	4	57.1	7	70.0	13	65.0
Nose								
Congestion, runny, DOS	6	46.2	12	41.4	9	33.3	27	39.1
Thereof work-related	4	66.7	8	66.7	5	55.6	17	63.0
Cough								
Complaints	4	30.8	12	41.4	8	29.6	24	34.8
Thereof work-related	1	25.0	8	66.7	5	62.5	14	58.3

FBS foreign body sensation, *DOS* Dysfunction of olfactory sense

Table 4 Multiple logistic regression analyses of the associations between occupational exposure and prevalence of conjunctivitis, rhinitis, cough, and chronic bronchitis

		Conjunctivitis (n = 20)		Rhinitis (n = 27)		Cough (n = 24)		Chronic bronchitis (n = 11)	
		OR	95%CI	OR	(95%CI)	OR	(95%CI)	OR	(95%CI)
Work task	Driver	1		1		1		1	
	Floater	1.05	0.20; 5.60	1.14	0.26; 5.00	1.68	0.36; 7.91	4.19	0.36; 48.66
	Loader	2.38	0.46; 12.29	0.92	0.21; 4.13	0.98	0.20; 4.80	5.25	0.44; 63.19
Employment	(10 year)	0.99	0.47; 2.06	1.12	0.58; 2.17	1.64	0.81; 3.35	2.18	0.80; 5.92
Smoking status	Never	1		1		1		1	
	Former	0.51	0.11; 2.28	3.13	0.76; 12.98	1.34	0.29; 6.12	7.13	0.62; 82.53
	Current	0.20	0.05; 0.80	0.61	0.18; 2.12	1.78	0.49; 6.47	4.22	0.44; 40.69
Atopy	No	1		1		1		1	
	Yes	3.70	1.10; 12.43	2.20	0.73; 6.66	2.71	0.91; 8.08	2.35	0.57; 9.77

OR odds ratio, *CI* confidence interval

Table 5 Univariate logistic regression analyses of the associations between the prevalence of conjunctivitis and upper and lower airway disease

		Cough (n = 24)			Chronic bronchitis (n = 11)		
	n	n	OR	(95%CI)	n	OR	(95%CI)
Conjunctivitis							
No	49	15	1		8	1	
Yes	20	9	1.86	0.64; 5.41	3	0.90	0.21; 3.93
Rhinitis							
No	42	11	1		6	1	
Yes	27	13	2.62	0.94; 7.27	5	1.36	0.37; 5.00

OR odds ratio, *CI* confidence interval

but still had no obvious association with cough or CB. Like in univariate logistic regression, a higher prevalence of conjunctivitis, rhinitis, and cough could be seen in workers with positive atopic status. The association with conjunctivitis remained statistically significant (OR = 3.70, 95 %CI 1.10; 12.43). In this model, the duration of employment seemed to have an obvious, but still insignificant impact on lower airway disease.

Results of univariate logistic regression analysis on the association between the prevalence of upper and lower airway disease are shown in Table 5. A positive association between cough and rhinitis was found (OR = 2.62, 95 %CI 0.94; 7.73), while CB was not associated with symptoms of upper airway disease. Due to a limited number of subjects, multiple logistic regression was not applicable for adjusting specific characters, e.g., as already mentioned, airflow limitation was exclusively detected in current smokers.

4 Discussion

To our knowledge, this is the first study in municipal solid waste collectors that focuses on the upper and lower airways with respect to prevalence and association of irritative symptoms. Our data indicate that the duration of employment in waste collection, but not the work task was associated with increased prevalence of rhinitis, cough, or CB.

Especially loaders are exposed to bioaerosols when volatile particles from decomposing biomass are aerosolised during handling, lifting, and emptying of waste bins and containers (Poulsen et al. 1995). However, even though in less magnitude, drivers are also substantially exposed to organic dust, because waste collection is processed at the back of the waste truck, proportionally close to the driver's cabin. Also, high biologic agent emissions occur at waste disposal sites. Bioaerosols comprise dust, bacteria and fungi and may contain various toxic components like endotoxins.

Previous investigations of the bioaerosol exposure in German municipal solid waste collection revealed inhalable dust quantities of about 2.6 mg/m^3 (respirable dust: 0.41 mg/m^3) in the air around the loading area (Neumann et al. 2005). Bacteria levels fluctuated between 10^3 CFU/m^3 and 10^5 CFU/m^3 (Neumann et al. 2002). Endotoxin levels up to 100 EU/m^3 but mostly below 40 EU/m^3 and mould levels between 10^3 CFU/m^3 and 10^5 CFU/m^3 were detectable (Neumann et al. 2005). By comparison, drivers were usually exposed to mould and bacteria levels slightly above background levels with values between 10^2 CFU/m^3 and 10^3 CFU/m^3 (Neumann et al. 2002). Mould levels of $<10^3$ CFU/m^3 may already suffice to induce MMI (Herr et al. 2010). Therefore, health effects provoked by organic dust inhalation are a realistic threat – for drivers as well as for loaders.

Most frequently reported symptoms were related to the eyes, nose, and lower airways according to the workers' self-assessment given in the questionnaire. These complaints could predominantly be attributed to working conditions. We found a relatively higher prevalence of above mentioned symptoms than described in previous reports on the hazards of the exposure to bioaerosols (Yang et al. 2001).

There is moderate evidence that waste collectors are at increased risk of developing respiratory complaints (Kuijer et al. 2010), e.g., bronchitis. Even though our statistical analyses were limited by the number of subjects, we found evidence for an association of cough and CB with the duration of employment. In this context, we demonstrated an increased odds ratio for cough and CB. Likewise, the prevalence of common non-productive cough in our study population was 35 %. Recurrent non-productive cough points to an irritation of the lower airways. All subjects additionally complaining about phlegm (16 %) fulfilled the criteria for having CB. The prevalence of respiratory symptoms in our study is in line with previous data on respiratory health in waste workers (Wouters et al. 2002). In general, it is conceivable that CB may be caused by occupational exposure (Blanc and Torén 2007). An airflow limitation with respect to adjusted reference values (GLI 2012) could be demonstrated in current smokers and long-term employed workers. This might point to a combined effect of personal and occupational exposure resulting in an increased risk of developing an obstructive lung disease. This has previously been suggested for occupational exposure to particulate matter (Eisner et al. 2010).

Notably, an underlying allergic disease could be suspected in 44 % of loaders (and 38 % of drivers) reporting symptoms in terms of rhino-conjunctivitis. These calculations are based on the assumption that symptoms of conjunctivitis in subjects with atopy were indicative of an allergic aetiology. In contrast, we addressed irritation of eyes or nose without an underlying allergy as MMI. However, it is to stress that only a nasal provocation test with the potential allergen can reveal a causative link between sensitization and rhino-conjunctivitis in terms of an allergic disease. Thus, atopy might solely be a condition triggering mucous membranes for an enhanced response towards nonspecific irritative hazards.

Municipal solid waste collection is an 'outdoor activity', which is necessarily performed along the circumscribed road network of municipal communities. Waste collectors are directly exposed to traffic-related air pollution including diesel exhaust, as well as background levels of airborne allergens like pollen and moulds (from other sources than domestic waste). Furthermore, we must not forget other sources of air pollution (e.g., industrial exhaust). This contamination may contribute to work-related health effects and might explain a lacking relation between symptom prevalence and work task. In contrast, it may emphasize the detected associations between the symptoms and the duration of employment. Moreover, healthy worker effects were previously observed in workers handling biological waste (Bünger et al. 2007) and have to be considered. Our data analyses were hampered by a relatively small number of subjects. However, the results indicate a high prevalence of work-related rhino-conjunctivitis in long-term exposed domestic waste collectors. This study supports associations between the prevalence of upper and lower airway disease. Finally, when adjusting for smoking status, our data suggest that atopic waste collectors have an increased risk for irritation of the lower airways as indicated by cough.

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Conflicts of Interest The authors declare no conflict of interest in relation to this article according to the recommendations of the International Committee of Medical Journal Editors.

