Health hazards of welding fumes

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ABSTRACT

Even in the twenty-first century, welding is still a common and a highly skilled occupation. The hazardous agents associated with welding processes are acetylene, carbon monoxide, oxides of nitrogen, ozone, phosgene, tungsten, arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, silver, tin, and zinc. All welding processes involve the potential hazards for inhalation exposures that may lead to acute or chronic respiratory diseases. According to literature described earlier it has been suggested that welding fumes cause the lung function impairment, obstructive and restrictive lung disease, cough, dyspnea, rhinitis, asthma, pneumonitis, pneumoconiosis, carcinoma of the lungs. In addition, welding workers suffer from eye irritation, photokeratitis, cataract, skin irritation, erythema, pterygium, non-melanocytic skin cancer, malignant melanoma, reduced sperm count, motility and infertility. Most of the studies have been attempted previously to evaluate the effects of welding fumes. However, no collectively effort illuminating the general effects of welding fumes on different organs or systems or both in human has not been published. Therefore, the aim of this review is to gather the potential toxic effects of welding fumes documented by individual efforts and provide information's to community on hazards of welding.

Saudi Med J 2003; Vol. 24 (11): 1176-1182

Welding is the process in which, metal or other thermoplastic materials are joined together by the application of heat or pressure, or both with or without the use of filler metal. Electric welding was introduced in 1940s and manual metal arc welding has become the predominant method. Uncoated and acidic-coated electrodes were used up to the early 1950s. These electrodes produced an abundance of fumes. By the mid 1950s, basic coated electrodes were mainly used. In the 1970s gas shielded welding and tungsten inert gas welding were introduced. Welding on aluminum and on zinc-primed steel occasionally took place before 1970. Until 1976, welding was performed mainly on mild steel. From 1977 onwards stainless steel (SS) was gradually introduced and by 1990 approximately 50% of the welding arc time was carried out on SS.[1] The American Welding Society defines welding as "a metal joining process wherein coalescence is produced by heating to suitable temperature with or without the use of filler metal". Welding includes processes used to join pieces of material by heat, pressure or both included 2 closely allied processes cutting, brazing and soldering.[2]

Types of welding. ***Arc welding.*** In this type of welding heat is generated by striking an arc between an electrode and the base metal. The high temperature of an electric arc causes combination of oxygen and nitrogen from the atmosphere. Many arc welding processes are automatic or semi automatic, but it is also carried out manually the process is known as manual metal arc (MMA) or open arc welding.

Carbon arc welding. Carbon arc welding process produces fusion of metals by heating them with an arc between a carbon electrode and the material welded and no shielding is used, pressure and filler metal may or may not be used.

Cold welding. A solid state welding process in which pressure is used at room temperature to produce coalescence of metals with substantial deformation at the weld.

Electron beam welding. A welding process that produces coalescence of metals with the heat obtained

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from a concentrated beam composed primarily of high velocity electrons impinging on the joint to be welded.

Flux core arc welding. An arc welding process that produces coalescence of metals by heating them with an arc between continuous filler metal (consumable) electrode and the material welded. Shielding is provided by a flux contained within the tubular electrode.

Gas welding. The gas welding is used for welding thin materials and low temperature gradients are required in order to avoid cracking. The most common gasses used are acetylene, natural gas and propane mixed with oxygen in order to achieve higher temperatures. Oxyacetylene torches may also be used to cut through the metal.

Gas metal arc welding. An arc welding process that produces coalescence of metals by heating them with an arc between continuous filler metal (consumable) electrode and the material welded. Shielding is obtained entirely from an externally supplied gas or gas mixture. In gas metal arc welding, fusion is produced by heating with an arc established between a consumable electrode and the piece metal.

Gas tungsten arc welding. Gas tungsten arc welding or tungsten inert gas (TIG) welding is a process in which fusion is produced by heating with an arc established between a non-consumable tungsten electrode and the base metal. Shielding of the arc and the molten weld metal is obtained by an inert gas (argon or helium) or a mixture of these gases.

