HEALTH EFFECTS FROM WELDING EXPOSURES:

2024 LITERATURE UPDATE

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TABLE OF CONTENTS

1.0 INTRODUCTION **1-1**

2.0 METHODS **2-1**
- 2.1 Search Strategy 2-1
- 2.2 PubMed and NIOSHTIC-2 Searches 2-1
- 2.3 Literature Review 2-1

3.0 EXPOSURE STUDIES **3-1**

4.0 HEALTH EFFECTS STUDIES **4-6**
- 4.1 Studies in Humans 4-6
  - 4.1.1 Neurological Effects 4-6
  - 4.1.2 Respiratory Effects 4-7
  - 4.1.3 Cancer 4-10
  - 4.1.4 Musculoskeletal Effects 4-11
  - 4.1.5 Other Health Effects 4-11
- 4.2 Animal Studies 4-14
- 4.3 Mechanistic/cell/*In vitro* 4-15

5.0 REFERENCES **4-1**

List of Acronyms and Abbreviations

Al	Aluminum
ANOVA	Analysis of Variance
As	Arsenic
ATS	American Thoracic Society
AWS	American Welding Society
BC	Bladder Cancer
BMI	Body Mass Index
CAs	Chromosomal Aberrations
CCEAW	Continuous Consumable Electrode Arc Welding
CdO	Cadmium Oxide
CI	Confidence Interval
COPD	Chronic Obstructive Pulmonary Disease
COSHH	Control of Substances Hazardous to Health
Cr	Chromium
CrIV	Hexavalent Chromium
CSAs	Chromosome-type Aberrations
CTAs	Chromatid-type Aberrations
CTS	Carpal Tunnel Syndrome
Cu	Copper
DALY	Disability Adjusted Life Years
DNA	Deoxyribonucleic Acid
EPA	Environmental Protection Agency
ER	Estrogen Receptor
Fe	Iron
FEF25%-75%	Forced Expiratory Flow between 25% and 75% of vital capacity
FEV1	Forced Expiratory Volume in 1 second
FP-XRF	Field Portable X-ray Fluorescence
FVC	Forced Vital Capacity
GMAW	Gas Metal Arc Welding
GSH	Glutathione
GTAW	Gas Tungsten Arc Welding
GU	Genitourinary
HDL	High Density Lipoproteins
HR	Hazard Ratio
HT	Hypothalamus
ICP-MS	Inductively Coupled Plasma Mass Spectroscopy
IL-24	Interleukin 24
IL-6	Interleukin 6
IL-8	Interleukin 8
ILO	International Labor Organization
K-CAREX	Korean CARcinogen EXposure
KC	Kidney Cancer
LBS	Low Birth Weight
LDH	Lactate Dehydrogenase
MAG	Metal Active Gas welding
ME	Middle Ear

MIG	Metal Inert Gas welding
MMA	Manual Metal Arc
MMA-SS	Manual Metal Arc-Stainless Steel
Mn	Manganese
MRI	Magnetic Resonance Imaging
MSS	Musculoskeletal Symptoms
MTL	Medial Temporal Lobe
Ni	Nickel
NIOSH	National Institute for Occupational Safety and Health
NSE	Neuron-specific Enolase
OB	Olfactory Bulb
ODSS	Occupational Disease Surveillance System
OEL	Occupational Exposure Limit
OP	Oxidative Potential
Pb	Lead
PBMC	Peripheral Blood Mononuclear Cells
PC	Prostrate Cancer
PEF	Peak Expiratory Flow
PM	Particulate Matter
$PM_{2.5}$	Fine Particulate Matter
PMN	Polymorphonuclear Neutrophiles
POD	Point of Departure
PPAR	Peroxisome Proliferator-activated Receptors
PPE	Personal Protective Equipment
QoL	Quality of Life
RF-EMF	Radiofrequency Electromagnetic Field
ROS	Reactive Oxygen Species
RR	Relative Risk
SAL	Serum Aluminum Levels
SHED	Special Health Examination Database
SMAW	Shielded Metal Arc Welding
Ti	Titanium
TIG	Tungsten Inert Gas welding
TP	Total Particulate Matter
TR	Thyroid Hormone Receptors
UFP	Ultrafine Particulate Matter
UVR	Ultraviolet Radiation
VOC	Volatile organic Compound
WEMD	Work Environment Measurement Database
WF	Welding Fume
WHO	World Health Organization
Zn	Zinc

1.0 INTRODUCTION

On behalf of the American Welding Society (AWS), Epsilon Associates conducted a comprehensive literature search and summary of studies related to the health effects of welding. In this update, we included literature published in 2024 (including electronic publications or epubs) but excluded any articles that have been included in previous literature updates. This report describes the literature search methods, provides a summary of the results of our searches (*e.g.*, how many articles we identified), and explains how we identified relevant articles to include in the report (Section 2). We also present summaries of the exposure-related studies in Section 3, and of relevant health effects studies in Section 4.