References

Blanc PD, Torén K (2007) Occupation in chronic obstructive pulmonary disease and chronic bronchitis: an update. The international journal of tuberculosis and lung disease. Off J Int Union Against Tuberc Lung Dis 11(3):251–257

Bünger J, Antlauf-Lammers M, Schulz TG, Westphal GA, Müller MM, Ruhnau P, Hallier E (2000) Health complaints and immunological markers of exposure to bioaerosols among biowaste collectors and compost workers. Occup Environ Med 57(7):458–464

Bünger J, Schappler-Scheele B, Hilgers R, Hallier E (2007) A 5-year follow-up study on respiratory disorders and lung function in workers exposed to

organic dust from composting plants. Int Arch Occup Environ Health 80(4):306–312
Eduard W, Douwes J, Mehl R, Heederik D, Melbostad E (2001) Short term exposure to airborne microbial agents during farm work: exposure-response relations with eye and respiratory symptoms. Occup Environ Med 58(2):113–118
Eisner MD, Anthonisen N, Coultas D, Kuenzli N, Perez-Padilla R, Postma D, Romieu I, Silverman EK, Balmes JR, Committee on Nonsmoking COPD, & Environmental and Occupational Health Assembly (2010) An official American thoracic society public policy statement: novel risk factors and the global burden of chronic obstructive pulmonary disease. Am J Respir Crit Care Med 182(5):693–718
GLI (2012) From lung function in growth and aging – a united worldwide approach. Global Lung Function Initiative (GLI). Available from: http://www.lungfunction.org/. Accessed 13 Oct 2013
GOLD (2013) From the global strategy for the diagnosis, management and prevention of COPD, Global Initiative for Chronic Obstructive Lung Disease (GOLD). Available from: http://www.goldcopd.org. Accessed 15 Oct 2013
Herr CEW, Eikmann T, Heinzow B, Wiesmüller GA (2010) Umweltmedizinische Relevanz von Schimmelpilzen im Lebensumfeld. Umweltmedizin in Forschung und Praxis 15(2):76–83
Ivens UI, Breum NO, Ebbehøj N, Nielsen BH, Poulsen OM, Würtz H (1999) Exposure-response relationship between gastrointestinal problems among waste collectors and bioaerosol exposure. Scand J Work Environ Health 25(3):238–245
Kuijer PP, Sluiter JK, Frings-Dresen MH (2010) Health and safety in waste collection: towards evidence-based worker health surveillance. Am J Ind Med 53 (10):1040–1064
Neumann HD, Mathys W, Raulf-Heimsoth M, Becker G, Balfanz J (2001) Gefährdung von Beschäftigten bei der Abfallsammlung und -abfuhr durch Keimexpositionen. Schriftenreihe der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin: Fb 920:41–49, 112–115, 159–160
Neumann HD, Balfanz J, Becker G, Lohmeyer M, Mathys W, Raulf-Heimsoth M (2002) Bioaerosol exposure during refuse collection: results of field studies in the real-life situation. Sci Total Environ 293 (1–3):219–231
Neumann HD, Becker G, Lohmeyer M, Mathys W (2005) Preventive measures to reduce bioaerosol exposure during refuse collection: results of field studies in the real-life situation. Sci Total Environ 341(1–3):1–13
Pekkanen J, Sunyer J, Anto JM, Burney P (2005) Operational definitions of asthma in studies on its aetiology. Eur Respir J 26(1):28–35
Poulsen OM, Breuma NO, Ebbehøjb N, Hansena ÅM, Ivensa UI, van Lelievelda D, Malmrosc P, Matthiasenc L, Nielsena BH, Nielsena EM, Schibyea B, Skova T, Stenbaeka EI, Wilkinsa KC (1995) Sorting and recycling of domestic waste. Review of occupational health problems and their possible causes. Sci Total Environ 168(1):33–56
van Kampen V, Deckert A, Hoffmeyer F, Taeger D, Brinkmann E, Brüning T, Raulf-Heimsoth M, Bünger J (2012) Symptoms, spirometry, and serum antibody concentrations among compost workers exposed to organic dust. J Toxicol Environ Health 75(8–10):492–500
Wouters IM, Hilhorst SK, Kleppe P, Doekes G, Douwes J, Peretz C, Heederik D (2002) Upper airway inflammation and respiratory symptoms in domestic waste collectors. Occup Environ Med 59(2):106–112
Wouters IM, Spaan S, Douwes J, Doekes G, Heederik D (2006) Overview of personal occupational exposure levels to inhalable dust, endotoxin, beta(1–3)-glucan and fungal extracellular polysaccharides in the waste management chain. Ann Occup Hyg 50(1):39–53
Yang CY, Chang WT, Chuang HY, Tsai SS, Wu TN, Sung FC (2001) Adverse health effects among household waste collectors in Taiwan. Environ Res 85(3):195–199

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Quality of Life and Health Care Utilization in Patients with Chronic Respiratory Diseases

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Abstract

High quality of life (QoL) may reduce the costs of medical care of chronically ill patients due to lower health care utilization. The purpose of this study was to establish the influence of the QoL of primary care patients with chronic respiratory diseases on the level of health care utilization and the predictors of hospitalization. The study group consisted of 594 adult patients with chronic respiratory diseases of the mean age 59.8 ± 14.9 years. The highest QoL was observed in the social relationship domain and the lowest in the physical domain. Low QoL was associated with a low level of health care utilization among patients with chronic respiratory diseases. Most patients were hospitalized during the past 3 years. In a group of patients with chronic respiratory diseases, chances for hospitalization were: higher among patients with low QoL and health satisfaction, low QoL levels in the physical and social relationship domains, high QoL levels in the psychological domain, those with higher education, residents of rural areas, patients using frequent consultations over the phone, and those with at least an average index of services.

Keywords

Chronic care model • Chronic disease • Health care services • Primary care • Well-being

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1 Introduction

The main focus of the European Health Report 2012 (WHO 2013) is the well-being expressed by quality of life (QoL). The report is also an integral part of the new European policy for health 'Health 2020' accepted by 53 countries in the European Region in September 2012 (WHO 2013). It was emphasized that the well-being and health are multidimensional and interactive concepts, and they both are conditioned by the functioning of the health care system. Many sectors, including the government and the society as a whole, are responsible for the provision of a high welfare level indicated by the level of QoL (WHO 2013).

The effectiveness of clinical interventions and the functional 'well-being' of patients with chronic diseases are assessed by means of a QoL measurement. The evaluation of QoL performed in chronically ill patients is not based exclusively on the analysis of health-related factors, such as physical, functional, and emotional well-being, but also non-medical aspects, such as work, family, and social contacts (Brown et al. 2004). Thus, the QoL analysis enables bio-psycho-social evaluation and facilitates efficient diagnostic and therapeutic management and interventions which improve the multidimensional functioning of patients. The QoL is understood not only as an indicator of the effectiveness of medical interventions, but also a gauge of the efficiency of social and political support systems (Mota-Pinto et al. 2011).

The above suggests the relationship between QoL and the level of health care utilization. It has been proved that patients who often use primary health care services have lower levels of QoL than those who use them less frequently (Jakobsson et al. 2011). Baernholdt et al. (2012) noted a significant relationship between the level of health care utilization and emotional well-being of patients. In addition, high medical costs associated with chronic diseases result from the fact that such diseases are often accompanied by low education and a more frequent use of medical services other than those provided within primary care. A high level of health care utilization is a basic indicator of such costs especially within primary care (Kersnik et al. 2001). Thus, a high QoL level may potentially reduce the costs of medical care of chronically ill patients by lowering the level of health care utilization.

The aim of care provided for chronically ill patients is to improve their functioning and to decrease medical costs through a reduction of health services (Frisch 1998). QoL improvement may lead to the achievement of both goals, especially if we accept Frisch's assumption (1998) that a high QoL level is the most important outcome of health care utilization or 'medical end-point' which prevents the recurrence of the disease, reduces symptoms, and increases patients' satisfaction with health care quality.

The purpose of this study was to establish the influence of QoL of primary care patients with chronic respiratory diseases on the level of health care utilization and to determine the hospitalization incidence rate and predictors of potential hospitalization in these patients.

2 Methods

The study has been carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and was approved by the Bioethical Commission of the Medical University of Wroclaw (no. KB 608/2011). The patients who participated in the study gave informed written consent.

The study group consisted of 594 adult patients, mean age of 59.8 ± 14.9 years, with chronic respiratory diseases. The patients' socio-demographic data and the chronic diseases diagnosed are shown in Tables 1 and 2, respectively. The patients were recruited from 136 general medical practices between July 2011 and April 2013. They obtained a questionnaire to be completed at home and returned in a stamped envelope.

