

Respiratory effects of occupational exposure to low concentration of hydrochloric acid among exposed workers: a case study in steel industry

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Abstract

Occupational exposure to hydrochloric acid in pickling of steel for remove rust or iron oxide scale from iron processing occurs at low concentration. This study aimed to investigate the respiratory symptoms and pulmonary dysfunction caused by exposure to low concentration of hydrochloric acid in acid washing unit in one of the steel industries. A case control study was carried out in the acid washing unit of the cold rolling of the steel industry in 2017. The exposed group included 45 male workers, and another 41 unexposed employees from official employees were enrolled as control group. A questionnaire was used to collect personal and occupational data and pulmonary function tests, including forced vital capacity (FVC), forced expiratory volume in the first second and peak expiratory flow rate followed guidelines given by the American Thoracic Society and measured with a portable calibrated vitalograph spirometer. For determination of acid concentration, 21 breathing zone air samples were collected in accordance with Method 7903 NIOSH. The findings showed that nose sensitivity, throat irritation and shortness of breath were the highest prevalence symptoms among exposed persons (30.4% to 32.6%). Also, the results showed that FVC and forced expiratory volume in the first second had highest and direct or positive correlation with height (0.965 and 0.927, respectively). Age and weight put in the next priorities ($P < 0.01$). On the other hand, based on the results of multivariate linear regression, exposing to the acid and job history are two main predictor factors for FVC. So that, the exposing to acid, by itself can reduce FVC as 4.386 units. This value is equal to 1.117 for the job history. Exposure to low concentrations of hydrochloric acid alone could increase the risk of respiratory tract damage and pulmonary function disorders. But the extent to which it can cause respiratory complications for occupational exposure is still unknown and requires further study. This study was approved by Ethical Committee of Qom University of Medical Sciences (approval No. IR.MUQ.REC.1397.118) on November 6, 2018.

Key words: hydrochloric acid; respiratory gas; vital capacity; expiratory reserve volume; chemical industry

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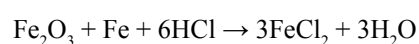
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INTRODUCTION

From occupational health perspective, the respiratory system is one of the most important systems in the body that can be affected by adverse effects and disorders, because inhalation is the main route of entry of gases and particulate matters in occupational exposure.^{1,2} Occupational respiratory disorders and signs may result from repetitive exposure, prolonged exposure or exposure to one or more hazardous chemicals, vapors or gases. Exposure to chemical substances and pollutants in a wide range can lead to acute and chronic pulmonary damages.³⁻⁵ A wide range and variety of respiratory disorders, from simple complications and bronchitis to pulmonary edema and allergic and non-allergic rhinitis can be caused by exposure to inhalation products. Also, the development of these complications can lead to the development of the reactive airways dysfunction syndrome, characterized by lower respiratory symptoms (such as cough, wheezing, shortness of breath) and asthma.^{6,7} Reactive airways dysfunction syndrome develops often after a single accidental exposure at work to a respiratory irritant in the setting of a spill or fire (*e.g.*, smoke inhalation and chlorine gas).⁸ Occupational exposure to irritants such as hydrochloric acid can cause or worsen respiratory complications such as asthma. So, recognition of work-related disease

in early stages is crucial to achieving a successful outcome for the exposed persons.⁹ Based on the population research, it is revealed that in general, about 10–15% of asthma in adults is occupational asthma (OA) and is due to a causal factor in a workplace.⁹ OA is a unique phenotype of asthma. Depending on the sensitivities that individuals are exposed to, different pathophysiologic mechanisms lead to the development of OA. Atopic, rhinitis, and genetic markers are the main contributors to host risk in the development of asthma, while contamination is a major contributor to the environmental risk factor that involves the development of OA.¹⁰

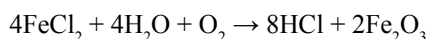
One of the most important applications of hydrochloric acid is in the pickling of steel, to remove rust or iron oxide scale from iron or steel before subsequent processing, such as extrusion, rolling, galvanizing, and other techniques.¹¹ Hydrochloric acid (HCl) at typically 18% concentration is the most commonly used pickling agent for the pickling of carbon steel grades.



