Iranian J Publ Health, Vol. 43, No.5, May 2014, pp.666-673

Original Article

Cancer Risk Assessment in Welder's Under Different Exposure Scenarios

*Abolfazl BARKHORDARI [1], *Mohammad Javad ZARE SAKHVIDI [1], Fariba ZARE SAKHVIDI [1], Gholamhossein HALVANI [1], Ali FIROOZICHAHAK[1], GholamAbbas SHIRALI [2]*

1. Dept. of Occupational Health, Faculty of Health, Shahid Sadoughi University of Medical Sciences, Yazd, Iran
2. Dept. of Occupational Health Engineering, School of Public Health, Ahvaz Jundishapur University of Medical Sciences, Iran

***Corresponding Author:** Email: ohyazd@gmail.com

(Received 23 Oct 2013; accepted 24 Jan 2014)

Abstract

Background: Welders exposure to nickel and hexavalent chromium in welding fumes is associated with increase of cancer risk in welders. In this study we calculated cancer risk due to exposure to these compounds in welders.

Methods: The role of exposure parameters in welders on derived incremental lifetime cancer risk were determined by stochastic modeling of cancer risk. Input parameters were determined by field investigation in Iranian welders in 2013 and literature review.

Results: The 90% upper band cancer risk due to hexavalent chromium and nickel exposure was in the range of 6.03E-03 to 2.12E-02 and 7.18E-03 to 2.61E-02 respectively. Scenario analysis showed that asthmatic and project welders are significantly at higher cancer risk in comparison with other welders ($P<0.05$). Shift duration was responsible for 37% and 33% of variances for hexavalent chromium and nickel respectively.

Conclusions: Welders are at high and unacceptable risk of cancer. Control measures according to scenario analysis findings are advisable.

Keywords: Inhalation exposure, Cancer risk assessment, Welding fume, Stochastic modeling

Introduction

About 0.2 to 2% of workforces in the industrialized countries perform welding regularly or as a part of their jobs. In 2011, about 316000 engaged in welding, soldering, cutting and brazing in the US (1). Welders are the specific group of workers because of their unique exposure pattern and occupational hazards that they are encountered with; including welding fumes. Inhalation exposure to welding fumes could lead to various undesirable effects ranged from simple pneumoconiosis to cancers (2). Occupational exposure to welding fumes is associated with coronary diseases, immunotoxicological effects and respiratory effects (3-5). Lung cancer due to inhalation exposure to hexavalent chromium (Cr(VI)) and nickel (Ni) in welding fumes have been reported in several studies (6).Risks of health effects depend on the wide range of parameters including welding type, composition of electrodes and base metals, duration of exposure and personal characteristics (7). Cancer risk assessment in welders can lead to better understanding of influential parameters on risk of cancer. It is a useful tool in health systems policy making. Epidemiological studies are the golden standard for this purpose. However, due to some limitations, the use of proposed quantitative models, in most situations is desirable.

In the simplest form, inhalation cancer risk assessment depends on personal characteristics, exposure intensity and duration, and cancer slope factor. United States Environmental Protection Agency (US EPA) proposed a deterministic approach for calculation of cancer risk due to inhalation exposure with carcinogens (8). Quantification of risk by deterministic models can be conduct by worst case or mean values scenarios. Application of this equation in deterministic mode seems to be non- realistic. Application of these approaches in the worst case scenarios also leads to unrealistic risk estimation (9). Furthermore; deterministic models cannot consider the role of parameters variability (10). Stochastic modeling is a desirable tool for considering parameters variability in health risk assessments. There are some successful examples of application of this approach for occupational and environmental risk assessment (11). Monte Carlo simulation probably is the most applied stochastic method for quantifying the role of variability (12).

The aims of this study was 1) to calculate the cancer risk due to occupational exposure to Ni and Cr(VI) in welders; 2) to determine the role of model input parameters variability's in risk estimation; 3) to analyze the sensitivity of model output different parameters on cancer risk; 4) to assess the role of workers' characteristics and employment status on cancer and finally 5) to compare welders cancer risk to acceptable level.