Quality of life was assessed with a Polish version of the World Health Organization

Table 1 Socio-demographic data of chronically ill patients

	n	%
Gender		
Women	301	50.8
Men	291	49.2
Age (years)		
24 and below	18	3.1
25–44	55	9.3
45–64	297	50.4
65–84	199	33.8
85 and above	20	3.4
Place of residence		
Village	242	41.0
Below 5,000[a]	99	16.8
5,000–10,000[a]	25	4.2
10,000–50,000[a]	118	20.0
50,000–100,000[a]	47	8.0
100,000–200,000[a]	33	5.6
Over 200,000[a]	26	4.4
Education		
Primary	105	17.8
Vocational	197	33.5
Secondary	168	28.5
Post-secondary	64	10.9
Higher	55	9.3
Marital status		
Single	60	10.5
Married	388	65.7
Divorced	35	5.9
Widowed	108	18.3

[a]City/town population

Quality of Life Instrument Short Form (WHOQOL-BREF) (WHOQOL Group 1998). The WHO Quality of Life (WHOQOL) is a generic quality of life instrument that has been designed to be applicable to people living in different conditions or cultures (Jaracz et al. 2006). The WHOQOL-BREF is a shorter version of the WHOQOL-100, developed by the WHO group for the Research on Quality of Life. It is confirmed that the WHOQOL-BREF provides a valid and reliable alternative to the assessment of domain profiles with the WHOQOL-100, and is especially sensitive to the health-related QoL status of those with chronic diseases. The WHOQOL-BREF assesses, on a five point Likert scale, quality of life, health satisfaction, and the following four domains:

D1 – Physical: activities of daily living, dependence on medicinal substances and medical aids, energy and fatigue, mobility, pain and discomfort, sleep and rest, work capacity

D2 – Psychological: bodily image and appearance, negative and positive feelings, self-esteem, religion/spirituality/personal beliefs, thinking/learning/memory/concentration

D3 – Social relationships: personal relationships, social support, sexual activity

D4 – Environmental: financial resources, freedom/physical safety and security, health and social care: accessibility and quality, home environment, opportunities for acquiring new information and skills, participation in, and opportunities for, recreation/leisure, physical environment (pollution/noise/traffic/climate) and transport.

The reliability of the Polish version of the WHOQOL-BREF has been validated concerning the questionnaire as a whole and its particular domains; α-Cronbach's is 0.90 and from 0.69 to 0.81, respectively (Jaracz et al. 2006).

The index of services was calculated by summing up the received services and dividing the sum by the number of types of those services.

Table 2 Patient diagnoses according to the 2013 ICD-10-CM Diagnosis Codes and comorbidity

	n	%
Diagnosis[a]		
J44 Other chronic obstructive pulmonary diseases	267	45.0
J45 Bronchial asthma	239	40.2
J42 Unspecified chronic bronchitis	65	10.9
J41 Chronic simple and mucous-purulent bronchitis	59	9.9
J43 Pulmonary emphysema	52	8.8
J47 Bronchiectasis	29	4.9
Most common co-existing diseases[a]		
I10 Primary hypertension	154	25.9
M47 Spondylosis	106	17.9
I70 Atherosclerosis	68	11.5
I50 Heart failure	42	7.1
E11 Non-insulin-dependent diabetes mellitus	41	6.9
I11 Hypertensive heart disease	40	6.7
M15 Osteoarthritis of multiple joints	40	6.7
I25 Chronic ischemic heart disease	37	6.2
I20 Angina pectoris	27	4.6
K58 Irritable bowel syndrome	21	3.5
Comorbidity		
1 chronic disease	108	18.2
2 and more	486	81.8
3 and more	341	57.4
4 and more	199	33.5
5 and more	114	19.2
6 and more	70	11.8
7 and more	42	7.1
8 and more	25	4.2
9 and more	15	2.5
10 and more	8	1.4
11 and more	4	0.7
14 and more	3	0.5
15 and more	2	0.3

[a]Some patients were diagnosed as having at least two pathological entities

The index included medical services provided during visits to a doctor's office during the past 12 months. At the same time, on the basis of data from the patients, the authors established the number of visits to a family doctor (including those associated with chronic diseases), home visits, consultations over the phone, interventions of a district nurse during the past 12 months, and the number of hospitalizations during the past 3 years.

2.1 Statistical Elaboration

The results of variables were not normally distributed as checked with the Shapiro-Wilk test. Arithmetic means ±SD, the first (Q1), second (Q2 – median), and third (Q3) quartiles, and maxima and minima were given for quantitative variables, while qualitative variables were presented as percentages. Spearman's rank test was used to check for associations between numeric and numeric or numeric and categorical variables.

Logistic regression analysis was used to examine the impact of explanatory variables on the odds ratio (OR) of hospitalization. The chance was defined as a ratio of probability of a certain event to the probability of an opposite event. The chance quotient was defined as a ratio of probability that a certain event occurs in one group to the probability of its occurring in the other group. The logistic regression was performed using a method of in-depth analysis of all models with the number of 17, 7, 6, 5, or 4 explanatory variables selected from the set of 17 variables. Explanatory variables were always selected from the group of the following 17 variables: gender, age, education, marital status, place of residence, index of services, number of home visits, number of consultations over the phone, number of interventions of a district nurse, body mass index (BMI), number of chronic diseases, level of satisfaction with QoL, level of satisfaction with health state, QoL level in all domains (physical, psychological, social relationship, and environment). Both the model with all 17 variables, and all models with 7 and 6 explanatory variables proved to be poorly matched, however models with 5 and 4 variables were well-matched.

Risks for the number of hospitalizations, home visits, consultations over the phone, and interventions of a district nurse were calculated. The risk was defined as a probability of a certain event to occur and was given as the incidence rate for 100,000 patients. The 95 % confidence interval was established for both chance quotient and risk. The critical level of significance was assumed at $p < 0.05$. Analysis was performed using R 2.10.1 (for Mac OS X Cocoa GUI).

3 Results

The median of a chronic disease duration was 3 (min–max: 0–30) years, the median of chronic diseases number was 3.0 (min–max: 1–15), the average number of visits to a family doctor was 5.6 ± 5.4, and visits to a doctor due to chronic diseases: 4.3 ± 7.4. Two chronic diseases were diagnosed in 145 (24.4 %) patients, 3 in 142 (23.9 %) patients, 1 chronic disease in 108 (18.2 %) patients, and 4 in 85 (14.3 %) patients.

The median of hospitalizations number during the past 3 years was 1 (min–max: 0–48), home visits – 0 (min–max: 0–365), consultations over the phone – 0 (min–max: 0–150), and interventions of a district nurse – 0 (min–max: 0–240). Two hundred fifty six (56.2 %) patients had an increased Body Mass Index (BMI); 163 (35.8 %) were overweight and 93 (20.4 %) were obese. Normal BMI was noted in 191 (41.9 %) patients and 9 (2.0 %) were underweight.

The WHOQOL-BREF results are shown in Table 3. The patients had higher levels of satisfaction with QoL than with health status. The highest QoL was observed in social relationship and environmental domains, lower in psychological domain, and the lowest in physical domain.

Table 3 Score of the World Health Organization Quality of Life Instrument Short Form (WHOQOL – BREF)

	x ±SD	Q1	Q2	Q3	Min–Max
Quality of life (QoL) satisfaction	3.5 ± 0.9	3.0	4.0	4.0	1–5
Health satisfaction	2.9 ± 0.9	2.0	3.0	4.0	1–5
QoL domains					
Physical domain	13.0 ± 3.0	11.4	13.1	14.9	4–20
Psychological domain	13.1 ± 2.9	10.7	13.3	15.3	4–20
Social relationships domain	14.1 ± 3.0	12.0	14.7	16.0	4–20
Environmental domain	13.4 ± 2.3	12.0	13.5	15.0	7–20

x ±SD mean ±SD, *Q* quartile, *Min–Max* minimum – maximum value

3.1 Associations

QoL was positively associated with health satisfaction in patients with chronic respiratory diseases ($r = 0.59$, $p < 0.0001$). The associations between health satisfaction and the individual QoL domains as well as among these domains were highly significant. These associations are presented in Table 4.

QoL satisfaction was high among single representatives of both genders and low among widows/widowers ($r = -0.15$). Health satisfaction ($r = -0.15$) was high among patients with graduate education and in younger patients, and low among patients with incomplete primary education ($r = 0.28$) ($p < 0.001$ for all).

QoL in physical domain was high in women ($r = 0.09$, $p = 0.027$), unmarried women and men ($r = -0.16$, $p < 0.001$), patients with graduate education ($r = 0.36$, $p < 0.001$), residents of cities/towns with a population of over 200,000 citizens ($r = -0.13$, $p = 0.001$), and in younger patients ($r = -0.49$, $p < 0.001$).

QoL in psychological domain also was high in women gender ($r = 0.08$, $p = 0.041$), patients with graduate education ($r = 0.39$, $p < 0.001$), inhabitants of cities/towns with a population over 200,000 ($r = -0.17$, $p < 0.001$), and with younger patients ($r = -0.41$, $p < 0.001$)

QoL in social relationship domain was high in unmarried women and men ($r = -0.26$, $p < 0.001$), in patients with graduate education ($r = 0.33$, $p < 0.001$), inhabitants of cities/towns with a population over 200,000 ($r = -0.11$, $p = 0.011$) and in younger patients ($r = -0.40$, $p < 0.001$).