2.0 METHODS

We searched the PubMed database for articles relevant to welding exposures and health effects as described below.

2.1 Search Strategy

1. To capture all the potentially relevant literature, the initial keyword searches included the word "welding" or "welders" or simply weld* (where the "*" is wild) in the title or abstract.
2. Searches were restricted to the year 2024 either electronically (epubs) or in print. Articles included in previous reviews were excluded from this review.
3. Where possible search terms were limited to searches of the titles and abstracts.
4. Searches were also limited to full text publications.
5. To further limit searches, we used the additional search word "health".

2.2 PubMed and NIOSHTIC-2 Searches

An initial search yielded 408 citations. We further refined the search to include "health", and this reduced the number of citations to 59. The 59 citations were uploaded to excel for further screening for relevance. We also searched the NIOSHTIC-2 database using the key words "welding" or "welder" in all fields for the year 2024.

2.3 Literature Review

We reviewed titles to assess the relevance to exposure and health effects from welding and identified duplicates for exclusion. We also excluded commentaries, conference abstracts, and any foreign studies that were deemed to be of little or no relevance. Some of the references were included in the 2023 review and thus not summarized in this report. The remaining citations were retained, and the article titles and abstracts were reviewed for relevance and sorted into the following categories:

- ♦ Particle characterization and exposure studies
- ♦ Epidemiology and controlled human exposure studies.
- ♦ Animal studies
- ♦ Mechanistic/cell/*in vitro* studies

The breakdown of the remaining references by category is listed in Table 2.1.

Table 2.1 Breakdown of Abstracts Reviewed by Study Category

Study Category	Totals from all databases
Particle characterization and exposure	15
Epidemiology and controlled human exposure	29
Animal	2
Mechanistic/cell/*in vitro*	8
Overall Total	**54**

3.0 EXPOSURE STUDIES

We identified 15 exposure-related studies or studies related to regulation or health and safety in welding occupational groups published in 2024 (*i.e*., particle characterization and exposure). Some studies were published online in 2024 (*i.e*., 2024 was the "epub date") and these were included in our summary. Articles that were not relevant or were included in prior AWS updates were excluded. A brief summary of the exposure abstracts is provided below for all the relevant studies.

Atalay *et al*. (2024) conducted a review of the prevalence of personal protection equipment (PPE) practices to avoid ocular damage from welding as well as factors that contributed to this prevalence in sub-Saharan Africa. The authors searched literature databases (PubMed, Scopus, web of Science) as well as Google Scholar and on-line African journals and conduced a meta-analysis of results. They also tested for publication bias and heterogeneity between studies. A total of 17 studies met the inclusion criteria. The authors reported that ocular protection practices averaged 53.7% and increased protection was associated with training, having work experience as a welder, and a history of ocular injury. Overall, the authors concluded that the use of PPE to prevent ocular injury was low and that welders in sub-Saharan Africa would benefit from training to increase use and prevent injuries.

Birhan *et al.* (2024) evaluated the prevalence of using personal protective equipment (PPE) to prevent eye injuries in 420 welders in Southern Ethiopia in 2023. The authors collected information using a questionnaire and logistic regression was applied to determine factors that impacted the use of PPE. The prevalence of eye protection was 43.6%, and training, permanent work conditions and previous eye injuries were all significantly associated with increased use of PPE. The authors concluded that the use of PPE was low in this group of welders and training, as well as more stable work conditions would help to improve the use of PPE. Buitrago-Cortes *et al.* (2024a) assessed the internal dose of metals from exposures to gas metal arc welding (GMAW) in 85 apprentice welders during the course of their training. The concentrations of arsenic (As), chromium (Cr), iron (Fe), and manganese (Mn), nickel (Ni), and cobalt (Co) were measured in urine, hair, fingernails and toenails at the beginning of the training program and at the end of the program. Personal exposure air measurements were also conducted. The authors reported high concentrations of Fe and Mn in personal air samples, with median (95th percentile) concentrations of 21 (300) and 230 (1900) $\mu g/m^3$, respectively. Short-term concentrations in urine and hair showed increases in As, Cr, Fe and Mn. Whereas longer-term concentrations indicative of cumulative exposures were determined from fingernail and toenail samples, which showed increases for Fe, Mn and Ni. The authors concluded that short-term exposures during training of welders can result in increased internal doses of metals, especially of Fe and Mn.