Shielded metal arc welding. An arc welding process that produces coalescence of metals by heating them with an arc between a covered metal electrode and the material welded. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode. Shielded welding processes are used extensively in many areas of industry as one or more of these processes can be used to join any of the weldable metals and alloys.

Plasma arc welding. An arc welding process that produces coalescence of metals by heating them with a constricted arc between an electrode and the work piece (transferred) arc or the electrode and the constricting nozzle (non transferred arc). Plasma arc welding uses a mixture of hydrogen, helium, argon or nitrogen at a small orifice through the gas flows. The plasma consists of ionized gas at a temperature of approximates 24000^{0}C which forms into a jet under the gas pressure and becomes an intense flame beyond the nozzle. However, shielding is obtained from the hot ionized gas, shielding gas may be an inert gas or mixture of gases. Pressure may or may not be used and filler metal may or may not be supplied. Plasma arc welding resembles welding in its use of an inert gas but differs from it in the use of a constricting orifice.

Oxyacetylene welding. An oxyfuel gas welding process that produces coalescence of metals of heating them with a gas flame obtained from the combustion of acetylene with oxygen. The process may be used with or without the application of pressure and with or without the use of filler metal.

Laser beam welding. A welding process that produces coalescence of materials with the heat obtained from the application of a concentrated coherent light beam impinging on the members to be joined.

Submerged arc welding. An arc welding process that produces coalescence of metals by heating them with an arc or arcs between a base metal electrode or electrodes and the material welded. Pressure is not used and filler metal is obtained from the supplemental source welding rod, flux or metal granules.[3,4]

The hazardous agents associated with welding process. In welding process, different agents are produced, which are hazardous to human health such as: a) Gases - acetylene, carbon monoxide, oxides of nitrogen, ozone, phosgene, tungsten. b) Metals - arsenic, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, nickel, silver, tin, and zinc. c) Physical agents - electricity, hot environment, vibration, ultraviolet radiation (UVR), ionizing radiation, noise and visible light.[4]

Pathogenesis. The welding workers have a highest exposure to welding fumes. Individual exposures would have depended on whether the welding took place on the ship, in confined space, workshop, or in the open air. The contents of welding fumes depend both on the metal welded and on the welding process involved.[5] The deposition of inhaled particles influenced by the physical and chemical properties of the inhaled agent and also by various host factors. The physical properties are of importance include particle size and density, shape and penetrability, surface area, electrostatic charge, and hygroscopicity. Among the more important chemical properties influencing the respiratory tract's response are the acidity or alkalinity of the inhaled agent.[6] In addition, Campbell and Schonell,[7] reported that, in occupational lung diseases, the inhaled particles produce a variety of reactions in the respiratory tract which depend upon the nature of the inhaled matter; the size, shape and concentration of the particles, the degree and duration of exposure, the site of the reaction and the individual workers susceptibility. The deposition of inhaled material is primarily dependent on particle size of solids substances and is best described in forms of an aerodynamic diameter. All particles with an aerodynamic diameter in excess of 10 μm are deposited on the mucous membrane in the nose and pharynx. Due to their momentum, they do not follow the air stream as it curves downward into the lungs and they impact on or near the tonsils and adenoids in the back of pharynx. Particles between 3 μm and 10 μm in diameter can be deposited throughout the tracheobronchial tree, where they initiate reflex bronchial constriction and coughing. Particles between 0.1 µm and 3 µm in diameter are mostly deposited within the alveoli. Particles smaller than 0.1 µm remain in the air stream and are exhaled.[8] However, the particles enter through the respiratory tract enter into the lungs and may cause disease. The pathogenesis is due to its exasperating, sensitizing and irritating properties. In welding process, metal fume is formed when vaporized metal condenses in air as metal oxide particles of respirable size. Metal oxide fume is particularly important component of the welding plume due to its size, it is small enough to deposit in terminal bronchioles and alveoli, distal to the cleaning action of the mucociliary system.[4] All welding processes involve the potential hazards for inhalation exposures that may lead to acute or chronic respiratory diseases.