QoL in environmental domain was high in women ($r = 0.08$, $p = 0.049$), in unmarried women and men ($r = -0.15$, $p < 0.001$), patients with graduate education ($r = 0.36$, $p < 0.001$), inhabitants of cities/towns with a population >200,000, ($r = -0.14$, $p < 0.001$), and in younger patients ($r = -0.35$, $p < 0.001$).

The BMI correlated positively with the number of hospitalizations ($r = 0.13$, $p = 0.027$), the frequency of visits to a family doctor due to diet control ($r = 0.20$, $p < 0.001$), and the number of chronic diseases ($r = 0.27$, $p < 0.001$). It correlated negatively with the number of spirometry tests ($r = -0.14$, $p = 0.020$), the number of vaccinations ($r = -0.13$, $p = 0.027$), the level of QoL satisfaction ($r = -0.13$, $p = 0.007$), the level of health satisfaction ($r = -0.16$, $p = 0.001$), and the QoL levels in the physical ($r = -0.16$, $p < 0.001$), psychological ($r = -0.13$, $p = 0.005$), social relationship ($r = -0.10$, $p = 0.028$), and environmental ($r = -0.11$, $p = 0.021$) domains.

Positive correlations were noted between the number of hospitalizations and those of home visits ($r = 0.23$) and consultations over the phone ($r = 0.34$), the number of chronic diseases ($r = 0.22$), and the index of services ($r = 0.37$) ($p < 0.001$ for all). Negative correlations, on the other hand, were between the number of hospitalizations and the level of QoL and its individual domains ($r = -0.19$, $p < 0.001$ for all), and the level of health satisfaction ($r = -0.30$, $p < 0.001$). The number of hospitalizations was high in men ($r = -0.10$, $p = 0.013$) and in inhabitants of rural areas ($r = 0.10$, $p = 0.011$).

Table 4 Associations among the quality of life domains

	QoL satisfaction	Health satisfaction	QoL Physical	QoL Psychological	QoL Social relation	QoL Environmental
QoL satisfaction	–	0.59	0.67	0.69	0.55	0.64
Health satisfaction	0.59	–	0.69	0.53	0.43	0.49
QoL – Physical	0.67	0.69	–	0.76	0.64	0.70
QoL – Psychological	0.69	0.53	0.76	–	0.71	0.80
QoL – Social relation	0.55	0.43	0.64	0.71	–	0.69
QoL – Environmental	0.64	0.49	0.73	0.80	0.69	–

QoL quality of life; data are Spearman rank's r correlation coefficients; $p < 0.0001$ for all

The number of visits to a family doctor was higher in patients with more frequent hospitalizations during the past 3 years ($r = 0.13$), home visits ($r = 0.23$), consultations over the phone ($r = 0.21$), interventions of a district nurse ($r = 0.21$), in those with lower levels of QoL satisfaction ($r = -0.25$) and health satisfaction ($r = -0.30$) ($p < 0.001$ for all), and lower QoL in all domains: physical ($r = -0.30$, $p < 0.001$), psychological ($r = -0.24$, $p < 0.001$), social relationship ($r = -0.14$, $p = 0.003$), and environmental ($r = -0.20$, $p < 0.001$). The number of visits to a family doctor also increased with increasing number of chronic diseases ($r = 0.29$, $p < 0.001$), with a higher index of services ($r = 0.43$, $p < 0.001$), a higher number of visits to a doctor due to chronic diseases ($r = 0.35$, $p < 0.001$); it was higher in patients with incomplete primary education ($r = -0.18$, $p = 0.002$), in habitants of rural areas ($r = 0.15$, $p = 0.002$), and in older patients ($r = 0.23$, $p < 0.001$).

The number of home visits correlated negatively with QoL satisfaction ($r = -0.27$, $p < 0.001$) and health satisfaction ($r = -0.29$, $p < 0.001$), and with QoL in all domains: physical ($r = -0.35$, $p < 0.001$), psychological ($r = -0.32$, $p = 0.002$), social relationship ($r = -0.24$, $p < 0.001$), and environmental ($r = -0.27$, $p < 0.001$). It correlated positively with the number of chronic diseases ($r = 0.37$, $p < 0.001$), the index of services ($r = 0.20$, $p < 0.001$), and the number of consultations over the phone ($r = 0.34$, $p < 0.001$). The number of home visits also was higher in widows/widowers ($r = 0.14$, $p = 0.004$), in patients with incomplete primary education ($r = -0.20$, $p < 0.001$), inhabitants of rural areas ($r = 0.13$, $p = 0.007$), and in older patients ($r = 0.35$, $p < 0.001$).

The number of consultations over the phone correlated negatively with QoL satisfaction ($r = -0.21$, $p < 0.001$) and health satisfaction ($r = -0.20$, $p < 0.001$), and with all QoL domains: physical ($r = -0.24$, $p < 0.0001$), psychological ($r = -0.25$, $p < 0.0001$), social relationship ($r = -0.13$, $p = 0.0069$), and environmental ($r = -0.14$, $p = 0.003$). It correlated positively with the number of home visits ($r = 0.34$, $p < 0.0001$), interventions of a district nurse ($r = 0.42$, $p < 0.001$), and with the number of chronic diseases ($r = 0.33$, $p < 0.001$) and the index of services ($r = 0.30$, $p < 0.001$). The number of consultations over the phone was higher in patients with incomplete primary education ($r = -0.17$, $p = 0.001$), inhabitants of rural areas ($r = 0.12$, $p < 0.010$), and in older patients ($r = 0.21$, $p < 0.001$).

The number of interventions of a district nurse correlated negatively with QoL satisfaction ($r = -0.24$, $p < 0.001$), health satisfaction ($r = -0.16$, $p < 0.001$) and with all QoL domains: physical ($r = -0.32$), psychological ($r = -0.41$), social relationship ($r = -0.24$), and environmental ($r = -0.28$) ($p < 0.0001$ for all). It correlated positively with the number of chronic diseases ($r = 0.29$) and the index of services ($r = 0.23$). The number of interventions of a district nurse was higher in widows/widowers ($r = 0.18$), in patients with incomplete primary education ($r = -0.36$), inhabitants of rural areas ($r = 0.38$), and in older patients ($r = 0.41$) ($p < 0.001$ for all).

The number of chronic diseases correlated negatively with QoL satisfaction and with all QoL domains: physical ($r = -0.50$), psychological ($r = -0.44$), social relationship ($r = -0.36$), and environmental ($r = -0.37$) ($p < 0.0001$ for all). It correlated positively with the number of hospitalizations ($r = 0.22$, $p < 0.001$), home visits ($r = 0.37$, $p < 0.001$), consultations over the phone ($r = 0.33$, $p < 0.001$ for all), and interventions of a district nurse ($r = 0.29$, $p < 0.001$), and with BMI ($r = 0.27$, $p < 0.001$) and the index of services ($r = 0.41$, $p < 0.001$). The number of chronic diseases was higher in widows/widowers ($r = 0.26$), in patients with incomplete primary education ($r = -0.24$), inhabitants of rural areas ($r = 0.38$), and in older patients ($r = 0.41$) ($p < 0.001$ for all).

The index of services correlated negatively with QoL satisfaction ($r = -0.34$, $p < 0.001$), health satisfaction ($r = -0.32$, $p < 0.001$), and with all QoL domains: physical ($r = -0.36$), psychological ($r = -0.26$), social relationship ($r = -0.21$), and environmental ($r = -0.21$) ($p < 0.0001$ for all). It correlated positively with the number of health education courses ($r = 0.20$, $p < 0.001$) and with the interventions of a district nurse ($r = 0.39$, $p < 0.001$). The index of services was higher in widows/widowers ($r = 0.10$, $p = 0.047$), in patients with incomplete primary education ($r = -0.26$), inhabitants of rural areas ($r = 0.16$), and in older patients ($r = 0.27$) ($p < 0.001$ for all).

3.2 Incidence Rate

The risk of hospitalization in a 3-year period per 100,000 patients with chronic diseases was: R = 69,360 (95 % CI 65,653–73,067). The rate of home visits per 100,000 patients with chronic diseases during one year is: R = 22,664 (95 % CI 18,698–26,630), consultations over the phone: R = 38,785 (95 % CI 34,169–43,401), and that of an intervention by a district nurse: R = 27,103 (95 % CI 22,892–31,314).