Buitrago-Cortes *et al.* (2024b) evaluated factors that contributed to increased internal dose of metals in 116 apprentice welders in Quebec exposed to welding fumes in a longitudinal follow-up study. The authors collected samples of hair, fingernails, and toenails at six different times during the training course and measured the concentrations of 14 metals. In addition, questionnaires were used to collect personal and sociodemographic information, as well as lifestyle factors. Statistical analyses using multivariate linear mixed-effects models were conducted to determine the factors associated with increased metal concentrations in each of the biological matrices, including exposure time. The authors reported significantly higher concentrations of chromium, iron, manganese, and nickel in hair, fingernails and toenails with exposure time. They also found that smaller work spaces and the combination of activities such as oxyfuel-cutting and welding in the same room resulted in much higher metal levels. Factors such as age, ethnicity and household income appeared to also be related to metal levels. Lastly, the authors noted differences in metal concentrations in different biological matrices, such as in hair and nails, emphasizing the importance of considering different biological media when evaluating exposures. Overall, the authors reported temporal variations in metal concentrations during the welder's training course, noting that exposure time was the highest predictor of elevated metal concentrations.

Buljat *et al.* (2024) assessed the concentration and metal composition of fine particulate matter ($PM_{2.5}$) in a metal workshop in Croatia at five different stations (each specializing in a different workshop technique). The authors collected a total of 53 samples that varied temporally between 30 minutes and 1 hour. $PM_{2.5}$ mass was assessed gravimetrically and elemental composition was determined using X-ray fluorescence for 14 elements. The different sources that were identified included background, steel grinding, metal active gas (MAG) welding, tungsten inert gas (TIG) welding, and machining. The sources were determined using source apportionment statistical techniques (positive matrix factorization) and the results corresponded well with workshop activities and results reported in other studies. $PM_{2.5}$ concentrations ranging from about 20 to 1800 $\mu g/m^3$, with the highest concentrations associated with MAG welding, polishing, grinding, and gas cutting. The lowest $PM_{2.5}$ concentrations were associated with TIG welding. The background source was characterized by high concentrations of iron (Fe) and calcium (Ca) and low concentrations of manganese (Mn), nickel (Ni) and copper (Cu). Steel grinding had high concentrations of Fe, zinc (Zn), Cu, and Mn. MAG welding was characterized as high Mn and Fe and low Zn, and TIG welding was characterized as having high Zn, Cr, Mn, Fe, Ni and Cu, and also was the only source that had molybdenum (Mo). The authors concluded that the source apportionment methods used in their study could be useful for identifying and characterizing indoor sources related to metal work.

De Rosa *et al.* (2024) assessed the urinary metabolic profiles of metal workers including 40 participants exposed to welding fumes, 13 participants exposed to volatile organic compounds (VOCs) from use of solvents and paints, and 24 unexposed control participants. The authors collected urine samples mid-week and measured 35 metabolites that belonged in different chemical classes including amino acids, organic acids, and amines. They used multivariate statistical analyses to identify the metabolites that were associated with each group of workers compared to controls. The authors reported that workers exposed to welding fumes had higher urinary concentrations of metabolites associated with oxidative stress (e.g., glutamine, tyrosine, taurine, creatine, methylguanidine and pseudouridine) and workers that were exposed to VOCs had higher concentrations of branched amino acids in their urine. Overall, the authors concluded that the study was useful for identifying specific urinary metabolic profiles for workers exposed to different occupational air contaminants.

Freire de Carvalho *et al.* (2024) evaluated data from a 10 year study that collected personal exposures from workers exposed to Shielded Metal Arc Welding (Stick) and Tungsten Inert Gas welding (TIG) in an oil refinery. Work was conducted in a ventilation controlled environment and respiratory protection was used depending on the welding process and base metal used. Measurements of total particulate matter (TP), hexavalent chromium (CrVI) and manganese (Mn) were collected. The study was conducted to assess the efficacy of controls and to collect data for estimating occupational exposures. The authors reported mean exposures of 2.01 mg/m^3 for TP (n = 94), 13.86 $\mu g/m^3$ for CrVI (n = 160), and 0.024 mg/m^3 for Mn (n = 95). Control measures were found to be adequate for limiting exposures. Statistical analyses showed that confined spaces increased exposures regardless of local exhausts or the addition of ventilation. The highest TP exposures were found during carbon arc processing, specifically gouging and grinding. Stick welding was associated with about a 50 fold higher exposure of CrVI, and 2.5 fold higher exposure to Mn compared to TIG welding. TP concentrations were about equivalent for the two welding processes and consistent with those reported in other studies. The authors concluded that the study contributed to a better understanding of exposures to welding fume in an oil refinery.

Fritschi *et al.* (2024a) evaluated the effectiveness of personal protective equipment (PPE) used during welding to reduce exposures to artificial ultraviolet radiation (UVR) – both ocular(eyes) and dermal (skin). The authors surveyed welders in Australia on control measures, with 634 responders of which 411 were welders, 36 were supervisors, and 130 were both welders and supervisors. The authors reported dermal UVR exposures in 7.8% of welders and 14.4% of supervisors, and ocular UVR exposures in 16.8% of welders and 33.1% of supervisors. Supervisors were less likely to use PPE, but supervisors were more likely to report the presence of warning signs in the workplace. Overall, the authors noted that a significant number of welders do not use adequate protection against UVR in the workplace.