The spent acid has long been reused as iron (II) chloride (also known as ferrous chloride) solutions, but high heavy-



metal levels in the pickling liquor have decreased this practice. The steel pickling industry has developed hydrochloric acid regeneration processes, such as the spray roaster or the fluidized bed HCl regeneration process, which allow the recovery of HCl from spent pickling liquor. The most common regeneration process is the pyrohydrolysis process, applying the following formula:



By recuperation of the spent acid, a closed acid loop is established. The iron(III) oxide by-product of the regeneration process is valuable, used in a variety of secondary industries.¹²

Studies have reported some of the toxic effects of exposure to hydrogen chloride gas. High solubility of this gas is a potent trigger for nasal mucous membranes, throat, respiratory system and the eye. In the most cases it causes irritating effects in the upper respiratory tract.¹³ Hydrochloric acid is classified in a group of chemicals that have acute effects such as burning eyes, respiratory tract and pulmonary edema, and chronic ones such as chronic bronchitis, dermatitis, and photo sensitivity.¹⁴ In addition, some studies have reported eye inflammation, headache, coughing, wheezing, dyspnea, as well as several cases of reactive airways dysfunction syndrome and asthmatics symptoms.¹⁵

The results of the other study on plating workers show that after controlling the effects of variables such as age and exposure time, there is a relationship between the exposure to chloride acid and the prevalence of mucosal and respiratory stimuli and the early stages of dental corrosion.¹⁶ Conversely, Patil et al.¹⁶ did not find any association between occupational exposure to low concentration of chlorine gas and the prevalence of respiratory symptoms. Also, no clinical significant symptoms of respiratory disorders in workers exposed to low concentration of chlorine gas were found.¹⁷

Respiratory effects of long-term exposure to low levels of hydrochloric acid gas have not been well documented, and are subjected to debate and controversy. According to the American Conference of Governmental Industrial Hygienists, ceiling threshold limit value, is defined as: the concentration of a chemical substance in air that should not be exceeded during any part of the working exposure. This value is equal to 2 ppm for hydrochloric acid exposure. So, in the present study, the value of less than 2 ppm for occupational exposure was supposed as low concentration of hydrochloric acid.¹⁸ Therefore, to find the answer of this question that whether (or not) respiratory symptoms or disorders can be caused in exposure to low concentration of hydrochloric acid in occupational settings, the present study was done. Also this investigation was done for two main objects: 1) Determining the prevalence of respiratory symptoms in exposed and non-exposed persons and 2) Evaluation of changes of pulmonary function parameters of exposed persons.

SUBJECTS AND METHODS

Subjects

This analytical descriptive case control study was carried out in the acid washing unit of the cold rolling of the steel industry. The subjects included male healthy workers, having at least one year of work experience in the acid washing unit as the exposed group and employees of the administrative depart-

ments of the steel industry who did not have any exposure to acid and other chemical agents in their work environment as the control (non-exposed) group. The selection of individuals was census-based, and all employees working in the acid washing unit of the company were fully volunteered and entered the research with previous satisfaction. The exposed group included 53 people, of whom 45 were volunteers (mean age 29.9 ± 3.3 years), and the non-exposed group included 124 people, 41 of whom (mean age 31.5 ± 4.5 years) were male employees of the company who were randomly selected. After giving informed consent, they entered the study voluntarily. Also, the inclusion criteria included lack of history of respiratory disease, smoking, pulmonary injury, chest surgery, contraindications for spirometric testing such as stroke and cardiac pain in 6 weeks prior to study, active blood transfusion, uncontrolled blood pressure and cold disease in the last few days before the study. Otherwise, subjects were excluded from the study. This article is the result of a research project at the Research Center for Environmental Pollutants, Qom University of Medical Sciences, approved with Grant No. 97947 and with the code of the ethics IR.MUQ.REC.1397.118 in Ethical Committee of Qom University of Medical Sciences on November 6, 2018. The writing and editing of the article was performed in accordance with the Transparent Reporting of Evaluations with Nonrandomized Designs (TREND) Statement.