3.3 Odds Ratio for Hospitalization

The results of logistic regression were shown in Table 5. The patients with the lowest QoL levels in the physical domain (*vs*. the patients with the highest QoL levels in this domain) had OR for hospitalizations equal to 30.58 (95 % CI 21.99–42.99). In patients with the highest QoL levels in the psychological domain (*vs*. the patients with the lowest levels in this domain), OR was 8.94 (95 % CI 3.16–34.92). In patients with the lowest levels of health satisfaction (*vs*. patients with the highest level) OR was 4.73 (95 % CI 3.67–6.13). In patients with the lowest QoL level in the social relationship domain (*vs*. patients with the highest level) OR was 4.26 (95 % CI 3.29–5.53). In patients with the lowest levels of satisfaction with QoL (*vs*. patients with the highest level) OR was 3.82 (95 % CI 2.95–4.96). In patients with higher education (*vs*. patients with primary education) OR was 2.31 (95 % CI 1.68–3.24). In patients with five consultations over the phone during 12 months (*vs*. patients without such consultations) OR was 2.07 (95 % CI 1.43–3.01). In patients with the index of services equal to 11 (*vs*. patients with the index of services equal to 1) OR was 1.94 (95 % CI 1.34–2.83). In patients from rural areas (*vs*. patients from cities/towns with a population over 200,000) OR for hospitalizations was 1.80 (95 % CI 1.26–2.60).

4 Discussion

In the study group, QoL satisfaction was higher than health satisfaction. It is worth emphasizing that health ranks high on the list of the most important social values. In accordance with the analyses of the Central Statistical Office in Poland (CSO 2012), the subjective Poles' health assessment improved by 5 percentage points between the years 2004 and 2009 (34 % *vs*. 39 % of Poles assessed their health as less than good, respectively). Women significantly more often evaluate their health as less than good, as also do older residents of rural areas and patients with lower level of education. The present study on a group of patients with chronic respiratory diseases did not confirm the correlation of QoL with gender or the place of residence. It was found, however, that the level of health satisfaction depended on age, the level of education, and marital status. Other studies suggest that low health assessment is a predictor of death, particularly in women, and in men: higher education, unhealthy behaviors, and chronic diseases, especially ischemic heart disease and asthma (Pac et al. 2012).

In the presented study, the lowest QoL was observed in psychological domain, increasing in the order of physical, environmental domain, and social relationship domains. Similar results were reported by Van Damme-Ostapowicz et al. (2012). It has been established that a low QoL level in physical domain, like that in

Table 5 Results of logistic regression ($n = 594$). Response variable: hospitalization in the period of 3 years

i	Constant/variables	Estimate β_i	SE	z-value	Pr (>lzl)
Model 1					
0	Intercept	1.59	0.64	2.51	0.01
1	Satisfaction with QoL	−0.34	0.16	−2.10	0.04
2	Consultations over the phone	0.15	0.06	2.55	0.01
3	Education	0.14	0.07	2.10	0.04
4	QoL – social relationship domain	−0.09	0.04	−2.09	0.04
5	Index of services	0.07	0.02	4.42	0.00
Model 2					
0	Intercept	1.53	0.61	2.53	0.01
1	Satisfaction with health state	−0.39	0.14	−2.81	0.01
2	Consultations over the phone	0.15	0.06	2.59	0.01
3	Education	0.14	0.07	2.06	0.04
4	QoL – social relationship domain	−0.09	0.04	−2.04	0.04
5	Index of services	0.07	0.02	4.31	0.01
Model 3					
0	Intercept	2.25	0.60	3.73	0.01
1	Satisfaction with health state	−0.34	0.16	−2.14	0.03
2	QoL – physical domain	−0.21	0.07	−3.20	0.01
3	Consultations over the phone	0.17	0.06	3.01	0.01
4	QoL – psychological domain	0.14	0.06	2.32	0.02
Model 4					
0	Intercept	1.91	0.61	3.10	0.01
1	QoL – physical domain	−0.22	0.05	−4.61	0.01
2	Education	0.18	0.07	2.66	0.01
3	Consultations over the phone	0.13	0.05	2.47	0.01
4	Index of services	0.07	0.02	4.33	0.01
Model 5					
0	Intercept	1.43	0.56	2.54	0.01
1	Satisfaction with health state	−0.44	0.15	−3.00	0.01
2	QoL – psychological domain	0.20	0.06	3.57	0.01
3	QoL – physical domain	−0.20	0.06	−3.11	0.01
4	Place of residence	0.10	0.04	2.81	0.01

QoL quality of life. Estimate βi – estimated coefficient βi in the regression equation; SE – standard error of the coefficient; z-value – value of normal reference distribution; Pr (>lzl) – two-tailed p-value corresponding to the z-value

education, is a strong predictor of frequent visits to a doctor (Rifel et al. 2013); the association was confirmed in the present study. The significance of the physical domain for the total QoL score has also been demonstrated by Gunaydin et al. (2011). They argue that the total QoL level can be increased through the influence exerted on this domain. The role of environmental domain in QoL modulation, described in the present study is in line with a report by Levasseur et al. (2009).

Additionally, we found that the number of visits to a doctor was higher among patients with low QoL in all domains, residents of rural areas, and in the elderly. Breeze et al. (2005) showed that patients of advanced age have low QoL in social relationship domain. Steptoe et al. (2013) showed in a group of 6,500 patients aged 52 years and older, that socially isolated patients had a higher death rate (HR 1.26, 95 % CI 1.08–1.48 for the highest quartile of isolation). Isolation was of greater significance than the feeling of loneliness in these patients (HR 0.92, 95 % CI 0.78–1.09). It also was found that social isolation involves a higher risk of cardiovascular disease, infectious diseases, cognitive disorders, and deaths. Patients with high levels of social isolation suffer from hypertension, have increased C-reactive protein levels and fibrinogen (Shankar et al. 2011), and increased inflammatory and metabolic response to stress-inducing factors (Grant et al. 2009). Social relationships are thus regarded crucial for the health state and QoL levels.

In the present study we noted lower QoL levels in patients with lower education, a feature also reported by Mota-Pinto et al. (2011). The pointed significance of age and marital status for the QoL level and of gender for the QoL in psychological domain stands in contradiction to the findings of Zielinska-Wieczkowska et al. (2011), but corresponds with the results obtained by Ordu Gokkaya et al. (2012). The study group analyzed by the former consisted of the Third Age University listeners. This group was more homogeneous regarding age and marital status than the group of patients with chronic respiratory diseases in the present study.

Patients with multiple diseases can be assumed to have lower QoL levels (Fortin et al. 2006), which was confirmed by the presented results. We also found that patients who used health care services more frequently had lower QoL, which indicates that counteracting excessive health care utilization may lead to an improvement in QoL. Also, Jakobsson et al. (2011) and Baernholdt et al. (2012) maintain that higher QoL levels are accompanied by lower levels of primary health care utilization.

We demonstrated a high incidence rate for hospitalization in the study group. The main contributor to the possibility of hospitalization was low QoL in physical domain (patients with the lowest level had nearly 31 times more chances for hospitalization than those with the highest level). Opposite results were obtained for QoL in psychological domain; patients with the highest level had almost nine times more chances for hospitalization than those with the lowest level. Patients with the lowest level of health satisfaction had almost five times more chances for hospitalization compared with those with the highest level. Patients with the lowest QoL in social relationship domain had over four times more chances for hospitalization than those with the highest level. Immediate family members, especially those who fulfill the role of home caregivers, can prevent potential hospitalizations through the provision of comprehensive home care. A high level of social isolation, expressed by low level of QoL in social relationship domain, involves a higher mortality rate, especially in case of aged patients (Steptoe et al. 2013). Moreover, patients with low QoL satisfaction had nearly four times more chances for hospitalization than those with the highest level of it. Patients with higher education, on the other hand, had over twice more chances for hospitalization than those with primary education. Likewise, doubling the hospitalization chance concerned patients from rural areas (*vs.* patients from cities/towns with a population of over 200,000 citizens), those with at least five consultations over the phone during the past 12 months, and those with an average value of the index of services.

Analysis of medical services (hospitalizations, visits to outpatient clinics, and admissions to the emergency unit) in the U.S. in 1990, 1995, and 1999 showed a relationship between the level of these services and the employment rate of primary care doctors in urban areas. A high participation of family doctors in the health care system was related to a significantly lower use of specialized medical services – the number of admissions to hospital was lower by 503 per every 1 %, the number of admissions to the emergency department was lower by 2,968 per every 1 %, and the number of visits to outpatient clinics was lower by 512 per every 1 % (Kravet et al. 2008). Einarsdóttir et al. (2010) showed that better primary care provided for patients with chronic respiratory diseases reduces the frequency of hospitalizations. Similar observations were made in patients with chronic obstructive pulmonary disease receiving outpatient treatment (Calderón-Larrañaga et al. 2011).

