Airborne toxic exposure and pulmonary outcomes among petrochemical complex workers

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Abstract

Background

Petrochemical workers are exposed to a variety of airborne toxic compounds which have been associated with increased risk for respiratory outcomes. However, long-term exposure to SO_2, NO_2, O_3, H_2S and NH_3 in relation to spirometric parameters and self-reported respiratory problems is largely unknown.

Methods

Airborne concentration levels of SO_2, NO_2, O_3, H_2S and NH_3 were collected from two fixed stations over a 3-year period in a petrochemical complex. We assessed spirometric parameters and respiratory symptoms in the petrochemical workers (n = 200) and in an unexposed group (n = 200). We calculated β-coefficients (β) and odds ratios (ORs) with 95% confidence intervals (CIs) before and after adjustment for covariates.

Results

The mean airborne pollution levels were 159 $\mu g/m^3$ for SO_2, 43 $\mu g/m^3$ for NO_2, 66 $\mu g/m^3$ for O_3, 6 $\mu g/m^3$ for H_2S, and 24 $\mu g/m^3$ for NH_3. We found a significant reduction in spirometric parameters among petrochemical workers compared to the unexposed: FEV1 (forced expiratory volume in 1s) (adjusted β -12; 95%CI -16, -7.64), FEV1/ FVC (forced vital capacity) (β -7.26; 95%CI -9.23, -5.28), and PEF (peak expiratory flow) (β -6.61; 95%CI -12, -0.76). Additionally, we observed higher adjusted risks for any respiratory symptom (OR 4.69; 95%CI 1.76, 12), mucus (OR 4.36; 95%CI 1.70, 11) and shortness of breath (OR 15; 4.95, 46) among petrochemical workers compared to the unexposed group.

Conclusions

Most measured airborne pollution levels were within the ambient recommendation levels. Still, long-term exposure to low level airborne pollutants, reduced FEV1, FEV1/FVC and PEF, and increased respiratory symptoms in Iranian petrochemical workers compared to unexposed controls.

1. Background

Petrochemical workers are exposed to a wide variety of airborne toxic and carcinogenic compounds and there is evidence for increased risk for several diseases such as different types of cancer (1–3), renal disease (4), hematological changes, and as well as pulmonary disease (5) among workers in petrochemical industries (4, 6). Emission of aerial toxic substances into the work environment at petrochemical plants and factories mostly happens through release of chemicals during production processes (e.g., separation, conversion, treating, combustion exhaust), but also from leakage of stored products and during transportation (7–9).

A recent investigation found that leakages from ammonia-filled transport vessels led to raised aerial ammonia levels in the working environment of an Iranian petrochemical plant (4). Ryerson and colleagues reported that petrochemical plants could be a significant source of volatile organic compounds (VOCs), nitrogen oxides (NOx), and ozone (O_3) (10). Also, a study of air pollutants within a radius of 5 km around a large complex of oil refineries and petrochemical manufacturing plants showed elevated airborne concentrations of sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and O_3 (11). Hydrogen sulfide (H_2S) is another pollutant that is produced naturally as one of the components of crude petroleum and natural gas. Operation processes including those in petroleum refineries, natural gas plants, and petrochemical plants are the major sources of H_2S, which is released into the environment (12). A Taiwanese refinery study reported emissions of NO_2, SO_2 and O_3, the latter as a result of the photochemical reaction of VOCs and NOx in the presence of sunlight (13). Another study in Romania found SO_2 and H_2S toxicants in the ambient air of almost all production units of a petroleum refinery (14).

Several epidemiological studies have shown significant associations between airborne toxic exposure and respiratory outcomes (15–20). Significant decreases in forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) have been associated with exposure to petrochemical pollutants including SO_2, CO, and O_3 (11). Also, allergic rhinitis, bronchitis and asthma have been associated with exposure to SO_2 (21).

Refinery workers have been reported to be exposed to toxic gases in the workplace (4, 12, 22), which has raised attention towards exposure assessment and health effects in this occupational group. However, long-term monitoring of exposure to SO_2, NO_2, O_3, H_2S and ammonia (NH_3) has, to our knowledge, not been examined in relation to objectively assessed spirometric parameters among petrochemical workers. In the current study, we therefore aimed to describe the long-term aerial concentration levels of SO_2, NO_2, O_3, H_2S and NH_3 in the ambient air of an Iranian petrochemical complex. Further, we compared spirometric parameters and respiratory symptoms between these petrochemical workers and unexposed controls.