Hazards to the respiratory system. Chronic bronchitis. Chronic bronchitis is clinically defined as cough and sputum production persisting for at least 3 months of the year for 2 consecutive years.[9,10] Chronic bronchitis with airflow obstruction is now the fourth leading cause of death among Americans. The trends over the past 2 decades indicate 60% increase in the mortality from chronic bronchitis.[11] The development of chronic bronchitis and other work related respiratory symptoms in welders related to exposure to a combination of dust and irritant gases in the work place. Many studies have noted an increased prevalence of cough and phlegm among welders. The shipyard welders and caulker or burners had a greater risk of chronic bronchitis. Among welders and caulker or burners who smoked, the increased risk of chronic bronchitis was related to the average fume exposure. The shipyard workers over the age of 50 were found to have significant respiratory morbidity including chronic bronchitis, wheeze on most days or nights and excessive breathlessness.[12,13] Several previous studies have noted that chronic bronchitis to be more prevalent in welders; however, this association has not been found in all studies.[14] Sulotto et al[15] reported the symptoms of chronic bronchitis in 22% and also signs of suspected radiological fibrosis in 18% of the subjects working in welding industry. Sobaszek et al[16] reported the effects of fumes from SS welding on the health of welders and determine the chronic effects of SS welding exposure. The respiratory symptoms were studied in 134 SS welders and 252 controls. The SS welders presented a higher prevalence of bronchial irritative symptoms such as cough or sputum production than the controls. Groth and Lyngenbo,[17] study the effects of welding fumes on respiratory symptoms. The welders showed a significantly higher prevalence of chronic bronchitis, 21% versus 9% in the control group. Other symptoms from the lower and upper respiratory system were also significantly increased among the welders and a dose-response relationship was found between exposure to welding fumes and the prevalence of symptoms. Erkinjuntti-Pekkanen et al[18] reported that, chronic bronchitis was more common among welders (24%) than non-welders (5%). Erhabor et al[19] reported that, the most frequent symptoms found among welding workers were obstructive lung disease compared to controls.

Interstitial lung disease. Acute chemical pneumonitis caused by inhalation of zinc fumes (zinc oxide) was accompanied by chronic siderosis in welding workers. It is well known that metal fume fever commonly occurs when inhaling zinc oxide fumes. However, acute chemical pneumonitis after exposure to zinc oxide during welding has been only rarely reported.[20] Similarly, Buerke et al[21] found interstitial pulmonary fibrosis after long term severe exposure to welding fumes in poorly ventilated workplaces. Erhabor et al[19] reported that 40.9% of the subjects working in welding industry were suffer from restrictive lung disease (Interstitial lung disease).

Asthma. Occupational asthma (OA) can be defined as variable airways narrowing casually related to exposure in the working environment to airborne dust, gases, vapors or fumes. There are many agents in the work place that can induce asthma or cause substantial deterioration in pre-existing asthma. It has been estimated that 5-15% of adult-onset asthma can be attributed to occupational exposures. Hence, adult patients, especially those with new-onset asthma, must be investigated with regard to occupational risk factors for disease. The prognosis for OA is improved if the causal exposure is controlled either by controlling the exposure at the workplace or by moving the patient out of the workplace. Keskinen et al[22] reported the significant increased in cases of occupational asthma caused by fumes from manual metal arc and SS welding.

Pneumoconiosis. The term pneumoconiosis [pneumo=lung, konis=dust] was coined by Zinker in 1866, to define a group of diseases caused by inhalation of dust. The word pneumoconiosis literally means dust in the lungs or dusty lungs.[23] A more widely accepted definition is that "pneumoconiosis is the accumulation of dust in the lungs and the tissue reaction to its presence".[24] Industrial welding has been associated with many respiratory problems, which vary from acute response such as that seen in metal fume fever to less common cases of hypersensitivity pneumonitis and chronic sequelae such as welding related pneumoconiosis. Welders may also develop pneumoconiosis from tin oxide (stannosis), carbon dust (anthracosis), and aluminum oxide (aluminosis). In a survey of actively employed electric arc welders in Britain reported in 1978, 7% had some degree of pneumoconiosis.[25] Hull and Abraham[26] showed that, chronic exposure to high concentrations of fumes during aluminum arc welding causes a severe pneumoconiosis. Tojima et al[20] found that, the respiratory health hazards associated with welding vary according to the material and the concentration of inhaled substances. Welding workers were suffering from acute chemical pneumonitis caused by inhalation of zinc fumes (zinc oxide) was accompanied by chronic siderosis.