Fritschi *et al.* (2024b) examined exposures to welding fume in Australian workplaces as well as use of personal protective equipment (PPE). The authors used on-line questionnaires in this cross-sectional study. Based on 634 responses, the authors determined that 91% of the workers were exposed to welding fumes, likely at high concentrations. They found that there was a wide range of welding processes used and work was often conducted in confined spaces with little mechanical ventilation. Use of PPE was not common. The authors found that Australian welders had potentially high exposures to welding fumes and that there was a general lack of controls in place to limit exposures and use of PPE was limited.

Garg *et al.* (2024) used machine learning techniques to estimate levels of ultraviolet radiation (UVR) and noise in foundries in India, with the aim of evaluating whether safety standards are adequate. The authors measured UVR and noise from arc welding of a ferrous alloy in three foundries. The measured levels were compared to estimates based on five machine learning algorithms. Based on the relative performance, for UVR, the Support Vector Machine regression algorithm performed the best, and for noise, the Random Forest algorithm performed the best. The authors noted that to the best of their knowledge, this was the first application of machine learning for estimating UVR and noise exposures from welding. Furthermore, the authors are providing the datasets and algorithms to others to continue the research.

Koh *et al.* (2024) developed an exposure matrix for occupational carcinogens that was based on occupation. The goal was to supplement the existing Korean CARcinogen EXposure (K-CAREX) system that specifies exposures by industry. The authors combined exposure estimates obtained from two databases: The Work Environment Measurement Database (WEMD), which contained exposure levels and the Special Health Examination Database (SHED), which provided data on occupations. Estimates of exposure levels were obtained for 22 carcinogens, and the prevalence of exposure was evaluated for 20 carcinogens across 156 occupations. For example, the authors noted that welders were assigned an exposure intensity rating of 3 and an exposure prevalence of 26% for welding fume exposure. The authors concluded that the exposure matrix supplements K-CAREX by providing occupation specific estimates of exposure that can be used for occupational cancer prevention and epidemiological studies.

Nakashima *et al.* (2024) evaluated the effects of gas metal arc welding of mild steel under different conditions to estimate the blue light hazards that could lead to photoreinopathy (*i.e.,* retinal injury). The authors measured spectral radiance of the arcs for various welding conditions and calculated the effective radiance, used to quantify blue light levels, based on the data. The results showed that blue light levels were in the hazardous range (5-118 E/cm^2/sr). Higher radiance was observed with increased currents and when pulsed vs steady currents were used. The type of shielding gas also influenced the radiance values. The authors concluded that eye protection is especially important when working with gas metal arc welding of mild steel to prevent retinal injury.

Nossa *et al.* (2024) evaluated whether measured levels of manganese (Mn) and iron (Fe) in toenails were associated with levels of the metals in the brain using data obtained from 17 exposed welders. At a baseline time point (T0), the authors collected T1 and R2* magnetic resonance imaging (MRI) maps of the welder's brain in addition to GABA, glutamate (Glu), and glutathione (GSH) levels from the thalamus and cerebellum. At T0 and every three months after, toe clippings were collected. The concentrations of metals in the toenails were compared to the concentrations in the brain. The authors did not find any significant associations at any of the time points for Mn. For Fe, cerebellum GSH concentrations were significantly correlated with Fe, 12 months after baseline, but no other significant associations were found. The authors concluded that toenail metal concentrations were not a good indicator of brain concentrations and potential neurotoxicity.

Pili *et al*. (2024) measured concentrations of inhalable particulate matter (PM) and ultrafine particulate matter (UFP) from welding processes in a steel factory. The authors collected air samples over four days, covering five different welding processes using a low-pressure electric impactor, model ELPI™ (range of sampling 0.006 µm and 10 µm) as well as an IOM sampler for inhalable PM. The authors reported that the majority of the measurements as particle concentration (the number of particles per cm^3 or part/cm^3) were found to be in the nanoscale range (0.010 µm to 0.071 µm), with average concentrations of 5.01×10^4 part/cm^3. Inhalable PM concentrations ranged from 0.1 mg/m^3 to 1.08 mg/m^3. The authors noted that even though inhalable PM concentrations were within permissible occupational standards, there remains a concern with exposures to UFP, which could be significant, but more research is needed.

Thunberg *et al*. (2024) used magnetic resonance imaging (MRI) to map the brains of welders and determine manganese (Mn) accumulation based on different welding processes. Air samples were collected at the welder's workplace three weeks before MRIs were obtained. The three welding processes that were evaluated included shielded metal arc welding (SMAW), inert gas tungsten arc welding (GTAW) or continuous consumable electrode arc welding (CCEAW). The authors found that SMAW was associated with lower accumulation of Mn compared with the other two processes, and that generally the accumulation of free, bound or compartmentalized Mn depended on the welding process. The finding that levels of Mn in blood correlated with deposition on Mn in the somatosensory and motor cortex areas of the brain may be indicative of potential neurological symptoms.