2. Methods

2.1. Participants

This retrospective cohort study was counducted in the Iranian petrochemical complex, consisting of 10 refinery and 15 petrochemical plants, in one of the largest industrial sites in the Middle East. Therefore, all workers in this industrial area will, to some extent, experience exposure to toxic chemicals in their work environments (22, 23). Eligibility criteria for the petrochemical worlers were (i) at least one year in their current position and (ii) no history of respiratory diseases or chemical exposures prior to the current position. Using the census sampling method, 200 males engaged in repair and maintenance (n = 182), warehous keeping (n = 9) and ancillary activities (n = 9) were included as petrochemical workers in the study. As unexposed subjects, we included 200 men with the same eligibility critera as the exposed, 100 were sampled from office workers and 100 from gas power plant operators, located 200 km away from the petrochemical complex. In total, the study population constituted 400 Iranian males.

The Ethics Committee of Qom University of Medical Sciences approved the protocol of the current study. All subjects gave written informed consent and all data was de-identified after collection.

2.2. Air pollutants measurments

We extracted data of airborne concentration levels of SO_2, NO_2, O_3, H_2S and NH_3 measured from March 2014 to March 2017 with two fixed, independent air pollutants measurments, located inside the petrochemical complex. All measurments were done by passive samplers, provided and analzed by Passam AG, Männedorf, Switzerland.

SO_2 was measured in the ambient air by a diffusive sampler, impregnated with the mixture of potassium carbonate and glycerol. The sampler was built in a polypropylene housing with an opening of 20 mm diameter. The data was collected from one station every second week over 3 years and one station over 1.5 years (total number of valid samples N = 101). Total amount of SO_2 per sample was extracted using ion chromatography (24). To measure NO_2, a triethanolamine coated sampler was used, placed in a polypropylene tube of 9.8 mm internal diameter and 7.35 cm length. The data collection and exposure period was the same as for SO_2 (total number of valid samples N = 103). The Griess-Saltzman method was applied to determine collected NO_2 (25). To measure O_3, a sodium nitrite coated diffusive sampler in a polypropylene housing (opening of 20 mm) was used. The samples were collected biweekly from one measurment station over 3 years and analyzed by ion chromatography (26) (total number of valid samples N = 46). H_2S was measured as molecules who diffused onto cadmium sulphate as an absorbent in a passive sampler. The samples were collected monthly from two measurement stations over 3 years and analyzed by spectrophotometry (27) (total number of valid samples N = 60). To measure NH_3, we collected airborne ammonia by absorption on phosphoric acid, collected monthly from two measurement stations over 3 years (total number of valild samples N = 58). The amount of NH_3 was determined spectrophotometrically by the indophenol method (28).

All sampling devices were protected from rain and wind by placing them in a special shelter. All devices were equipped with a glass fibre membrane, supported by a wire net, to reduce wind disturbance. All samples were set up at the middle of each month and removed two weeks-one month later. Because of invalid measurement methods (sampler placement error, using invalid sampler, late or early removal of sampler) or instrument errors (e.g. errors in preparation, collection or analysis) the following proportions of samples had to be excluded from our analysis: 7% of SO_2 samples (101/108), 5% of NO_2 samples (103/108), 36% of O_3 samples (46/72), 17% H_2S (60/72) and 20% of NH_3 samples (58/72).

Because the exposure assessment methods were based on stationary, as opposed to personal measurements, it was not possible to directly link exposure to each individual worker. Therefore, for the current analyses we assumed that all petrochemical workers were exposed to the same levels of environmental pollutants.

Because the background exposure level of the investigated pollutants might be high in vicinity of the industrial site, we selected the control group of unexposed workers from the city > 200 km away from petrochemical complex. Levels of average daily exposure for the control population to airborne toxicants were extracted from the literature. Two independent studies reported allmost the same values for public exposure of SO_2, NO_2 and O_3 from 2006–2015 where the controls were living and working (29, 30) while ambient air concentrations of H_2S and NH_3 was exteracted from other reports (31, 32). Two other studies showed that the maximum emmited SO_2 and NO_2 of gas power plants in Iran did not exceed 15 and 5 $\mu g/m^3$, respectively (33, 34).

2.3. Assessment of pulmonary outcomes

2.3.1. Spirometry

We measured FVC, FEV1, FEV1/FVC and peak expiratory flow (PEF) at the beginning of each participant's work shift during the period March to December 2017. We used a calibrated spirometry device (Spirolab III, MIR Italy) and performed the measurements according to the American Thoracic Society guidelines (35). Each participant was examined three times and the best test result for each spirometric parameter was used for the analysis (36). Participants were asked to not smoke, or engage in heavy excersice for at least one hour before the test. Additionally, they were asked to abstain from alchol for at least 8 hours before the test. Spirometric parameters were standardized, based on height-, age- and sex-stratified reference data (general Caucasian population) recommended by the European Respiratory Society and expressed as percent predicted (100%=general population) (37, 38).