Lung function. The assessment of pulmonary function with a spirometer has become common practice in patient settings and industry. Spirometry is now regarded as an integral component of any respiratory medical surveillance program. Pulmonary functions test has assumed a key role in epidemiological studies investigating the incidence, natural history and causality of environmental lung disease.[27] The pulmonary functions in the welders were found significantly altered. Previously, Hunnicutt et al[28] have reported a significant difference in forced expiratory volume in one second (FEV_1) between the welders who smoked and the controls who smoked. Welders who smoked had an increased incidence of abnormal pulmonary function test than the controls that smoked. In other words, smoking and welding almost double the percentage of those having abnormal pulmonary function tests. In addition, Kierst et al[29] showed that a FEV_1 reduced with increasing length of exposure in welding industry. Khanzadeh[30] observed the different parameters of pulmonary function test between control and welding works and reported that, in the mean of the FEV_1, forced expiratory ratio (FEV_1/FVC%) peak expiratory flow (PEF), and maximal voluntary ventilation were significantly decreased in welding workers compared with controls. The $FEF_{25-75\%}$ is decreased in welding workers as compared to control but not statistically significant. Stern et al[31] reported that FEV1, $FEF_{25-75\%}$ and PEF may sometimes be reduced in welders. Chinn et al[32] showed that among welders the effect of fumes was greatest in those who admitting not using proper preventive measures and such man experienced a work related deterioration in FEV_1. Mur et al[33] reported that the only significant differences between the welders overall compared to the controls were a slightly higher bronchial hyper-reactivity to acetylcholine and a lower lung diffusing capacity for carbon monoxide (CO) in the welders. However, non-specific, radiologic abnormalities (reticulation, micro nodulation) and obstructive signs were more frequent in the most exposed welders (welding inside tanks) than in welders working in well-ventilated workplaces. In the mild-steel welders, respiratory symptoms for example dyspnea, recurrent bronchitis and obstructive signs were more frequent in the welders using a manual process than in the welders involved with the semi-automatic process (MIG). Sobaszek et al[34] examined the chronic effects of fumes from SS welding on the health of welders. Pulmonary function tests were performed at the start and at the end of the work shift. The study of sensitization to harmful respiratory effects of welding was based on the study of the Spirometric variations during the shift. In SS welders, they observed a significant decrease in forced vital capacity (FVC) during the shift. Significant across-shift decrements in FEV_1 and FVC were related to the SS welding exposure compared with MS welding. Moreover, the across-shift decreases in FEV_1, FVC, and peak expiratory flow (PEF) were significantly related to the manual metal arc welding process, compared with metal inert gas techniques. They concluded that welding-related lung function responses are seen in SS compared with MS welders and in those with a longer lifetime welding history. Erkinjuntti-Pekkanen et al[18] reported that, welders who smoked had a significantly greater annual decline (88.8 ml) in FEV_1 than non-welders, who had a slight non-significant annual decline (34.2 ml). In addition, they showed that, welders without respiratory protection or local exhaust ventilation while welding, had a greater annual decline both in forced vital capacity (FVC) and FEV_1 than welders with protection. Among welders a significant association was found between the acute across shift change and the annual decline in FEV_1. Welders who smoked and welders working without local exhaust ventilation or respiratory protection have an increased risk of accelerated decline in FEV_1. Nakadate et al[35] observed the obstructive changes in pulmonary function, to be related to level of cumulative exposure to welding fume in male Japanese arc welders after controlling for age and smoking. Sobaszek et al[34] examined the acute respiratory effects of welding fumes in the workplace by measuring the across-shift changes in a population of 144 SS and mild steel (MS) welders and 223 controls. Pulmonary function tests were performed at the start and at the end of the work shift. In SS welders, they observed a significant decrease in FVC during the shift. Significant across-shift decrements in FEV_1 and FVC were related to the SS welding exposure compared with MS welding. Moreover, the across-shift decreases in FEV_1, FVC, and PEF was significantly related to the manual metal arc welding process, compared with metal inert gas techniques. They also demonstrated the influence of duration of SS welding exposure on the course of lung function during the work shift. After 20 years of SS welding activity, SS welders had more significant across-shift decreases than MS welders with a similar MS exposure duration. Erhabor et al[19] reported that the arc-welders were found to have characteristically lower lung function parameters than controls.