5 Conclusions

Low QoL level is associated with a low level of health care utilization among patients with chronic respiratory diseases. Most patients were hospitalized during the past 3 years. The target group in hospitalization prevention programs should include patients with chronic respiratory diseases and low levels of QoL in physical and social relationship domains, low levels of health satisfaction, high levels of QoL in psychological domain, higher education, residents of rural areas, those using frequent consultations over the phone, and those with at least an average index of services.

Conflicts of Interest The authors have no financial or otherwise relations that might lead to a conflict of interest.

References

Baernholdt M, Hinton I, Yan G, Rose K, Mattos M (2012) Factors associated with quality of life in older adults in the United States. Qual Life Res 21:527–534

Breeze E, Jones DA, Wilkinson P, Bulpitt CJ, Grundy C, Latif AM, Fletcher AE (2005) Area deprivation, social class, and quality of life among people aged 75 years and over in Britain. Int J Epidemiol 34(2):276–283

Brown J, Bowling A, Flynn TN (2004) Models of quality of life: a taxonomy and systematic review of the literature. Report commissioned by European Forum on Population Ageing Research/Quality Life, University of Sheffield

Calderón-Larrañaga A, Carney L, Soljak M, Bottle A, Partridge M, Bell D, Abi-Aad G, Aylin P, Majeed A (2011) Association of population and primary healthcare factors with hospital admission rates for chronic obstructive pulmonary disease in England: national cross-sectional study. Thorax 66(3):191–196

CSO – Central Statistical Office (2012) Concise statistical yearbook of Poland. Available from: www.stat.gov.pl/cps/rde/xbcr/gus/oz_maly_rocznik_statystyczny_2012.pdf. Accessed 11 Oct 2012

Einarsdóttir K, Preen DB, Emery JD, Kelman C, Holman CD (2010) Regular primary care lowers hospitalisation risk and mortality in seniors with chronic respiratory diseases. J Gen Intern Med 25(8):766–773

Fortin M, Bravo G, Hudon C, Lapointe L, Dubois MF, Almirall J (2006) Psychological distress and multimorbidity in primary care. Ann Fam Med 4 (5):417–422

Frisch MB (1998) Quality of life therapy and assessment in health care. Clin Psychol Sci Pract 5:19–40

Grant N, Hamer M, Steptoe A (2009) Social isolation and stress-related cardiovascular, lipid, and cortisol responses. Ann Behav Med 37(1):29–37

Gunaydin R, Karatepe AG, Kaya T, Ulutas O (2011) Determinants of quality of life (QoL) in elderly stroke patients: a short-term follow-up study. Arch Gerontol Geriatr 53(1):19–23

Jakobsson U, Kristensson J, Hallberg IR, Midlöv P (2011) Psychosocial perspectives on health care utilization among frail elderly people: an explorative study. Arch Gerontol Geriatr 52(3):290–294

Jaracz K, Kalfoss M, Gorna K, Baczyk G (2006) Quality of life in Polish respondents: psychometric properties of the Polish WHOQOL-Bref. Scand J Caring Sci 20 (3):251–260

Kersnik J, Svab I, Vegnuti M (2001) Frequent attenders in general practice: quality of life, patient satisfaction, use of medical services and GP characteristics. Scand J Prim Health Care 19(3):174–177

Kravet SJ, Shore AD, Miller R, Green GB, Kolodner K, Wright SM (2008) Health care utilization and the proportion of primary care physicians. Am J Med 121(2):142–148

Levasseur M, St-Cyr Tribble D, Desrosiers J (2009) Meaning of quality of life for older adults: importance of human functioning components. Arch Gerontol Geriatr 49(2):e91–e100

Mota-Pinto A, Rodrigues V, Botelho A, Veríssimo MT, Morais A, Alves C, Rosa MS, de Oliveira CR (2011) A socio-demographic study of aging in the Portuguese population: the EPEPP study. Arch Gerontol Geriatr 52(3):304–308

Ordu Gokkaya NK, Gokce-Kutsal Y, Borman P, Ceceli E, Dogan A, Eyigor S, Karapolat H (2012) Geriatric Rehabilitation Research Group of Turkish Society of Physical Medicine and Rehabilitation. Pain and quality of life (QoL) in elderly: the Turkish experience. Arch Gerontol Geriatr 55 (2):357–362

Pac A, Tobiasz-Adamczyk B, Brzyska M, Florek M (2012) The role of different predictors in 20-year mortality among Krakow older citizens. Arch Gerontol Geriatr 56(3):524–530

Rifel J, Svab I, Selič P, Rotar Pavlič D, Nazareth I, Car J (2013) Association of common mental disorders and quality of life with the frequency of attendance in Slovenian family medicine practices: longitudinal study. PLoS One 8(1):e54241

Shankar A, McMunn A, Banks J, Steptoe A (2011) Loneliness, social isolation, and behavioral and biological health indicators in older adults. Health Psychol 30 (4):377–385

Steptoe A, Shankar A, Demakakos P, Wardle J (2013) Social isolation, loneliness, and all-cause mortality in older men and women. Proc Natl Acad Sci U S A 10 (15):5797–5801 van Damme-Ostapowicz K, Krajewska-Kulak E, Rozwadowska E, Nahorski WL, Olszanski R (2012) Quality of life and satisfaction with life of malaria patients in context of acceptance of the disease: quantitative studies. Malar J 11:171

WHO – European health report 2012. Available from: http://www.who.un.org.pl/aktualnosci.php?news=84&wid=14. Accessed 14 Mar 2013

WHOQOL Group (1998) Development of the World Health Organization WHOQOL-BREF quality of life assessment. Psychol Med 28:551–558

Zielinska-Wieczkowska H, Kedziora-Kornatowska K, Ciemnoczolowski W (2011) Evaluation of quality of life (QoL) of students of the University of Third Age (U3A) on the basis of socio-demographic factors and health status. Arch Gerontol Geriatr 53(2):e198–e202

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Usage of Medical Internet and E-Health Services by the Elderly

Maria M. Bujnowska-Fedak and Agnieszka Mastalerz-Migas

Abstract

Internet and e-health services have a substantial potential to support efficient and effective care for the elderly. The aim of the study was to investigate the use of Internet for health-related purposes among Polish elderly, the frequency and reasons of use, the importance of e-health services, and factors affecting their use. A total of 242 elderly at the age of ≥60 years were selected from the Polish population by random sampling. Data collection was carried out by phone interviews in October–November 2012. The study shows that the Internet was ever used by 32 % of the elderly and 1/5 claimed a regular use. Among the Internet users, 81 % of older people used it to obtain information about health or illness. The Internet was one of the less important sources of information (important for 27 % of respondents), face to face contact with health professionals and family and friends are still the most required source of medical information (75 %). Only 7 % of elderly Internet users approached the family physician, specialists, or other health professionals over the Internet. Factors that positively affected the use of Internet among elderly were male gender, younger age, higher education, living with family, mobile phone use, and a subjective assessment of one's own health as good. The doctor's provision of Internet-based services was important in the opinion of approximately 1/4 of older people. We conclude that the development of information and communications technology (ICT) tools increasingly meets the evolving needs of patients in the field of e-health. More and more elderly become beneficiaries of these services.

Keywords

Eldercare • Health service • Health status • Information and communications technology • Internet

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1 Introduction

The number of computer users and people who have access to the Internet increases in Poland every year, which is consistent with the European and global trend (Fox 2013; Seybert 2012; Bujnowska-Fedak and Staniszewski 2008; Kummervold et al. 2008; Trotter and Morgan 2008; Andreassen et al. 2007; Bujnowska-Fedak et al. 2007). According to the 2012 Eurostat report, 70 % of Polish households have access to the Internet, which is a 22 % increase compared with 2008 and an increase of 7 percentage points compared with 2010 (Seybert 2012). The internet has become one of the essential sources of medical information, and also the important medium offering different types of e-health services (Bujnowska-Fedak and Pirogowicz 2014; Duplaga 2013; Takahashi et al. 2011; Jung and Loria 2010; Glinkowski and Sawińska 2008; Kummervold et al. 2008; Andreassen et al. 2007). At the same time, the world population is rapidly aging as a result of both longer lifespan and declining fertility rates. Between 2000 and 2050, the proportion of the world's population over 60 years of age will double from about 11–22 % (WHO 2012). While in the 1930s people over 65 years of age accounted for 4.8 % of the Polish population, this proportion increased to 13.8 % in 2012, and it is projected to reach about 30 % in 2050 (Central Statistical Office 2013; The World Bank Group 2011). The demographic change implies a significant increase in the demand for health care and social services, and increasing funds in the health sector (Bloom et al. 2011). The information and communication technologies (ICT) have a substantial potential to support efficient and effective care for the elderly.