Material and Methods

Study design and subjects

In an analytical study in 2013, 30 Iranian welders in an oil and gas industry randomly selected and were asked to complete questionnaire about daily work hours, work experience and daily tasks descriptions.All participants were informed about the aim of study and involved voluntarily in the study. Work load of welders was estimated according to method developed by Burford et al. (13). Welder specific parameters (daily work hour) and exposure intensity were determined from field survey and literatures and used for determination of cancer risk. Cancer risk was calculated for exposure to Ni and Cr (VI) in healthy and asthmatic welders. All of these calculations were repeated for two type of welder according to their employment status, leading to totally 4 scenarios for each hazardous element.

Cancer risk calculation

Deterministic Incremental Lifetime Cancer Risk (ILCR) due to inhalation was calculated according to the model proposed by the US EPA (Equation I) (8).

ILCR = Exposure (µg/kg/d) × Cancer Slope Factor (µg/kg/day)$^{-1}$ equation [I]

In this equation, exposure is the product of seven factors pertained to exposure intensity, exposure duration and exposed subject characteristics. Therefore, it can be rewritten as an equation II:

ILCR = [(C × BR × DS × EF × ED)/(BW × AT × 365)] × (SF) equation [II]

Where; C is exposure intensity (mg.m^{-3}), BR is breathing rate (m^{3}.hr^{-1}), DS is daily exposure duration (hr), EF is weakly exposure period (day), ED is exposure duration in work life (years). BW is body weight (kg), AT (time to cancer; usually described as life expectancy) and SF is cancer slope factor (mg/kg-d)$^{-1}$. Data on DS was gathered from 30 welders in an oil refinery in Iran.

Input parameters distribution selection

EF was determined according to previous studies (14, 15). It can be varied from 1 to more than 40 years. Li et al. reported some cases with 36 years of working history as a welder (14). However in some other studies, there are cases with 40 years of experience in welding (15). Based on the available data on literatures, a triangle distribution was determined for this parameter (Table 1).

Exposure intensity in welding operations is quietly different based on welding processes, welding parameters, environmental parameters and even welder experience. Recently Golbabaei et al. thoroughly examined the exposure intensity in the group of stainless steel welders in an oil and gas pipeline project who exposed to hazardous fumes

(16).We used Golbabaei data to infer exposure intensity (Table 1). Breathing rate was also selected for healthy and asthmatic subjects according to EPA exposure factors handbook (17).
The distribution factors were defined according to anthropometric study conducted by Shahnawas et al. on Iranian industrial workers (18). AT was considered according to Iranian population life expectancy. According to Khosravi et al. life expectancy of Iranian males is 66.8 years (19). Exposure frequency was calculated based on Iranian calendar and holidays. Body weight was considered with normal distribution.

Table 1: Input parameters distributions and distribution definition parameters

Input parameter	Distribution type	Distribution parameters	Reference
Body weight (kg)	Lognormal (mean, std)	(78.1,13.5) p5+55, p95=96)	(18)
Breathing rate ($m^3.hr^{-1}$)			
Healthy	Triangular (min, likeliest, max)	(0.72, 0.78, 3.06)	(13)
Asthmatic	Triangular (min, likeliest, max)	(1.02, 1.68, 2.46)	(13)
Exposure intensity ($mg.m^{-3}$)			
Cr (VI)	Lognormal (mean, std)	(0.00501, 0.00276)	(16)
Ni	Lognormal (mean, std)	(0.233, 0.128)	(16)
Daily exposure duration (hr)			
Maintenance welder	Lognormal (mean, std)	(3,1)	Field study
Project welder	Lognormal (mean, std)	(10.13, 1.49)	Field study
Yearly exposure period (day)	Triangular (min, most probable,max)	(240, 250, 260)	
Exposure duration (year)	Triangular (min, most probable ,max)	(1, 30,40)	(14, 15)
Time to cancer(year)	Normal(mean, std)	(56,7, 0.33)	(19)
Cancer slope factor $(mg/kg\text{-}d)^{-1}$			(24, 25)
Cr (VI)	Triangular (min, likeliest, max)	(34,41,310)	
Ni	Triangular (min, likeliest, max)	(0.84,1.2,5.5)	

Statistics

Stochastic risk modeling was performed by Crystal Ball 11.1.1.1.00 (Oracle, Redwood Shores, CA, USA) in Excel© environment. Input distributions were fitted according to data from the field and literatures. Distributions were fitted by Easy fit software (Mathwave Tech.).SPSS software package version 16 (SPSS, Inc., Chicago, IL), was used for statistical tests. One way analysis of variance (ANOVA) test was performed to investigate difference in ILCR in different scenarios.