Air sampling of hydrochloric acid

Breathing zone air samples were collected in accordance with Method 7903 NIOSH,¹⁹ and solid sorbent tube (washed silica gel, 400 mg/200 mg with glass fiber filter plug) were used. Before sampling the standard personal sampling pump (micro pump) manufactured by Scientific Kit Corporation Inc. (NV, USA) was calibrated using electronic soap bubble flow meter (Scientific Kit Corporation Inc.) for a flow rate of 0.3 L/min. Then sampling was done for 2 hours, to achieve the appropriate volume of the sample by standard methods. In total, 21 main air samples were taken from the beginning, middle and end of the acid washing line (7 samples in each section) plus 3 blank samples. After the sampling, the samples were analyzed using Ion chromatography in accordance with Method 7903 NIOSH. So that, the mass, μg , of anion found in the sample front (W_f) and back (W_b) sorbent sections, and in the average media blank front (B_f) and back (B_b) sorbent sections were determined and calculation of HCl concentration, C , in the air volume sampled, V , in term of liter was done as follows:

$$C = \frac{((W_f + W_b) - (B_f + B_b))F}{V}$$

where: F (conversion factor from anion to acid) = 1.028 for HCl.

Study of respiratory effects

The demographic properties of all participants (such as age, weight, height, education level, etc.) were gathered and subjects by smoking habit avoided participating in this research. To study respiratory symptoms in two study groups (exposed and non-exposed subjects), we used a researcher made questionnaire based on respiratory symptom questionnaire suggested by the American Thoracic Society,¹⁵ with a few modifications. The questionnaire's validity and reliability in



a pilot study was confirmed (Cronbach's alpha was 0.736). The questionnaire contained two kinds of questions including demographic questions and health effect questions (acute and chronic effects related to hydrochloric acid exposure). After interviewing of subjects and fulfill the questionnaire, subjects of two groups tested for pulmonary function parameters immediately after 2 hours of exposure. Pulmonary function tests, including forced vital capacity (FVC), forced expiratory volume in the first second (FEV1) and peak expiratory flow rate measured by spirometry guidelines given by the American Thoracic Society and measured with a portable calibrated vitalograph spirometer (Vitalograph Ltd. UK Maids Moreton, Buckingham, UK) on site.

Statistical analysis

Data were statistically analyzed using appropriate tests including Chi square or Fisher exact test or Yets Continuity Correction, one-way analysis of variance, Pearson's correlation test, multivariate linear regression and multivariate logistic regression tests (with a preset probability of $P < 0.05$). Statistical tests were conducted using SPSS software (version 22; IBM, Armonk, NY, USA).

RESULTS

Descriptive results

The results of the demographic data analysis of the participants in this study are shown in **Table 1**, where almost all parameters are statistically similar in two groups.

Air monitoring of hydrochloric acid in different places in the acid washing line was done with 21 air samples to demonstrate HCl concentration of the beginning, middle and the end of the acid washing line. As shown in **Table 2**, the HCl concentration in the middle line was significantly higher than that in the beginning and end lines ($P < 0.001$).

Analytic results

To compare the incidence rate of respiratory symptoms in two studied groups, chi-square test was done. The findings showed that nose sensitivity, throat irritation and shortness of breath were the highest prevalence symptoms among exposed persons (30.4% to 32.6 %). On the other hand, except stridor, all of symptoms in exposed subjects were significantly different compared to non-exposed subjects (**Table 3**). Similar comparisons were made for pulmonary function between two groups based on the obtained results of the pulmonary function tests by spirometry (**Table 4**). According to the table, FVC and FEV1 were the two parameters differed significantly between exposed and non-exposed groups ($P < 0.01$).

Comparing pulmonary function

Correlation between the pulmonary function criteria and demographic characteristics of exposed subjects was determined using Pearson correlation test. The results showed that FVC and FEV1 have shown highest and direct or positive correlation with height ($r = 0.965$, $P < 0.01$; $r = 0.927$, $P < 0.01$) respectively. Age and weight put in the next priorities ($P < 0.01$). In addition, the job history in terms of year has not been different significantly in exposed subjects with or without having respiratory symptoms ($P < 0.05$).

On the other hand, based on the results of multivariate linear

Table 1: Demographic characteristics of the exposed workers and unexposed controls

Individual variable	Exposed (n = 45)	Non-exposed (n = 41)	P-value [†]
Age (year)	29.9±3.3	31.5±4.5	0.06
Job history (year)	5.2±1.5	5.2±2.0	0.99
Wight (kg)	82.1±12.2	77.2±13.4	0.08
Height (cm)	177.6±5.1	177.9±5.9	0.8
Body mass index (kg/m ²)	26.03±3.7	24.36±3.7	0.042

Note: Data were analyzed by independent t-test.