Lung cancer. Sjogren[2] observed that, SS welding is associated with exposure to metals including hexavalent chromium and nickel and their result suggest a causal relation between exposure to SS welding and lung cancer. Stern et al[31] reported that welding fumes contain significant amount of chromium, manganese, and nickel, and trace amount of arsenic and lead. These metals exhibit mutagenicity in one or more in-vitro bio-assays and several are strongly suspected human carcinogens. It might, therefore, be expected that welders experience an excess risk of respiratory tract cancer due to their occupation. Tojima et al[20] reported that, the respiratory health hazards associated with welding vary according to the materials and the concentration of inhaled substances. Welding workers developed malaise, cough, and dyspnea after inhalation of smoke. Moreover, diffuse granular and linear opacities on a chest x-ray were also observed. Transbronchial lung biopsy showed siderosis and exudation of fibrin and neutrophils into alveolar spaces. Moulin et al[36] reported that the overall mortality was slightly higher for welders (SMR = 1.02, 95% confidence interval [CI] 0.89-1.18) than for controls (SMR = 0.91, 95% CI 0.84-0.99). For lung cancer, the SMR was 1.24 (95% CI 0.75-1.94) for welders, whereas the corresponding value was lower for controls (SMR = 0.94, 95% CI 0.68-1.26). The SMR for lung cancer was 1.59 among non-shipyard MS welders (95% CI 0.73-3.02). Pezzotto and Poletto[37] observed the histological findings and showed that, the squamous cell carcinoma increased risks were observed in the metal industry, particularly in welders (OR = 2.9, CI = 1.0-10.1) and mechanics (OR = 1.8, CI = 0.9-4.2) and suggested that the Occupational exposures partly account for the high lung cancer mortality.

Hazards to the kidney. Pesch et al[38] demonstrated that substantial exposure to metals and solvents may be nephrocarcinogenic. There is evidence for a gender-specific susceptibility of the kidneys.

Hazards to the eye. Tenkate[39] reported that welding is one of the most intense artificial sources of optical radiation. Each type of welding process emits a different spectrum and intensity of optical radiation. For most processes, ultraviolet and visible radiation are the main components of the emission. Such factors as arc current, shielding gas, and base metal influence the emission spectrum. Adverse effects are confined to the eyes, with welders suffering from a higher proportion of optical radiation associated eye conditions than do non-welders. In addition, Tenkate[40] reported that, welding may cause photokeratitis and some types of cataract. Erhabor et al[19] reported the most frequent symptoms found among the welders were eye irritation (95.4%). Okuno et al[41] reported that, arc welding emit high levels of UVR, and this often causes acute injuries in the workplace, particularly photokeratoconjunctivitis. Guenel et al[42] showed the elevated risks of ocular melanoma for people with light eye color, light skin color, and for subjects with several eye burns. Also showed a significantly increased risk of ocular melanoma in occupational groups exposed to artificial UVR, but not in outdoor occupational groups exposed to sunlight. An elevated risk of ocular melanoma was seen among welders (OD = 7.3; 95% CI 2.6-20.1 for men), and a dose-response relationship with job duration was observed. Mariutti and Matzeu[43] suggested that, welding arc machines are widespread sources of intense UV, as well as visible and infrared radiation. Exposure to UV radiation can result in short- and long-term injury to the eyes. Fich et al[44] reported that radiation from welding arcs can cause keratoconjunctivitis and 'glassblower's cataract' and cause maculopathy. Barth et al[45] reported the clinical examinations of welding workers and observed the chronic damage of the external parts of the eyes in a higher percentage in welders than in a control group. Komarova et al[46] observed that welders using Quant-type laser devices were exposed to bright light flashes of plasma and laser exceeding in normal levels, such hazards could induce disorders in eyes, autonomic nervous, circulatory and immune systems of workers. In addition, impaired humoral immunity could lead to increased incidence of acute respiratory tract diseases.