The aim of the present study was to investigate the use of Internet for health-related purposes among the Polish elderly, the frequency and reasons of use, the importance of e-health services, and the factors affecting their use.

2 Methods

Respondents were provided with the comprehensive information about the objectives and scope of the survey. The survey protocol was approved by the Bioethical Committee of the Medical University of Wroclaw, Poland (statutory activity number 481/2010).

A total of 242 elderly in the age of $\geq$60 years were selected from the Polish population by random sampling. Data collection was carried out by the Polish opinion poll agency 'TNS POLSKA SA' by computer-assisted telephone interviews in October-November 2012. The study was conducted with a specially designed questionnaire related to the use of the Internet for health purposes.

The distinguished groups (Internet users, Internet non-users, Internet users for health purposes, Internet non-users for health purposes) were compared in terms of their average scores to identify the significant predictors. For normally distributed variables with equal variances in groups, significance of differences between means was estimated by a t-test. In case of non-normally distributed variables, the Mann-Whitney U test was used for comparisons. For qualitative variables, chi-squared test was performed to determine significant dependencies. All tests were two-sided and $p < 0.05$ was defined to indicate statistical significance. Statistical analysis was performed using a commercial SPSS 21.0 package.

3 Results and Discussion

The study group included 97 males (40 %) and 145 females (60 %), and the mean age was 70.3 $\pm$ 8.2 years. A hundred and fifty nine of the respondents (66 %) lived in cities and 83 (34 %) in rural areas.

The Internet was ever used by 32 % of the elderly ($n = 77$) and 22 % of the respondents had

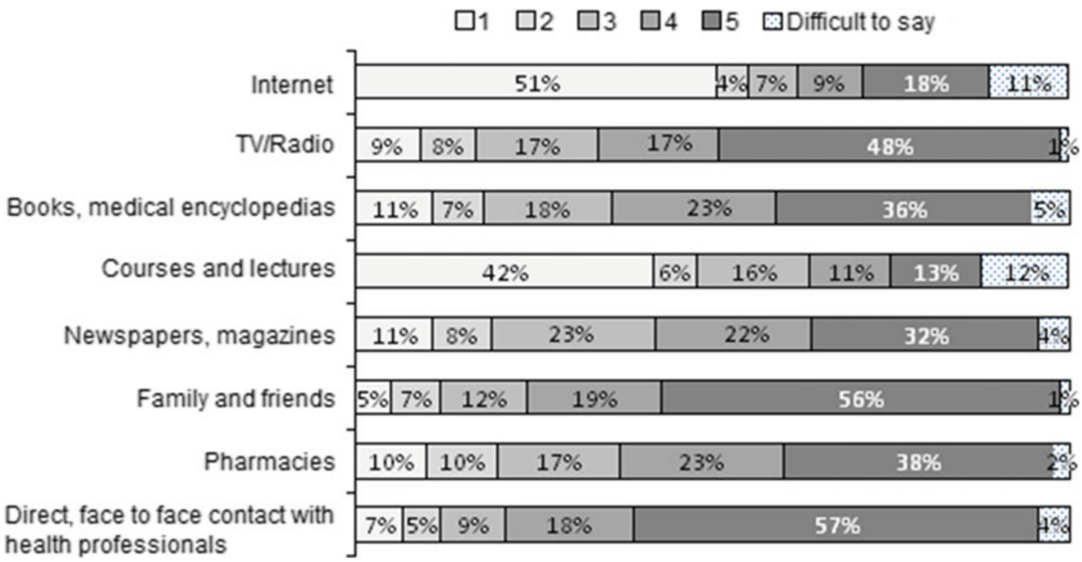

Fig. 1 **Sources of information about health or illness** (5-point scale of importance, where 1 is 'unimportant' and 5 is 'very important')

used it at least once a week. Among the Internet users 81 % of older people used it to obtain information about health or illness. The Internet was one of the less important sources of information (important/very important for 27 % of respondents), next to courses and lectures (24 %). As in previous studies (Kummervold et al. 2008; Andreassen et al. 2007; Bujnowska-Fedak et al. 2007), a face to face contact with health professionals, family, and friends is still the most required source of medical information for the elderly (75 %). Recently, a growing importance of pharmacies had been observed in the oldest patients (Fig. 1).

The search for information about health and illness was definitely the most frequent activity performed online by elderly and reflected their main interests in this area (72 % of Internet users), which is in rapport with other studies (Takahashi et al. 2011; Glinkowski and Sawinska 2008; Trotter and Morgan 2008; Andreassen et al. 2007; Bujnowska-Fedak et al. 2007). Overall, only did 7 % of the elderly Internet users approach their family physician, specialist, or other health professionals over the Internet; 4 % of the elderly did it to schedule appointments, 2.5 % to request or renew the prescription, another 2.5 % to ask specific health questions or to get medical recommendations, 1 % to study their medical records, and another 1 % to become acquainted with the doctor's website. However, a positive change has been found in this regard and the overall trend is moving toward an increase in the communication with health personnel over the Internet (Kummervold et al. 2008; Beckjord et al. 2007). On the other side, the majority of elderly reported a strong preference to have a direct contact with health professionals (61 %), 16 % had concerns about the confidentiality of such contact and 8 % reported the lack of sufficient skills for interactive online activities.

When choosing a new doctor, e-health solutions proved to be important/very important in the opinion of approximately 1/4 of elderly. Older people were most interested in the possibility to search the doctor's own website (3.22 ± 1.99 on the 1–5 scale of importance), to get SMS (short message system) reminders about the upcoming doctor's visit or simple medical

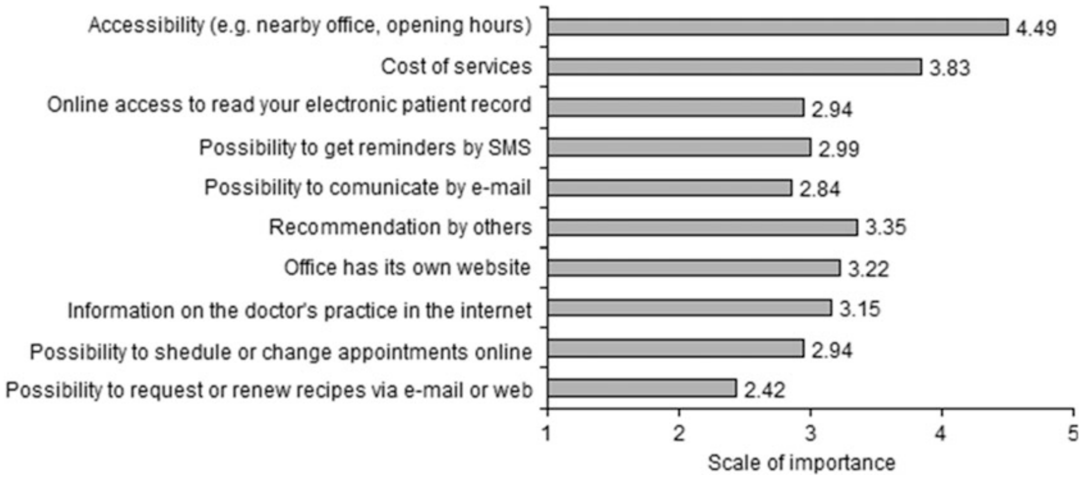

Fig. 2 **Factors determining the choice of a new doctor** (in a 5-point scale of importance, where 1 stands for 'not important' and 5 stands for 'very important')

recommendations (2.99 ± 1.92), to get access to their own medical records (2.94 ± 1.98), or to schedule or change appointments online (2.94 ± 2.07) (Fig. 2). The results are, to an extent, consistent with other surveys (Duplaga 2013; van Uden-Kraan et al. 2009; Glinkowski and Sawinska 2008; Andreassen et al. 2007; Bujnowska-Fedak et al. 2007).

Multivariable analysis of different factors influencing a general use of Internet and Internet for health purposes was conducted (Table 1). Factors that positively affected the use of Internet among elderly were male gender ($p = 0.016$), younger age ($p < 0.001$), higher education ($p = 0.001$), living with family (0.006), mobile phone use ($p < 0.001$). And a subjective assessment of one's own health as good ($p = 0.025$). Factors influencing the use of Internet for health purposes were similar, except for the male gender and good health assessment, a significant relationship was not confirmed for. No significant associations between Internet users in general/users specifically for health purposes and Internet non-users/non-users for health purposes were found in regard to the place of residence, employment status, frequency of visits to the doctors, long-term illnesses, or disability. Some of these associations were found by other researchers; especially the effect of younger age, higher education, mobile phone use, and the influence of good health status (Duplaga 2013; Bujnowska-Fedak and Pirogowicz 2014; Takahashi et al. 2011; Cresci et al. 2010; Glinkowski and Sawinska 2008; Andreassen et al. 2007).