Results

According to their work hours (DS), two distinct types of welders were found (Fig.1). Maintenance welders are those with long time contract with company and lower exposure duration in day or week. They are in standby position in the company and only perform unscheduled and emergency maintenances.

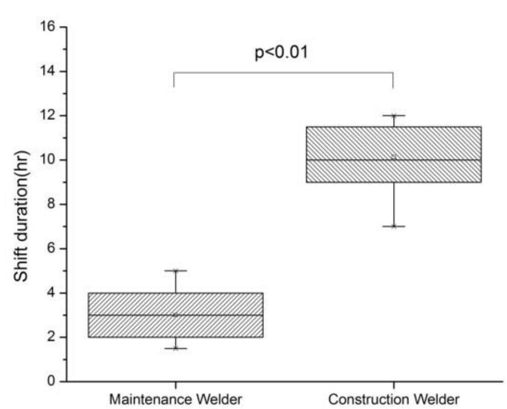

Fig. 1: Statisticalrepresentation of daily shift duration (h) in two groups of welders

Table 2: Estimated ILCR under different exposure scenarios for Cr (VI) and Ni

Element	Scenario	ILCR		
		10%	mean	90%
Cr(VI)	Cr Asthma Maintenance	9.73E-04	3.39E-03	6.55E-03
	Cr Asthma Project	3.77E-03	1.14E-02	2.12E-02
	Cr Healthy Maintenance	7.34E-04	3.03E-03	6.03E-03
	Cr Healthy Project	3.09E-03	1.04E-02	2.02E-02
Ni	Ni Asthma Maintenance	1.27E-03	4.32E-03	8.29E-03
	Ni Asthma Project	4.30E-03	1.39E-02	2.61E-02
	Ni Healthy Maintenance	9.30E-04	3.61E-03	7.18E-03
	Ni Healthy Project	3.14E-03	1.20E-02	2.41E-02

Table 3: Contribution to variance for different input parameters under different exposure scenarios

Scenario	Assumption	Contribution to Variance	
		Cr(VI)	Ni
Healthy, Project	AT	0.2	0.3
	BR	24.8	24.8
	BW	2.8	3.1
	C	40.6	38.7
	DS	3.6	3
	ED	26.6	28.5
	EF	0	0.6
	SF	1.4	1.1
Healthy, Maintenance	AT	0.6	0.1
	BR	20.2	18.8
	BW	2.1	2.4
	C	39.8	40
	DS	14	9
	ED	23.3	28.9
	EF	0	0.5
	SF	0.1	0.3
Asthmatic, Project	AT	0	0
	BR	8.1	5.7
	BW	4.3	4
	C	46.5	47.6
	DS	4.9	1.3
	ED	35.6	39.6
	EF	0.1	0.5
	SF	0.5	1.3
Asthmatic, Maintenance	AT	0	0.1
	BR	9.6	5.1
	BW	2.5	4.2
	C	41.5	43
	DS	14.2	11.6
	ED	31.8	33.9
	EF	0.1	0.3
	SF	0.1	1.8

Construction welders are those with short time contract (e.g. in the specific projects), and have higher exposure duration in comparison with maintenance welders (*P*<0.01). The latter category is predominant in oil and gas projects. According to our field survey, lognormal distribution was selected for DS but there is no consensus data about it (Table 1).

The cumulative distribution function of ILCR due to Cr(VI) and Ni was calculated according to EPA procedure for different exposure scenarios. Four different scenarios including healthy construction welder, healthy maintenance welder, asthmatic construction welder and asthmatic maintenance welder were considered. Table 2 shows the cancer risk statistics under different scenarios for Cr(VI) and Ni. The 90% upper band cancer risk due to Cr(VI) exposure in stainless steel welding was in the range of 6.03E-03 to 2.12E-02. This value for Ni exposure was in the range of 7.18E-03 to 2.61E-02. Mean ILCR for Cr(VI) and Ni was in the range of 3.03E-03 to 1.14E-02 and 3.61E-03 to 4.32E-03, respectively. ANOVA analysis showed significant difference between ILCR for Cr(VI) and Ni in different scenarios (*P*<0.05).