Yu *et al*. (2024) conducted *in vitro* experiments to determine the bioaccessibility of metal components of welding fume in normal lung fluid and in lung fluid that represented an inflammatory state. Bioaccessibility refers to the amount of the metal that can actually be absorbed by the body and available to potentially cause harm. The authors also estimated the overall exposure dose of each metal. The authors analyzed the components of the carbon dioxide gas shielded welding fumes using a scanning electron microscope, and determined that the main components included iron (Fe), manganese (Mn), zinc (Zn), titanium (Ti), aluminum (Al), copper (Cu), chromium (Cr), nickel (Ni) and arsenic (As). They reported that the bioaccessibility increased when tested in lung fluid that represented an inflammatory state compared to normal lung fluid, with the maximum results ranging from 6% for Cr to 88% for As compared to a range of 1% for Cr to 43% for As. In addition, the average daily dose of several components in either lung fluid exceeded inhalation reference limits including Mn (> 50 times), and in the inflammatory lung fluid Ti and Cr (> 1.3 times). The authors concluded that bioaccessibility is an important characteristic to consider in determining the potential health hazards of exposures to welding fume components.

4.0 HEALTH EFFECTS STUDIES

4.1 Studies in Humans

We identified studies in humans that assessed various health effects related to welding fume exposures. These health effects included neurological effects (5 studies), respiratory effects (8 studies), cancer (2 studies), musculoskeletal effects (2 studies), and other health effects (12 studies). Summaries of these studies are provided below.

4.1.1 Neurological Effects

Abdel-Rasoul *et al.* (2024) conducted a cross-sectional study of 130 welders and 130 controls across 50 welding facilities in Egypt to assess the neurobehavioral performance of the workers and how the results were influenced by manganese (Mn) exposures. The authors measured the concentrations of dust, Mn and welding fumes in the workplace air, measured blood levels of Mn, conducted neurobehavioral tests, and surveyed for neurological symptoms. They reported higher blood Mn levels in welders (4.16 ± 0.61 ug/l) compared to controls (1.72 ± 0.41 ug/l). In addition, welders had a higher prevalence of neurological symptoms and tested lower in neurobehavioral tests. Test results correlated with increased work duration and Mn blood levels. The authors noted that workers should wear personal protective equipment and increase ventilation to reduce welding fume exposures.

Asildağ *et al.* (2024) presented a case of a 28 year old welder that had been working for 14 years and his complaints included forgetfulness, reasoning issues, and overall decreased mental function that started 10 years ago. At a work screening, the doctor determined that he had a blood Mn level of 25.9 ug/l. In addition, based on a physical examination, the worker was found to have hyperactive patellar reflexes, an exaggerated reflex response when the patellar tendon under the is tapped and causes the person to kick out. It can be a sign of neurological dysfunction. A cranial Magnetic Resonance Imaging (MRI) confirmed that the worker suffered from manganism as a result of exposure to elevated Mn concentrations from welding.

Lee *et al*. (2024) evaluated the impacts of exposures to welding fumes on medial temporal lobe (MTL) structural changes as well as neuropsychological performance to assess whether workers had an increased risk of neurodegenerative diseases such as Alzheimer's. The authors recruited 42 welders and 31 controls and collected information on exposure history. In addition, blood samples were collected to determine iron (Fe) and manganese (Mn) concentrations, Magnetic Resonance Imaging (MRI) was conducted to measure R1 (1/T1) as an estimate of brain Mn concentrations and R2* (1/T2*) as an estimate of brain Fe concentrations. Neuropsychological tests were also performed and morphologic and diffusion tensor imaging was used to evaluate MTL structural changes. Exposed welders were found to have MTL changes and poorer performance on neuropsychological tests (specifically in processing/psychomotor speed, executive, and visuospatial domains), although no morphological changes were observed. The authors concluded that the observed results could be indicative of welding fume exposures resulting in changes similar to those seen in Alzheimer's patients. Further study is needed to determine the mechanism by which exposures could lead to these neurological outcomes.

Li *et al.* (2024) conducted a literature review and summarized data related to the neurological impacts of electric welding operations. The search was conducted on the Web of Science Citation Index (Web of Science), China Journal Full-Text Database (CNKI) and Wanfang Database databases dating back to 1976, when the first Chinese paper was published. The authors identified a total of 309 publications (112 in Chinese from 52 journals and 197 in English from 86 journals). The number of publications peaked in 2006 and again in 2018. Most of the articles were related to the neurological risks from exposures to manganese in welding fume, and research trends showed that initial publications were related to clinical manifestations, then to evaluation of the toxic mechanisms, and more recently were related to evaluating early biomarkers of exposure and neurological effects.