4 Conclusions

The development of information and communication technologies makes the needs of patients to increase in the field of e-health. The beneficiaries of these services are becoming more and more elderly people. The study shows that the Internet was ever used by almost 1/3 of the elderly, 1/5 of them used it regularly, and more than 80 % of the users did it for health purposes. Older people rarely used the Internet as a communication tool for health-related matters. Factors that positively affected the use of Internet among the elderly were male gender, younger age, higher education, living with family, mobile phone use, and a subjective assessment of one's own health as good. There is certainly a need to continue research in this area.

Table 1 Factors influencing general and for health purpose internet users[a]

Characteristics	Internet users in general (n = *77*) %	Internet non-users in general (n = *165*) %	p	Internet users for health (n = *62*) %	Internet non-users for health (n = *180*) %	p
Men	50.6	35.2		46.8	37.8	
Women	49.4	64.8	**0.016**	53.2	62.6	0.213
Age (years ± SD)	66.7 ± 6.7	72.0 ± 8.3	<**0.001**	66.0 ± 5.6	71.8 ± 8.4	<**0.001**
Education[b]						
A level	33.8	55.2		30.6	54.4	
B level	36.3	32.7		40.3	31.7	
C level	29.9	12.1	**0.001**	29.1	13.9	**0.002**
Employment status						
Paid work (including self-employment)	6.5	1.8		3.2	3.3	
Retired/housework/care for relations/unemployed and others	92.2	92.7		95.2	91.7	
Permanently sick or disabled	1.3	5.5	0.059	1.6	5.0	0.511
Residence						
Big cities (above 100,000 residents)	26.0	30.3		25.8	30.0	
Minor cities	45.4	32.7		46.8	33.3	
Villages/rural area	28.6	37.0	0.155	27.4	36.7	0.158
Living						
Alone	20.8	37.6		22.6	35.6	
With family	79.2	62.4	**0.006**	77.4	64.4	**0.040**
Health status (subjective assessment)						
Very good/good	37.7	24.8		37.1	32.0	
Fair	54.5	55.9		53.2	56.3	
Poor/very poor	7.8	19.3	**0.025**	9.7	11.7	0.347
Frequency of doctor's visits (During last 12 months)						
0 times	5.2	6.7		4.8	6.7	
1–2 times	14.3	13.9		11.3	13.9	
3–6 times	46.7	33.2		46.8	33.2	
7–12 times	22.1	27.8		27.4	27.8	
13–24 times	10.4	10.6		8.1	10.6	
>24 times	1.3	7.8	0.108	1.6	7.8	0.320
Chronic diseases/disability						
Yes; myself	22.6	28.7		23.3	28.0	
Yes; a person close to me	33.3	24.1		33.3	24.9	
No	44.1	47.2	0.263	43.4	47.1	0.383
Mobile phone use						
Yes	87.0	64.8		88.7	66.1	
No	13.0	35.2	<**0.001**	11.3	33.9	<**0.001**

[a]Significant differences between groups are in bold
[b]The item related to the education of the respondents included 11 options, from basic to university level, specific to the Polish education system. The 11 levels were collapsed into three categories according to the International Standard Classification of Education (ISCED): (A) education level lower than upper secondary; (B) education level including upper secondary to post-secondary non-tertiary; and (C) education level covering all levels according to ISCED higher than post-secondary non-tertiary. P-values are common for all pairwise comparisons in a given category

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References

Andreassen HK, Bujnowska-Fedak MM, Chronaki CE, Dumitru RC, Pudule I, Santana S, Voss H, Wynn R (2007) European citizens' use of e-health services: a study of seven countries. BMC Public Health 7(1):53

Beckjord EB, Finney Rutten LJ, Squiers L, Arora NK, Volckmann L, Moser RP, Hesse BW (2007) Use of the internet to communicate with health care providers in the United States: estimates from the 2003 and 2005 Health Information National Trends Surveys (HINTS). J Med Internet Res 9(3):e20

Bloom DE, Canning D, Fink G (2011) Implications of population aging for economic growth. Program on the global demography of aging. Working paper No 64. Available from: http://www.diseaseriskindex.harvard.edu/pgda/WorkingPapers/2011/PGDA_WP_64.pdf. Accessed 5 Feb 2014

Bujnowska MM, Pirogowicz I (2014) Support for e-health services among elderly primary care patients. Telemed e- Health 20(8):696–704. doi:10.1089/tmj.2013.0318. Epub 2013 Dec 20

Bujnowska-Fedak MM, Staniszewski A (2008) The needs of the Polish society concerning the use of medical Internet and e-Health services in the context of other European countries. In: Steciwko A (ed) Selected issues in family medicine, vol 12: Reducing diagnosis and treatment risks by leveraging knowledge and practices of health care professionals. Published by Continuo, Wrocław, pp 127–133 (Publication bilingual in English and Polish)

Bujnowska-Fedak MM, Staniszewski A, Steciwko A (2007) A survey of Internet use for health purposes in Poland. J Telemed Telecare 13(Suppl 1):16–19

Central Statistical Office. Demographic Year Book of Poland (2013) Available from: http://www.stat.gov.pl/gus/5840_rocznik_demograficzny_PLK_HTML.htm. Accessed 24 Oct 2013

Cresci MK, Yarandi HN, Morel RW (2010) The digital divide and urban older adults. Cin-Comput Inform Nurs 28(2):88–94

Duplaga M (2013) The acceptance of e-health solutions among patients with chronic respiratory conditions. Telemed e-Health 19(9):683–691

Fox S (2013) Pew Internet & American Life project. Pew Internet: health. Available from: http://www.pewinternet.org/Commentary/2011/November/Pew-Internet-Health.aspx. Accessed 24 Oct 2013

Glinkowski W, Sawinska M (2008) Consumers use of the internet health information resources: results of the Omnimas Polish Survey 2007. In: Blobel B, Pharow P, Zvarova J, Lopez D (eds) eHealth: combining health telematics, telemedicine biomedical engineering and bioinformatics to the edge. CeHR conference proceedings 2007. IOS Press, AKA, Berlin, pp 251–256. Available from: http://books.google.pl/books?id=e0aohtxt5bqc&pg=pa251&dq=glinkowski+sawinska&hl=pl&sa=x&ei=rr0eut3ammkio6idgegb&ved=0cdiq6aewaa. Accessed 29 Oct 2013

Jung M-L, Loria K (2010) Acceptance of Swedish e-Health services. J Multidiscip Healthc 3:55–63

Kummervold PE, Chronaki CE, Lausen B, Prokosch HU, Rasmussen J, Santana S, Staniszewski A, Wangberg SC (2008) E-Health trends in Europe 2005–2007: a population-based survey. J Med Internet Res 10(4):e42

Seybert H (2012) Internet use in households and by individuals in 2012. EUROSTAT. Industry, trade and services. Statistics in focus. Available from: http://epp.eurostat.ec.europa.eu/cache/ity_offpub/ks-sf-12-050/en/ks-sf-12-050-en.pdF. Accessed 29 Oct 2013

Takahashi Y, Ohura T, Ishizaki T, Okamoto S, Miki K, Naito M, Akamatsu R, Sugimori H, Yoshiike N, Miyaki K, Shimbo T, Nakayama T (2011) Internet use for health-related information via personal computers and cell phones in Japan: a cross-sectional population-based survey. J Med Internet Res 13(4):e110

The World Bank Group (2011) Population projection tables by country and group. Poland. Available from: http://web.worldbank.org/wbsite/external/topics/exthealthnutritionandpopulation/extdatastatisticshnp/exthnpstatS/0,,contentMDK:21737699~menuPK:3385623~pagePK:64168445~piPK:64168309~theSitePK:3237118,00.html. Accessed 5 Feb 2014

Trotter MI, Morgan DW (2008) Patients' use of the internet for health related matters: a study of internet usage in 2000 and 2006. Health Inform J 14(3):175–181

van Uden-Kraan CF, Drossaert CHC, Taal E, Smit WM, Moens HJB, Siesling S, Seydel ER, van de Laar MAFJ (2009) Health-related Internet use by patients with somatic diseases: frequency of use and characteristics of users. Inform Health Soc Care 34(1):18–29

WHO (2012) Ageing and life course. Ten facts on ageing and the life course. Available from: http://www.who.int/features/factfiles/ageing/ageing_facts/en/index.html. Accessed 29 Oct 2013

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