A quantitative sensitivity analysis was performed to explore the role of each parameter in the model output.

Tornado plots (Fig.2) show the spearman rank order correlation coefficients for sensitivity analysis. In all scenarios exposure intensity (C) and exposure duration (ED) are the most influential parameters on output variance. Breathing rate and DS are also among the most influential parameters on output variance (Table 3 and 4).

Table 4: Cumulative rank correlation and contribution to variance for input parameters

Assumption	Contribution to Variance	Rank Correlation
ED	0.368	0.580
BR	0.250	0.482
C	0.242	0.474
DS	0.107	0.315
BW	0.026	-0.155
Other	0.007	---

However breathing rate was the third most influential parameter in all cases except for asthmatic maintenance welders. In asthmatic maintenance welders for both elements, duration of shift (DS) was also the third most influential parameter (responsible for 37 and 33% of variances for Cr(VI) and Ni respectively).

Discussion

The purpose of the current study was to quantify the role of various exposure scenarios in ILCR in welders. This study showed that welders can be grouped into different levels of cancer risk according to their employment and health statuses. As described in method section, breathing rate has a wide range of variability. According to US EPA, asthmatic people have higher breathing rate in comparison with healthy adults. Scenario analysis was performed to examine the role of worker asthma on cancer risk due to Ni exposure. According to EPA, ILCR less than 10^{-6} can be assumed as low risk region, 10^{-6} to 10^{-4} is moderate risk; and values above10^{-4}areregarded as high risk region. For ILCR greater than 10^{-5}different control options should be considered in general risk management actions. As our results show ILCR in all scenarios were higher than 10^{-4}. Therefore welders, even in the case of maintenance, are at unacceptable risk of cancer.

In this study we used a conservative range of slope factor for both elements. For example, Health Canada reported 320 as a slope factor for hexavalent chromium it is 5.1 for Ni (20). Even in the case of using conservative slope factor, the calculated risk was more than the cut point proposed by EPA.

Sjogren et al. found significant increase in risk of lung cancer due to welding fume exposures especially hexavalent chromium and Ni in welder (21). Our results showed that asthmatic welders are significantly at higher risk in comparison with healthy welders.

This point, as an important factor, can be considered in pre-employment screening tests. Asthmatic patients had higher ventilation rate and breathing rate in comparison with normal subjects (22).