Monsivais *et al*. (2024) evaluated deposition of manganese (Mn) in different regions of the brain, comparing results from 36 exposed welders to 23 non-exposed controls in a truck manufacturing facility. The authors also evaluated the effects of Mn deposition on neuropsychological and motor test results. Questionnaires were used to collect demographic (age, education), medical history, and work history information on all participants. Estimates of each participant's cumulative Mn exposure were calculated using the work history and an exposure model. Motor function was evaluated using the Unified Parkinson's Disease Rating Scale, and cognitive testing included test for attention, memory, processing speed, verbal fluency, and executive function. A whole-brain 3D magnetic resonance imaging (MRI) methodology was used to map Mn deposition (R1 relaxation), and regional differences were assessed using statistical analyses. The authors reported that Mn deposition was found both in the basal ganglia, but also appears to diffuse to brain areas associated with motor and cognitive function and therefore has impacts in those regions as demonstrated by the results of motor and cognitive function tests. The authors highlight the new MRI methodology that can be used to further examine the effects of Mn exposures on various regions of the brain.

4.1.2 Respiratory Effects

Badima *et al.* (2024) conducted the first study of its kind of welding fume exposures in small-scale industry metal workers in Akaki Kality Sub city, Ethiopia. The authors conducted a cross-sectional study of 226 welders and 217 controls. Standardized questionnaires were used to collect data on respiratory symptoms, and personal exposure measurements of welding fume were obtained via active sampling onto PVC filters. The results showed much higher prevalence of respiratory symptoms in welders (23.9%) compared to controls (9.2%). Welding fume concentration among welders was mean = 5.98 mg/m^3 (± geometric standard deviation or GSD = 1.54), and the majority (53%) of the samples exceeded occupational health standards. Statistical analyses showed that increased respiratory symptoms were significantly associated with older workers compared to younger workers, less educated workers, inadequate use of personal protective equipment, smokers, lack of training, poorly maintained equipment, and work conducted indoors vs. outdoors. The authors concluded that findings show that there is a need to improve working conditions of welders in Ethiopia, reduce exposure to welding fumes, and thereby reduce the risks of chronic respiratory disease.

El-Sherif *et al*. (2024) evaluated the association between welding fume exposures, specific biomarkers of injury including serum neuron-specific enolase (NSE)[1] and welders' pneumoconiosis. The authors recruited 37 welders and 38 administrative controls, collected work histories and serum samples (chromium and NSE), and conducted clinical examinations and chest x-rays on all the participants. Air samples including for total suspended and respirable particles

[1] Serum neuron-specific enolase is a biomarker of potential neural injury

and welding fumes were also collected. The authors reported that all air sampling results were below health threshold limit values. In 22% of the welders, chest abnormalities were observed (reticular or ground-glass opacities). Both serum chromium and NSE were reported to be significantly higher in welders and were positively correlated with each other. The authors concluded that serum levels of NSE could potentially be used as an early biomarker of welders' pneumoconiosis.

Galarneau *et al*. (2025) conducted an evaluation of the association between respiratory symptoms and disease and occupational exposures in a cohort study of 1001 Canadian welders, 884 electrical workers, and 1338 matched controls. The authors collected self-reported incidence of asthma/wheeze and rhinitis every 6 months for five years. Data on physician diagnosed asthma and chronic obstructive pulmonary disease (COPD) were obtained from the Alberta administrative health database. Using job histories, cumulative exposures to particulate matter (PM), chromium (Cr) and nickel (Ni) were estimated. Statistical analyses using proportional hazards regression were conducted adjusting for sex, age, and smoking. The authors reported that welders had significantly higher risks of COPD compared to electrical workers (hazard ratio [HR] = 1.87; 95% CI = 1.27–2.77), but no higher incidence of asthma. Self-reported asthma and rhinitis were found to develop sooner in welders. Cumulative exposures to Cr were statistically significantly associated with COPD, and marginally associated with PM. Increased ventilation appeared to decrease respiratory risks. Asthma was also marginally associated with cumulative exposures to Ni. The authors concluded that welders had an increased risk of COPD and there was some evidence to suggest that COPD may be associated with exposures to Cr.

Li *et al*. (2024) evaluated the incidence of pneumoconiosis among welders and the factors that influence the development of disease as well as potential interventions. To study the disease burden, the authors used disability adjusted life years (DALY) analyses of welders diagnosed with pneumoconiosis between June 2022 and June 2023. Regression analyses were used to evaluate factors associated with disease and the authors also calculated economic losses from disease. The authors reported 974 cases of pneumoconiosis in welders, associated with loss of DALY of 6301 person-years or per capita of 6.5 person-years. The factors that most influenced the DALYs were age at diagnosis, pneumoconiosis grade and the amount of dust exposure. The authors concluded that pneumoconiosis is a serious risk from welding fume exposures and can be costly. They recommend safety measures to reduce the potential for disease.