Obstructive lung function was classified according to the Global Initiative for Chronic Obstructive Lung Disease as (39):

- "no impairment"= $FEV_1/FVC \geq 70\%$-predicted (grade 0);
- "mild impairment"= $FEV_1/FVC < 70\%$ and $FEV_1 \geq 80\%$-predicted (grade 1);
- "moderate impairment"= $FEV_1/FVC < 70\%$ and $FEV_1 < 80–50\%$-predicted (grade 2).

Obstructive impairment was defined as having grade 2 impairment in obstructive parameters.

Restrictive impairment was defined as grade 2 or higher impairement in restrictive parameters (or FVC < 75%-predicted and FEV1/FVC > 0.70 if TLC was missing) (40).

2.3.2. Respiratory symptoms

All participants completed the European Community Respiratory Health Survey questionnaire II (ECRHS II) to assess prevalence of self-reported respiratory problems (41). The ECRHS II has been widely used to assess prevalence of respiratory symptoms including wheezing, chest tightness, cough, chronic cough, mucus, chronic phlegm and shortness of breath in populations who were occupationally or environmentally exposed to aerial chemical subestanses (42, 43). We further generated a binary variable no respiratory problems vs. any respiratory problem based on the answers to the ECRHS II.

2.4. Covariates

We assessed the following information by questionnaire: age at study entry, height, weight, working hours per week, length of employment, smoking status (smoker, non-smoker), number of cigarettes smoked per day and number of years smoking, marital status (single, married), education (high school diploma or less, higher education) and residential status (permanent residents, non-permanent residents). We calculated the number of pack-years by multiplying the number of packs of cigarettes smoked per day by the number of years the person has smoked (44).

2.5. Data analysis

Statistical analyses were carried out with Stata MP 14.0 (Stata; TX, USA). We used descriptive statistics (means ± SD and numbers with proportions) to present levels of environmental air pollution in vicinity to the the petrochemical complex and the prevalence of lung dysfunction and respiratory symptoms in exposed and unexposed participants. Fisher's exact test and two sample t-test were used to test for significant differences between the exposed and unexposed workers. Univariable and multivariable linear regression models were used to analyse the spirometric parameters in relation to exposure status (exposed vs. unexposed). Univariable and multivariable logistic regression models were used to analyze risk of self-reported respiratory problems and obstructive and restrictive lung dysfunction (grade 2 or higher) in relation to exposure status. The multivariable models were adjusted for number of working hours per week, work type, age at study entry, weight, height, marital status,education level, length of employment, current smoking status, and residential status. A p-value < 0.05 was considered statistically significant.

3. Results

3.1. Study population

We included 200 workers exposed to SO_2, NO_2, O_3, H_2S and NH_3 and 200 unexposed workers (Table 1). The two groups differed by all covariates, except number of cigarette pack-years and educational level. For exposed and unexposed, the respective means were, 37 and 35 years of age when answering the questionnaire, 44 and 48 working hours per week, 10 and 7 years of employment, 8 and 11 cigarettes smoked per day among 26% and 9% current smokers, respectively.

All spirometry parameters were significantly ($p < 0.001$) reduced in the petrochemical workers compared to the unexposed workers when looking at the crude outcomes (Table 1).

Among the petrochemical workers, nine (4.5%) were classified with obstructive impairment compared to one among the unexposed (Table 1). In total, 75 (37%) of the petrochemical workers (exposed) and 30 (15%) of the unexposed workers reported at least one respiratory symptom ($p < 0.001$). The petrochemical workers reported most often shortness of breath followed by mucus. Those two symptoms were reported more often by the petrochemical workers than the unexposed workers (both $p < 0.001$) (Table 1).

Table 1
Charactristics of petrochemical workers and other workers

Variable	Exposed (n = 200)	Unexposed (n = 200)	p-value*
Persional charactristics			
Age (years), mean (SD)	37.0 (7.8)	34.8 (8.4)	0.006
Height (cm), mean (SD)	175.1 (6.0)	173.4 (8.5)	0.020
Weight (kg), mean (SD)	80.9 (12.1)	76.3 (11.5)	< 0.001
Working hours per week, mean (SD)	44.3) 18.1)	47.8 (5.4)	< 0.001
Length of employment (years), mean (SD)	9.9 (4.6)	7.4 (5.7)	< 0.001
Marital status, N (%)			
Single	26 (13)	42 (21)	0.040
Married	174 (87)	158 (79)	
*Education**, N (%)*			
Diploma or less	40 (20)	40 (20)	0.99
Higher education	160 (80)	160 (80)	
Smoking status, N (%)			
Non-smoker	148 (74)	183 (92)	< 0.001
Smoker	52 (26)	17 (8)	
Years smoked, mean (SD)***	9.7 (6.6)	12.2 (9.1)	0.002
Cigarettes per day, mean (SD)***	7.5 (4.4)	10.5 (3.8)	0.007
Pack-years, mean (SD)†	3.52 (3.28)	8.01 (10.13)	0.392
Residency††, N (%)			
Permanent residents	161 (81)	198 (99)	< 0.001
Non-permanent residents	39 (19)	2 (1)	
Spirometry, mean (SD)			
Forced vital capacity (FVC)	95.71 (11.73)	100.99 (11.96)	< 0.001
Forced expiratory volume in 1 second (FEV1)	88.50 (11.36)	100.76 (11.79)	< 0.001
FEV1/FVC	76.67 (5.15)	83.43 (5.26)	< 0.001
Peak expiratory flow (PEF)	97.24 (13.51)	103.93 (16.89)	< 0.001
Obstructive parameters, N (%)‡			
No impairment (grade 0)	178 (89)	199 (99)	< 0.001
Mild impairment (grade 1)	13 (6.5)	0 (0)	
Moderate impairment (grade 2)	9 (4.5)	1 (0.5)	