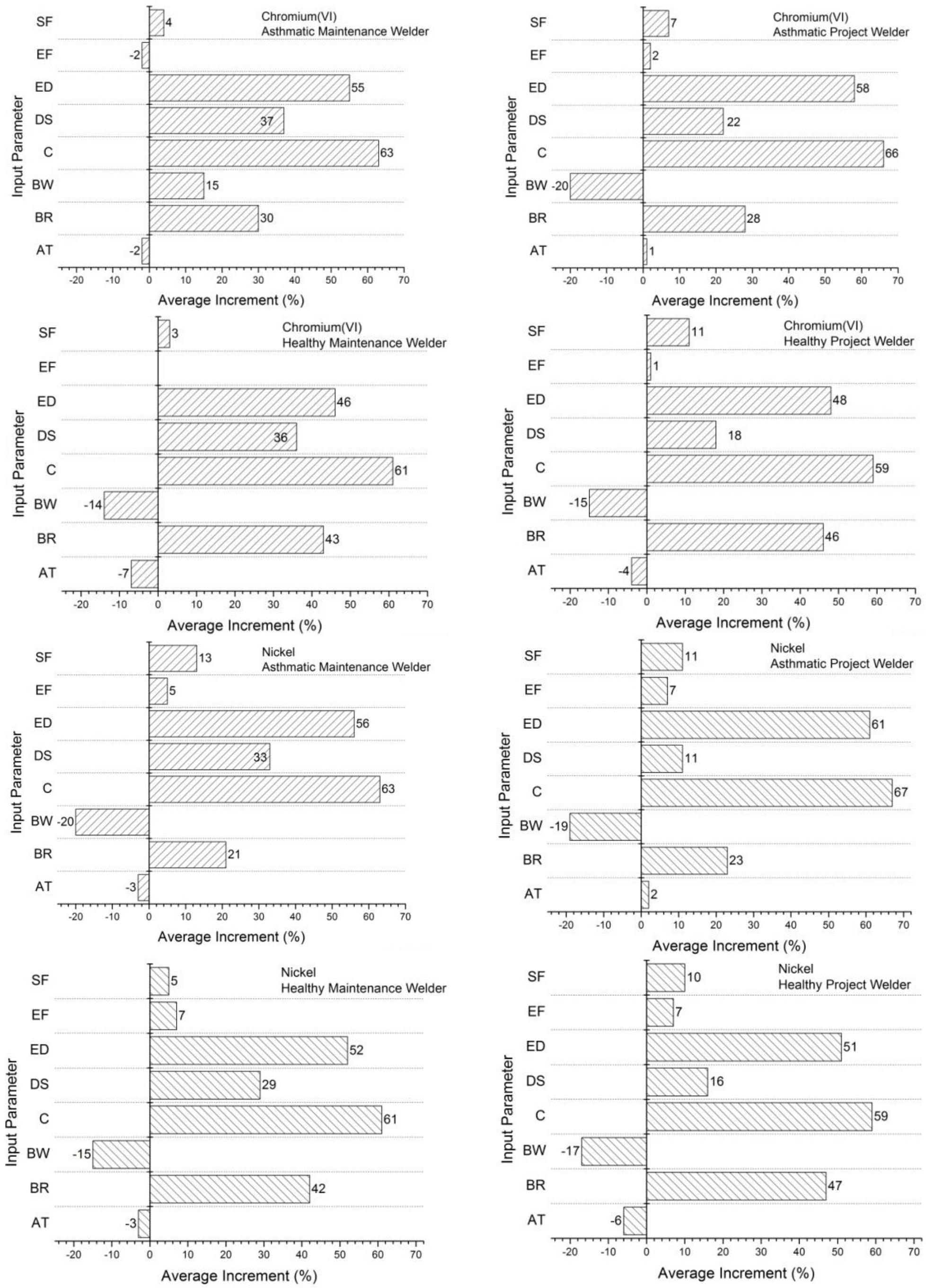

Fig. 2: Results of Sensitivity analysis under different exposure scenarios

Therefore it is feasible to consider higher exposure with pollutants for this group of workers. A meta-analysis by Santillan et al. also showed that asthmatic persons are at higher risk of cancer in comparison with non asthmatic persons (23).

Conclusion

Welders can be considered as a high risk group for cancer. Secondly the employment status has considerable affect on ILCR values in same conditions. Third, the daily work hour is the most influential parameter in cancer risk of welders. Our comparisons also showed that there is significant difference in cancer risk between asthmatic and healthy welders. Further studies need to be done to investigate the role of welding operation parameters, and other exposure modifying factors on cancer risk in welders.

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

Acknowledgement

The authors wish to thank Shahid Sdoughi University of medical sciences for financial support of this study. The authors declare that there is no conflict of interests.