Qumu *et al.* (2024) evaluated the effects of welding fume exposures on lung function as well as the influencing risk factors in workers in Tianjin, China from 2020 to 2022. The authors collected occupational health data from the China Disease Prevention and Control Information Platform including electrocardiograms, chest x-rays, and lung function results. The data were analyzed using multiple regression to evaluate potential influencing factors such as age, gender, and region. The results showed significantly higher lung function abnormalities in workers exposed to welding fumes. Male workers had higher rates than female workers, and these rates increased with age. The rates differed depending on the districts. The authors concluded that preventing measures should focus on middle-aged men and on specific industries in districts that showed excess rates of lung function abnormalities.

Saadiani *et al.* (2024) conducted a retrospective cohort study of 1200 welders and 1200 administrative staff in the automotive industry from 2018 to 2022 to evaluate the effects of exposures on lung function. Pulmonary function tests were performed and the authors collected air samples from the respiratory zone of welders to obtain measurements of copper (Cu), iron (Fe) and lead (Pb). The authors reported mean concentrations of Cu, Pb, and Fe of 0.12, 0.12, and 1.42 mg/m^3, respectively, with Pb exceeding occupational limits. Compared to control groups, welders had significantly lower lung function. The authors concluded that welding fume exposures could result in impaired lung function and recommended safety precautions in the workplace along with regular health screenings of the workers to ensure early detection and prevention of chronic lung disease.

Saraei *et al.* (2024) evaluated the effects on lung function from exposures to welding fumes in spot-welders (exposed group) compared to assembly line workers (unexposed group) in a major Iranian automotive company. This cross-sectional study included 3,958 male workers of which 1,798 were spot-welders (exposed) and 2,160 were assembly line workers (unexposed). The authors collected information on the worker's demographics, anthropometric indices (height, weight and body mass index [BMI]), smoking history (pack-year index), pulmonary symptoms, and occupational history. Breathing zone air samples were collected to measure concentrations of aluminum (Al), nickel (Ni), chromium (Cr), iron (Fe), manganese (Mn), zinc oxide (ZnO), and other metals using NIOSH 7300 method. Results were compared against occupational standards. Spirometry was used to measure lung function (including Forced Expiratory Volume in 1 second [FEV1], Forced Vital Capacity [FVC], FEV1/FVC ratio, Forced Expiratory Flow between 25% and 75% of vital capacity [FEF25%–75%], and Peak Expiratory Flow [PEF]) and assess whether workers had obstructive, restrictive or mixed pattern lung disease based on American Thoracic Society (ATS) standards. Statistical analyses were conducted to analyze the data including tests for correlations and regression analyses. The authors reported that there was no significant difference between the two groups with regards to mean age (42 years) and anthropometric indices (height, weight, BMI). The percentage of current smokers was also not significantly different: exposed (19.5%) and unexposed (16.7%). Air samples indicated that levels of metals were all within occupational limits. The authors also reported that predicted lung function results were as expected and there was no difference in the lung function test results between welders and assembly line workers. Similarly, the rates of pulmonary disease were similar between the two groups: obstructive: 5.1% total (no group difference), restrictive: 4.5%, mixed: 2.5%. Pulmonary symptoms reported were 1.9% overall (slightly higher in exposed, but not statistically significant). The authors also found that obstructive pulmonary disease was significantly correlated with BMI, prior smoking, and pulmonary symptoms, but not welding fume exposure. They concluded that the company's occupational health programs, regular screening and preventive measures likely resulted in positive health outcomes.

Tran *et al*. (2024) evaluated associations between several biomarkers of respiratory inflammation and oxidative stress (α1-antitrypsin, inter-α-trypsin inhibitor heavy chain [ITIH4], and 8-isoprostane) and lung function in 180 shipyard workers. The authors also collected personal samples of welding fume ($PM_{2.5}$) over an 8 hour workday. Urine samples were obtained pre- and post-work to measure biomarker concentrations and metal concentrations post-work. Lung function testing was also conducted post-work. They reported that increases in $PM_{2.5}$ were associated with small decreases of 2.2% in Forced Expiratory Volume in 1 second (FEV_1), 2.8% in Peak Expiratory Flow (PEF), 4.3% in Forced Expiratory Flow $(FEF)_{25\%}$, 5.0% in $FEF_{50\%}$, and 7.2% in $FEF_{75\%}$ and increases in α1-antitrypsin and ITIH4. Increased urinary metal concentrations were also associated with increases in these biomarkers. The authors concluded that these biomarkers could be an early indicator of adverse lung function impacts potentially associated with metal fume exposures. Better health and safety programs would be helpful for reducing potential lung function impacts from workplace exposures to metal fumes.