Variable	Exposed (n = 200)	Unexposed (n = 200)	p-value*
Restrictive parameters, N (%)‡‡			
Not impaired (< grade 2)	196 (98)	199 (99.5)	0.372
Impaired (≥ grade 2)	4 (2)	1 (0.5)	
Respiratory symptom, N (%)			
Any symptom	75 (37.5)	30 (15%)	< 0.001
Wheezing	6 (3%)	2 (1%)	0.284
Chest tightness	12 (6%)	10 (5%)	0.661
Cough	12 (6%)	6 (3%)	0.227
Chronic cough	8 (4%)	2 (1%)	0.105
Mucus	34 (17%)	8 (4%)	< 0.001
Chronic phlegm	12 (6%)	6 (3%)	0.227
Shortness of breath	54 (27%)	4 (2%)	< 0.001

Abbreviations: N, number; SD, standard deviation.

* P-value comparing exposed and unexposed participants

** Diploma or less includes: compulsory school only, high school; higher education includes: bachelor degree, master degree or higher.

*** Mean (SD) calculated in current smokers only ($n_{exposed}$=52, $n_{unexposed}$=17)

† calculated by multiplying the number of packs of cigarettes smoked per day by the number of years the person has smoked

†† Permanent residents: workers who live in the city; Non-permanent residents: workers who work and live temporarily (usually 14 day/month) in the city

‡ “no impairment”=FEV_1/FVC ≥ 70%-predicted (grade 0), “mild impairment”=FEV_1/FVC < 70% and FEV_1 ≥ 80%-predicted (grade 1), “moderate impairment”=FEV_1/FVC < 70% and FEV_1 < 80–50%-predicted (grade 2);

‡‡ “no or mild imperment”=FVC < 75%-predicted (grade 0 and 1), moderate or higher impairement = FVC < 75%-predicted and FEV1/FVC > 0.7 (grade 2 or higher)

3.2. Levels of environmental air pollution

Table 2 shows the overall average aerial concentration of the five measured toxicants during the the 3-year sampling period as well as the ambient recommendation levels (ARL), established by the World Health Organization (WHO-ARL) and permissible exposure limits (PEL), established by the Occupational Safety and Health Administration (OSHA-PEL). The mean levels were 159 μg/m^3 (SD = 84) for SO_2, 43 μg/m^3 (SD = 16) for NO_2, 66 μg/m^3 (SD = 47) for O_3, 6 μg/m^3 (SD = 13) for H_2S, and 24 μg/m^3 (SD = 11) for NH_3.

Table 2
Airborne concentration of toxic chemicals (μg/m3) in the surrounding area of the petrochemical complex

Chemical	sample*	Mean (SD)	25th	50th	75th	Min	Max	ARL / MRL**	PEL***	MDE†
SO_2	101	158.61 (83.95)	108.30	139.60	196.85	1.20	625.00	20 (24-hours)	13000	10.50
NO_2	103	43.48 (15.77)	33.90	45.60	52.40	0.50	111.70	40 (annual)	900 (Ceiling limit)	3.60
O_3	46	66.48 (47.46)	18.87	66.60	100.45	5.10	192.70	100 (8-hours)	200	5.90
H_2S	60	6.14 (13.47)	1.62	3.40	4.67	0.90	87.60	28 (up to a year)	28000 (Ceiling limit)	< 1
NH_3	58	24.18 (10.80)	16.30	24.15	32.52	5.60	47.60	70 (a year or longer)	35000	0.1–10

Abbreviations: ARL, ambient recommendation level; MDE, mean daily exposure; MRL, minimal risk level; PEL, permissible exposure limits.