Table 2: Concentration of hydrochloride acid in different stations of the acid washing line

Sampling station	n	Concentration (ppm)				P-value
		Min	Max	Mean	SD	
Beginning of the line	7	0.12	2.1	0.6	0.64	< 0.001
Middle line	7	0.17	5.97	1.59	1.84	
End of line	7	0.13	1.5	0.58	0.62	
Total	21	0.12	5.97	0.98	1.3	

Note: The concentration of three blank samples was not detected and supposed zero for all samples. Data were analyzed by one-way analysis of variance.

Table 3: The incidence rate of respiratory symptoms in the exposed workers and unexposed controls

Symptoms	Exposed	Non-exposed	P-value
Cough	11(23.9)	1(2.5)	0.004*
Phlegm	10(21.7)	0(0)	0.005**
Shortness of breath	14(30.4)	1(2.5)	< 0.001*
Throat irritation	15(32.6)	0(0)	< 0.001**
Stridor	2(4.3)	1(2.5)	0.55*
Wheezing	9(19.6)	0(0)	0.009**
Nose sensitivity	15(32.6)	0(0)	< 0.001**

Note: Data are expressed as number (percent). Data were analyzed by chi-square test (*) or Yets Continuity Correction (**).

Table 4: Comparing the pulmonary function between exposed workers and unexposed controls

Pulmonary function criteria	Exposed (n = 45)	Non-exposed (n = 41)	P-value
FVC	85.71±9.29	91.42±9.25	0.020
FEV1	84.69±10.49	91.15±7.66	0.041
FEV1/FVC	82.74±0.5	83.42±5.2	0.49
PEFR	95.80±14.45	95.82±14.04	0.739

Note: FVC: Forced vital capacity; FEV1: forced expiratory volume in the first second; PEFR: peak expiratory flow rate.

regression (**Table 5**), exposing to the acid and job history are two main predictor factors for FVC. Also based on the results of multivariate logistic regression (**Table 6**), only exposing to the acid can be a predictor for respiratory symptoms including shortness of breath and cough ($P < 0.05$). Other pulmonary function criteria or respiratory symptoms were not entered to the models due to negligible correlations and non-significant statistically differences.

**Table 5: The results of multivariate linear regression for predictor factors of forced vital capacity**

Model	Unstandardized coefficients		Standardized coefficients (Beta)	t	Sig.	95% Confidence interval	
	B	Std. Error				Lower	Upper
Exposing to acid	-4.386	1.969	-0.232	-2.228	0.029	-8.303	-0.47
Job history	-1.117	0.55	-0.212	-2.031	0.046	-2.21	-0.023

Table 6: The results of multivariate logistic regression for predictor factors of respiratory symptoms (shortness of breath and cough)

Respiratory symptoms	Covariates in model	B	S.E.	Wald	df	Sig.	Exp(B)	95% Confidence interval	
								Lower	Upper
Shortness of breath	Exposing to acid	2.837	1.062	7.133	1	0.008	17.062	2.128	136.839
Cough	Exposing to acid	2.506	1.07	5.485	1	0.019	12.257	1.505	99.83

DISCUSSION

The present study demonstrated the respiratory changes and pulmonary function of exposed persons to low concentration of hydrochloric acid in acid washing process in a steel industry. One of the most important measures in identifying occupational diseases is the accurate identification of the work environment and the harmful factors that workers are exposed to. American Conference of Governmental Industrial Hygienists defined the value of 2 ppm as ceiling threshold limit value for HCl.¹⁸ Ceiling occupational exposure limit presented in Iran country is 2 ppm, too.²⁰ The air monitoring of hydrochloric acid in different places of acid washing line showed low concentration of acid, totally. This value is lower than defined standard value. Although significant differences between the middle of line was seen compared to the beginning and the end of the line ($P < 0.001$). On the other hand, it was revealed that in spite of exposure to low concentration of HCl, the prevalence of respiratory symptoms was considerable among exposed persons. So that, nose sensitivity, throat irritation and shortness of breath were the most important complaint which workers expressed. The similar findings can be seen in the research of Aminian et al.²¹ This is probably due to high solubility of HCl which has made it as a potent trigger for nasal mucous membranes, throat, respiratory system, and in most cases it causes irritating effects in the upper respiratory tract.⁹ According to the findings, there was no significant difference between the mean values of demographic characteristics between the exposed and non-exposed groups. This finding will be very important because it will diminish the role of demographic variables in the spread of respiratory symptoms and pulmonary disorders.^{1,4,14}