References

1. U.S. Bureau of *Labor Statistics*, National employment and wage data from the Occupational Employment Statistics survey by occupation. *U.S.* Bureau of *Labor Statistics* (2011).
2. Stern RM, Berlin A, Fletcher A, et al. (1986). International conference on health hazards and biological effects of welding fumes and gases. *Int Arch Occup Environ Health*, 57 (3): 237-246.
3. Ibfelt E, Bonde JP, Hansen J (2010). Exposure to metal welding fume particles and risk for cardiovascular disease in Denmark: a prospective cohort study. *Occup Environ Med*, 67(11): 772-777.
4. Zeidler-Erdely PC, Erdely A, Antonini JM (2012). Immunotoxicology of arc welding fume, Worker and experimental animal studies. *J Immunotoxicol*, 9(4): 411-425.
5. Sobaszek A, Boulenguez C, Frimat P, et al. (2000). Acute respiratory effects of exposure to stainless steel and mild steel welding fumes. *J Occup Env Med*, 42(9): 923-931.
6. Moulin JJ (1997). A meta-analysis of epidemiologic studies of lung cancer in welders. *Scand J Work Environ Health*, 23(2): 104-113.
7. Doull J, Cattley R, Elcombe C, et al. (1999). A cancer risk assessment of di (2-ethylhexyl) phthalate: application of the new US EPA Risk Assessment Guidelines. *RegulToxicol Pharm: RTP*, 29(3): 327-357.
8. U.S EPA, Guidelines for Carcinogen Risk Assessment (2005). *EPA*: Washington, DC.
9. Sander P, Öberg T (2006). Comparing Deterministic and Probabilistic Risk Assessments. A case study at a closed steel mill in southern Sweden. *J Soil Sediment*, 6(1): 55-61.
10. Cullen AC, HC Frey (1999). *Probabilistic techniques in exposure assessment: a handbook for dealing with variability and uncertainty in models and inputs*. Springer.
11. Yeheyis M, Aguilar G, HewageK, et al. (2012). Exposure to Crystalline Silica Inhalation Among Construction Workers: A Probabilistic Risk Analysis. *Hum Ecol Risk Assess*, 18(5): 1036-1050.
12. Thompson KM, Burmaster DE, Crouch EAC (2006). Monte Carlo Techniques for Quantitative Uncertainty Analysis in Public Health Risk Assessments. Risk Anal, 12(1): 53-63.
13. U.S. Environmental Protection Agency (2011). *Exposure Factors Handbook 2011 Edition*. Washington, DC 20460
14. Li GJ, Zhang LL, Lu L, et al. (2004). Occupational exposure to welding fume among welders: alterations of manganese, iron, zinc, copper, and lead in body fluids and the oxidative stress status. *J Occup Env Med*, 46(3): 241-248.
15. Ellingsen DG, Dubeikovskaya L, Dahl K, et al. (2006). Air exposure assessment and biological monitoring of manganese and other major welding fume components in welders. *J Environ Monit,* 8(10): 1078-1086.
16. Golbabaei F, Seyedsomea M, Ghahri A, et al. (2012). Assessment of Welders Exposure to Carcinogen Metals from Manual Metal Arc Welding in Gas Transmission Pipelines. *Iranian J Publ Health*, 41(8): 61-70.

17. Burford CL, Ramsey JD, Tayyari F, et al. (1984). *A method for systematic workload estimation (SWE). in Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, SAGE Publications.
18. Shahnawaz H, Davies B (1977). Anthropometric study of Iranian steel workers. *Ergonomics*, 20(6): p. 651-658.
19. Khosravi A, Taylor R, Naghavi M, et al. (2007). Mortality in the Islamic Republic of Iran, 1964-2004. *Bull World Health Organ*, 85(8): 607-614.
20. Health Canada, Federal Contaminated Site Risk Assessment in Canada (2004). Part II: Health Canada Toxicological Reference Values (TRVs) and Chemical-Specific Factors, Version 2.0. 2004. Available from: http://www.hc-sc.gc.ca/ewh-semt/pubs/contamsite/part-partie_ii/index-eng.php. [access date: 2013 January 14].
21. Sjögren B, Hansen KS, Kjuus H, et al. (1994). Exposure to stainless steel welding fumes and lung cancer: a meta-analysis. *Occup Environ Med*, 51(5): 335-336.
22. Kesten S, Maleki-Yazdi R, Sanders B R, et al. (1990). Respiratory rate during acute asthma.*CHEST Journal*, 97(1): 58-62.
23. SantillanAA, Camargo CA, Colditz GA (2003). A meta-analysis of asthma and risk of lung cancer (United States). *Cancer Causes Control*, 14(4): 327-334.
24. Health Canada, Federal Contaminated Site Risk Assessment in Canada. Part II: Health Canada Toxicological Reference Values (TRVs). Version 2.0. 2007.
25. U.S. Environmental Protection Agency, Human Health Risk Assessment, available from: http://www.epa.gov/reg3hwmd/risk/human/index.htm, [access date: 2013 January 14].