* SO_2 and NO_2: collected every second week from one fix station for 3 years and one station for 1.5 years; O_3: collected every second week from one fix station; H_2S and NH_3: collected monthly from two fix stations; 7% of SO_2 samples, 5% of NO_2 samples, 36% of O_3 samples, 17% H_2S and 20% of NH_3 were excluded because of invalid measurement method or instrument errors.

** Ambient recommendation level (ARL) provided for SO_2, NO_2 and O_3 as recommended by the Word Health Organization recommendations for ambient air pollution (45). Minimal risk levels (MRL) provided for and H_2S and NH_3 as recommended by the Agency for Toxic Substances and Disease Registry (46).

*** Permissible exposure limits, administered by the Occupational Safety and Health Administration (47).

† Mean daily exposures in the area of the unexposed works as reported by Soleimani and colleagues (30) (SO_2, NO_2 and O_3), Abdollahi and Hosseini (31) (H_2S), and Fowler and colleagues (32) (NH_3).

3.3. Pulmonary outcomes

3.3.1. Spirometric parameters

After adjusting for important confounders, petrochemical workers showed reduced respiratory function compared to other workers, reaching statistical significance for FEV1 (mean difference − 12; 95%CI -16, -7.55; comparing exposed to unexposed workers), FEV1/FVC (mean difference − 7.27; 95%CI -9.21, -5.25), and PEF (mean difference − 6.60; 95%CI -12, -0.74; Table 3). After adjusting for covariates, no significant difference in obstructive and restrictive impairment was observed between the exposed and unexposed workers.

Table 3
Mean differences (and 95% CIs) of spirometric parameters in petrochemical workers compared to unexposed workers (from univariable and multivariable linear regression models)

Parameter	Unadjusted β-coefficient (95% CI)	P-value	Adjusted β-coefficient (95% CI)*	P-value
FVC	-5.27 (-7.60, -2.94)	< 0.001	-4.15 (-8.61, 0.42)	0.067
FEV_1	-12 (-14.53, -9.99)	< 0.001	-12 (-16, -7.55)	< 0.001
FEV1/FVC	-6.76 (-7.78, -5.74)	< 0.001	-7.27 (-9.21, -5.25)	< 0.001
PEF	-6.69 (-9.69, -3.68)	< 0.001	-6.60 (-12, -0.74)	0.030

Abbreviations: CI, confidence interval; FEV1, forced expiratory volume in one second; FVC, forced vital capacity; PEF, peak expiratory flow

* Adjusted for number of working hours per week, work type, age, weight, height, marital status, education, length of employment, current smoking status, cigarette pack-years, and residential status.

3.3.2. Respiratory symptoms

After adjusting for covariates, working in the petrochemical facility remained significantly associated with having at least one respiratory symptom (OR 4.71; 95%CI 1.79, 12), mucus (OR 4.27; 95%CI 1.70,11) and shortness of breath (OR 15; 95%CI 5.00, 46; Table 4). None of the other symptoms were significantly associated with exposure from work in the petrochemical facility.

Table 4
Risk of respiratory symptoms in petrochemical workers compared to unexposed workers (from univariable and multivariable logistic regression models)

Respiratory symptom	Exposed/unexposed cases	Unadjusted OR (95% CI)	p-value	Adjusted OR (95% CI)*	p-value
Any symptom	75/30	3.40 (2.10, 5.51)	< 0.001	4.71 (1.79, 12)	0.002
Wheezing	6/2	3.06 (0.61, 15.36)	0.174	3.49 (0.17, 7.11)	0.851
Chest tightness	12/10	1.21 (0.51, 2.87)	0.660	1.50 (0.37, 6.53)	0.573
Cough	12/6	2.06 (0.76, 5.61)	0.163	2.33 (0.69, 9.55)	0.185
Chronic cough	8/2	4.12 (0.86, 19.67)	0.075	5.37 (0.80, 38)	0.085
Mucus	34/8	4.91 (2.21, 10.91)	< 0.001	4.27 (1.70, 11)	0.002
Chronic phlegm	12/6	6.32 (1.39, 28.61)	0.021	2.35 (0.76, 6.83)	0.151
Shortness of breath	54/4	24.29 (7.45, 79.21)	< 0.001	15 (5.00, 46)	< 0.001

Abbreviations: CI, confidence interval; OR, odds ratio.

* Adjusted for number of working hours per week, work type, age, weight, height, marital status, education, length of employment, current smoking status, cigarette pack-years, and residential status.

4. Discussion

In the present study, we examined spirometric parameters and respiratory symptoms among petrochemical workers exposed to airborne toxic pollutants compared to unexposed workers. Concentrations of SO_2 at the petrochemical complex were considerably higher than those recommended by the WHO (48). The average levels of NO_2 and O_3 were within the WHO recommendations but 25% of all samples taken were above the recommendations for both gases. However, the environmental exposure concentrations did not exceed the OSHA-PELs for workers (47). We found significant reductions in spirometric parameters (FEV1, FEV1/FVC, PEF) and that higher proportions reported mucus and shortness of breath among petrochemical workers compared to unexposed workers.