Among pulmonary function criteria, FVC and FEV1 were the two parameters which significantly different in exposed and non-exposed subjects ($P < 0.05$). Also, as shown in the **Table 5**, the exposing to acid, by itself can reduce FVC as 4.386 unit. This value is equal to 1.12 for the job history. On the other words, for each year of increased work experience, 1.12 units of FVC are reduced. Other pulmonary function indices have not shown significant differences between exposed and non-exposed subjects. However, in univariate analysis job history was not significant variable, but, in multivariate model after controlling the confounders, job history and exposing to acid were significant determinants of FVC. In addition, the correlation of job history and age is demonstrated. In the line of

present study, Agabiti et al.²² showed that spirometric indices of FVC, FEV1 and forced expiratory flow at 25–75% tended to be lower among those people with the highest exposure to chlorine, although the results from linear regression analysis were significant only for FEV1.

In another study, Gorguner et al.²³ showed that FEV1 and peak expiratory flow rate were the two spirometric indices affected by exposure to chlorine in housewives due to exposure to bleach. Similar results reported by other investigators.^{24,25} This can point to the fact that the exposure to this compound is accompanied by a reduction in the irreversible chronic changes in some parameters of pulmonary function. In this study, the type of complication, as the results of spirometry show, is a type of restrictive pulmonary disease. In these types of diseases, FVC is decreased, but FEV1 is either normal or decreases in the same proportion as the FVC is lowered. Therefore, the ratio of FEV1 to FVC is in normal level. FVC reduction can be due to reduced compliance of the lung. Other studies reported similar findings regarding to other irritants compounds.^{1,26-28}

In the case of respiratory symptoms, the affected symptoms were shortness of breath and cough, which are influenced by exposing to acid significantly ($P < 0.05$). So that, exposing to acid can increase the shortness of breath and cough as equal to 2.837 and 2.506, respectively.

HCl is a very soluble gas which makes by hydrolyzing of chlorine gas. The solubility of HCl is five times stronger than its physical solubility of chlorine. Therefore, although chlorine is absorbed at low concentrations in the upper respiratory tract (below 5%), HCl can penetrate much deeper into the respiratory tract, thus increasing its toxicity.²⁹

Médina-Ramon et al.³⁰ expressed that irritant cleaning agents such as degreasing sprays or atomizers, hydrochloric acid, and ammonia might be related to asthma and chronic bronchitis symptoms. Due to the irritating effect of chlorine, chlorine intoxication rarely leads to serious injury. People exposed to chlorine, immediately after they sense the irritating smell, try to leave the danger zone. That is why death caused by exposure to chlorine usually occurs in cases of sudden exposure to a large quantity.³¹

Totally, our findings reveal that occupational exposure to HCl can cause some respiratory problems even at low concentration. But the extent to which acid concentration reduction can continue to cause respiratory complications



is still unknown. Therefore, it is strongly recommended to other researchers for further studies in this area focusing dose-response relation in low or very low HCl concentration.

The findings of this study showed that exposure to low concentration of hydrochloric acid alone could increase the risk of respiratory tract damage and pulmonary function disorders.

But the extent to which it can cause respiratory complications for occupational exposure is still unknown and requires further study. Therefore, risk management should be considered as a prevention strategy in the face of this combination.

Conflict of interest statement

The authors declare that there is no conflict of interest.

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Author contributions

Study conception or design and data interpretation: HH, AM; data acquisition: AS; data collection: MD, MAG; data analysis: AM, AS, MD; manuscript drafting: AS, MD, MAG; manuscript revising: MAG. All authors approved the final version of the manuscript for publication.

Conflicts of interest

There is no conflict of interest.

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Institutional review board statement

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Declaration of participant consent

The authors certify that they have obtained participants consent forms. In the form, participants have given their consent for the participants' images and other clinical information to be reported in the journal. The participants or their legal guardians understand that their names and initials not be published and due efforts will be made to conceal their identity.

Reporting statement

The writing and editing of the article was performed in accordance with the Transparent Reporting of Evaluations with Nonrandomized Designs (TREND) Statement.

Biostatistics statement

The statistical methods of this study were conducted and reviewed by the epidemiologist of Qom University of Medical Sciences, Iran.

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Data sharing statement

Datasets analyzed during the current study are available from the corresponding author on reasonable request.

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