Hazards to the skin. Tenkate[39] showed that, erythema is a common skin condition among welders. Similarly, in the occupational environment, there are also many artificial sources, of which welding arcs are the predominant and most intense.[39] Adverse health effects include erythema, pterygium, non-melanocytic skin cancer, and malignant melanoma. Erhabor et al[19] observed the (43.19%) cases of skin irritation in arc-welders compared to the controls. In addition, Mariutti and Matzeu[43] suggested that, welding arc machines are widespread sources of intense UV as well as visible and infrared radiation. Exposure to UV radiation can result in short- and long-term injury to the skin.

Hazards to the reproductive system. Tejral et al[47] conducted a study on the health state, as well as hematological, biochemical and cytogenetical changes of 53 SS welders. Results were compared to those of non-exposed persons and to a group of firemen. In the majority of welders, typical complaints appeared for example aqueous nasal secretion of a clogged nose feeling, only some of workers also suffered from a metal vapors fever. Bonde[48] examined the fertility in a Danish male metalworkers and information on births was obtained by record linkage to the Danish Central Population Register. Among the persons who had ever worked as welders, the probability of having a child was slightly reduced the year after a year of welding exposure, even after control for differences in age, birth cohort, paternal parity, birth of a child in the preceding 5 years, smoking, and consumption of alcoholic beverages (The reduction in fertility was associated with the welding of MS, but not with the welding of SS). Bonde[48] conducted a study on the hazards of welding on parameters of reproductive system and observed the sperm count per ejaculate, proportion of normal sperm forms, degree of sperm motility, and the linear penetration rate of the sperm were significantly decreased and the sperm concentration of follicle stimulating hormone (FSH) was non-significantly increased in MS welders. A dose response relation between exposure to welding fumes and these semen parameters was found. Semen quality decreased and FSH concentrations increased with increasing exposure. Bonde[48] conducted a cross sectional study concerning the male reproductive system in metalworkers and reported a moderate deterioration of semen quality in MS welders and less reliable changes in semen quality in low exposed SS welders. Similarly, Bonde[49] suggest that welding is detrimental to the male reproductive system, study investigates the semen quality, and sex hormone concentrations among 17 manual metal arc alloyed steel welders with a moderate exposure to radiant heat. They showed that Sperm count and motile sperm count were non-significantly reduced among welders in comparison with 2 different reference groups. Wu et al[50] showed that, the time from ejaculation to liquefaction of semen in exposed workers was longer than that in controls, and volume of semen, sperm count, viable sperm count and percentage were significantly lower in the exposed workers than in the controls and stepwise regression analysis suggests a direct toxic effect of manganese on sperm production. Mortensen[51] observed a greater risk for poor sperm quality among welders than controls; the risk for poor sperm quality was increased for those welders who worked with SS. Welding in general, and specifically with SS, is connected with a risk of reduced sperm quality.

Recommendations: 1. Workers exposed to welding fumes should wear safety apparel including, mask and safety goggles and must get pre-employment and periodic medical surveillance. 2. Welding should be performed in well-ventilated areas and use local-exhaust ventilation to remove fumes and gases at their source in still air. 3. Welders should use the safest welding materials and remove all the paint and solvents before welding or torch cutting and make sure all residues are removed. 4. Welders should use welding guns that capture and extract the fumes. 5. Welders must keep their faces faraway from the welding plume. 6. To identify the susceptible workers in due time and to improve the technical preventive measures are needed to reduce the risk of welding fumes in industrial workers.

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