The current study demonstrated a higher exposure level of SO_2, NO_2, O_3, H_2S and NH_3 among petrochemical workers compared to mean daily exposures of the general population. Although the concentration levels of all pollutants in our study were above the daily exposures in the general population, only SO_2 and NO_2 exposure levels exceeded the WHO-ARL (45). This might suggest that SO_2 and NO_2 are more important drivers for respiratory problems among petroleum workers than other pollutants. This finding is in line with other reports observing that SO_2 and NO_2 were among the most common chemical pollutants released into the atmosphere at the petrochemical workplaces (49, 50). However, our maximum concentration levels were higher than those of other studies where SO_2 and NO_2 have shown ranges of 105–550 μg/m^3 and 9.6–87 μg/m^3, respectively (50–53). This inconsistency in air concentration levels might be due to differences in environmental conditions (temperature, wind, rain, etc.) (54), location of the plant (55), type of production (55), time and period of measurement (56), but also methodological differences in the sampling, the modeling systems, and in the equipment (4).

Although all exposure levels in our study were below the OSHA-PEL, our findings might suggest that the airborne toxic exposures are harmful even at a lower level if exposed over a long time. The petrochemical workers were on average employed for 10 years in their current position. The reductions we found for FEV1 and PEF among the petrochemical workers are in line with Neghab and colleagues who found a significant decrease in FEV1 and FVC among operational petrochemical workers (57). Also, Meo and colleagues observed a significant decline in FEV1, FEV1/FVC and PEF but no change in mean FVC among oil refinery workers compared to a control group (8). In another study, FEV1/FVC was significantly lower in petrochemical workers than in controls (58). Exposure to SO_2 and NO_2 have been associated with reductions in FVC and FEV1 (59–61), which suggest that the reductions in spirometric parameters (FEV1, FEV1/FVC, PEF) observed in our study might be due to SO_2 and NO_2 exposure.

Although only nine (< 5%) of the petrochemical workers in our study had obstructive impairment, our findings are pointing in the same direction as those of others where exposure to high levels of NO_2 and SO_2 have been associated with obstructive impairment, although low concertations of these toxicants may not lead to obstructive impairment (62–64).

Our finding that risk of any respiratory symptom was elevated among the exposed group, is in line with other studies in petroleum and gas refinery workers (14, 65). We also found significant increases in reported mucus hypersecretion and shortness of breath among petrochemical workers, which accord with the results of a study in residents near petro-refinery plants where symptoms such as shortness of breath, cough, phlegm and weakness were reported (66). Mucus hypersecretion and shortness of breath are symptoms of obstructive lung disease (67, 68), but the increase we found in these self-reported symptoms deviates from the objective spirometric assessment where only nine petrochemical workers had obstructive impairment (grade 2 or higher), highlighting the importance of an objective assessment in addition to self-reports.

Generally, using personal protective equipment (PPE) is routine in the petrochemical industries of Iran, but not throughout the whole shift and during all operations (69). Therefore, continuous improvement in PPE use throughout the shift, could minimize exposure to toxic chemicals and is warranted. In addition, applying control measures to reduce SO_2 and NO_2 emissions to environmentally acceptable levels are urgent. Our findings also indicated that the current recommendations for occupational exposure limits (OELs) are not sufficient to preserve the workers' lung function and avoid respiratory problems. This suggests that OELs in this occupational setting needs to be revised to minimize adverse health effects.

The current study was conducted in a well-defined group of petrochemical and unexposed workers with measurement data of gaseous pollutants, objective assessment of spirometric parameters, as well as self-reported respiratory symptoms. A major strength is the long-term measurement of five pollutants with standardized and high quality sampling techniques and instruments resulting in reliable levels of airborne concentrations in the vicinity of the petrochemical plant. Because the literature suggested a relationship between exposure to low level of any of SO_2 (70), NO_2 (71), O_3 (72), H_2S (73) and NH_3 (57, 74) and respiratory symptoms, the current study focused on these pollutants rather than other petrochemical airborne chemicals such as VOCs. Although air concentrations of gaseous pollutions were measured in a reliable way, we did not have individual exposure data and had to assume a constant level of exposure among all workers in the petrochemical plant.

Conclusion

This study indicated that even exposure to low-level of gaseous pollutants, particularly SO_2 and NO_2, could adversely affect spirometric parameters and significantly increase respiratory problems among petrochemical workers.

Abbreviations

SO_2
Sulfur dioxide
NO_2
Nitrogen dioxide
O_3
Ozone
H_2S
Hydrogen sulfide
NH_3
Ammonia
VOCs
volatile organic compounds
NOx
nitrogen oxides
FEV1
forced expiratory volume in 1 second
FVC
forced vital capacity
PEF
peak expiratory flow

ECRHS II
European Community Respiratory Health Survey questionnaire II
ARL
ambient recommendation levels
WHO
world health organization
PEL
permissible exposure limits
OSHA
occupational safety and health administration
PEL
permissible exposure limits
PPE
personal protective equipment

Declarations

Ethics approval and consent to participate

All subjects gave written informed consent and all data was de-identified after collection.

The Ethics Committee of Qom University of Medical Sciences approved the protocol of the current study

Consent for publication

Not applicable

Availability of data and materials

The data that support the findings of this study are available from corresponding author but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Qom University of Medical Sciences

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

Conceived and designed the analysis (HJ, AM), Collected the data (SKH, EJ, FR, RM), Contributed data or analysis tools (HJ, CR, JS), Performed the analysis (HJ, CR), Wrote the paper (HJ, AM, CR, JS), reviewing the final draft of paper (HJ, SKH, EJ, FR, RM, CR, JS, RM)

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Figures

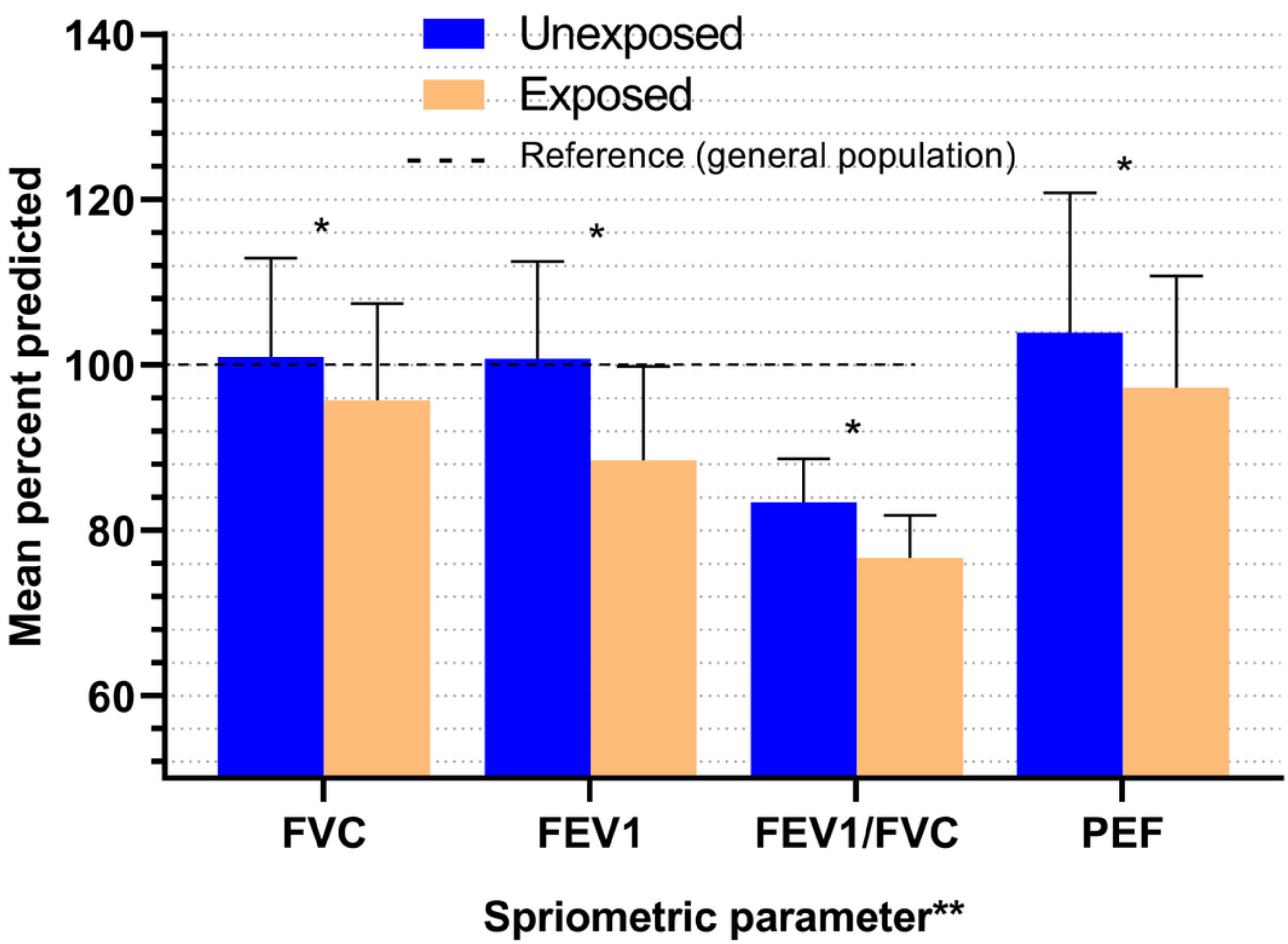

Figure 1

Mean value (with 95% CIs) of spirometric parameters in percent predicted by unexposed and exposed to petrochemicals. * p-value <0.001 ** FVC: Forced vital capacity; FEV1: Forced expiratory volume in one second; PEF: Peak expiratory flow

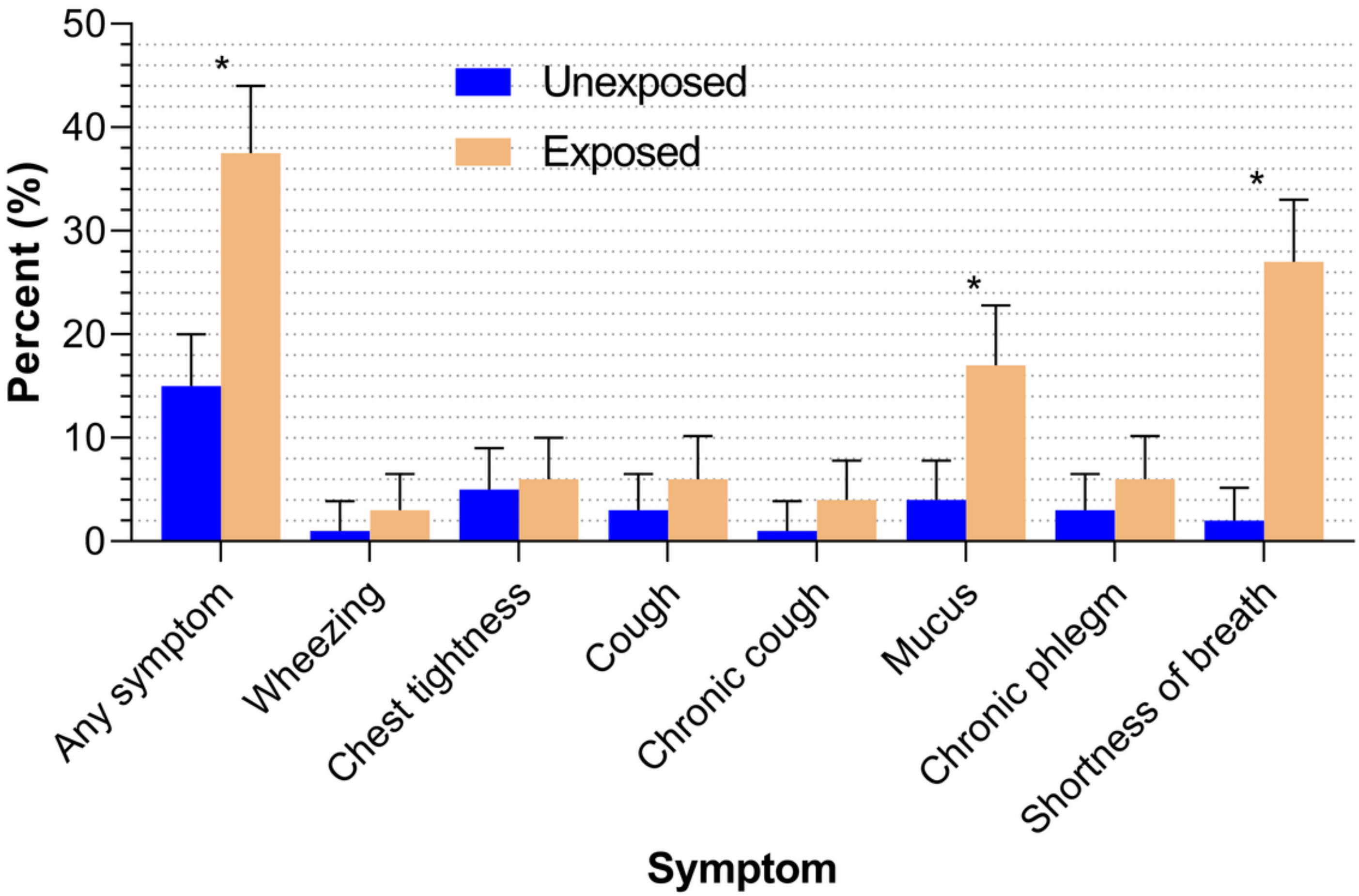

Figure 2

Prevalence of respiratory symptoms stratified by petrochemical exposure. The bars represent the proportion and 95% CIs of participants reporting the respective symptom. * p-value <0.001