4.1.3 Cancer

Collatuzzo *et al.* (2024) presented results of a meta-analysis of studies that evaluated the association between welding fume (WF) exposures and genitourinary (GU) cancers, which include cancers of the prostrate (PC), bladder (BC), and kidney (KC). The authors followed PRISMA guidelines for conducting a systematic review. A literature search identified 2,582 publications of which seven studies were included in the analysis. A random effects meta-analysis was conducted to calculate the overall relative risk (RR) and 95% confidence interval (CI) for GU cancers. The authors reported significant associations for all GU cancers (RR 1.19; 95% CI = 1.07-1.32, based on 16 risk estimates), BC (RR 1.26; 95% CI = 0.98-1.60, based on 7 risk estimates), and KC (RR 1.28; 95% CI = 1.12-1.47, based on 5 risk estimates), but not for PC (RR 1.13; 95% CI = 0.90-1.42, based on 4 risk estimates). Larger associations were reported for North America compared to Europe. The study could not analyze specific associations by industry or welding type. In addition, potential confounding factors could not be ruled out. The authors concluded that the results are suggestive of an association, but more research is needed to confirm the results and to assess any differences by welding type or industry.

Momen *et al.* (2025) conducted a systematic review and meta-analysis to estimate the potential number of deaths and disability adjusted life years from trachea, bronchus, and lung cancer that is associated with both regular welding fume exposures and occasional welding fume exposures. The authors prepared a study protocol for a previous systematic review that was applied to this review. They conducted a thorough literature search of various databases (Medline, EMBASE, Web of Science, CENTRAL and CISDOC) through May 2024, and included grey literature, internet searches and relevant websites. The authors included any studies that evaluated associations between the relevant cancers and welding fume exposures that reported estimates of prevalence, incidence or mortality, excluding studies of workers < 15 years of age or unpaid workers. They had at least two reviewers screen publications for eligibility, extract relevant information, and evaluate the risk of bias, study quality, and strength of the evidence. They also conducted subgroup analyses and sensitivity analyses. A total of 19 studies (17 case-control and two cohort) spanning 17 countries were included in the meta-analysis. Although risk of bias was determined to be low, the authors found high risk of selection bias and exposure assessment bias. The authors reported an increased risk of developing trachea, bronchus, and lung cancer (higher incidence) from both regular and occasional exposures to welding fume (RR 1.39, 95% confidence interval [CI] 1.15-1.67, and RR 1.16, 95% CI 1.06-1.27, respectively). The risks for dying from trachea, bronchus, and lung cancer were also increased (RR 1.25, 95% CI 0.88-1.77 and RR 1.31, 95% CI 1.07-1.59, respectively). The results did not vary by region or gender and the sensitivity analyses supported the main results. Overall, the authors found the evidence for the association between welding fume exposures and incidence of trachea, bronchus, and lung cancer to be sufficient both for regular and occasional exposures. However, the risk of dying from trachea, bronchus, and lung cancer was found to be inadequate based on their review. The authors noted that these results could be used to inform the World Health Organization (WHO) and the International Labor Organization (ILO) Joint Estimates of the Work-related Burden of Disease and Injury.

4.1.4 Musculoskeletal Effects

Eros *et al.* (2024) evaluated the prevalence of carpal tunnel syndrome (CTS) in Ontario workers and to evaluate if there were gender differences. The authors consulted the Occupational Disease Surveillance System (ODSS) to identify CTS cases between 2002 and 2020. The authors analyzed the data using Cox proportional hazardous models to estimate hazard ratios (HR) and 95% confidence intervals (CI) for CTS based on occupation and industry, adjusted for age and stratified by gender. For welding and flame cutting the authors reported an HR for men of 1.65 (95% CI = 1.35–2.01) and for women of 1.83 (95% CI = 1.01–3.32), other occupations such as meat cutting, motor vehicle assembly, and packaging had higher HRs especially for women. The results highlight elevated risk of CTS for various industries, with some industries having especially high rates for women.

Figueira *et al*. (2024) conducted a systematic review of the use of wearable devices (*e.g.*, watches) that provide corrective feedback regarding posture in the workplace. A literature review was conducted for studies published between 2000 and 2023 and found in literature databases (PubMed, Web of Science, and Scopus) and Google Scholar. The authors found 12 studies for inclusion with only one study in welders. The type of sensor varied with most using accelerometers and feedback provided from the sensor itself mostly through vibration or motion (haptic feedback). Sensors were primarily prototype devices and most studies focused on health care workers.

4.1.5 Other Health Effects

Bruno *et al.* (2024) presented a case of damage to the middle ear (ME) in a welder and a literature review. The case was a description of an injury caused by the largest welding foreign body ever reported in the ME. The review included clinical presentation, diagnostic-therapeutic work-up, and outcomes.

Cui *et al.* (2024) evaluated the toxicity and magnetic properties of particulate matter (PM) generated during typical welding and cutting processes. The major magnetic component of PM from welding was found to be magnetite, which is formed during high-temperature operation with less oxygen pressure. The authors reported greater magnetization associated with fine PM ($PM_{2.5}$) from welding processes (1.4–4.2 times greater) and from cutting processes (2.0-5.7 times greater) compared to PM emitted from other sources (*e.g.*, iron and steel plants). In addition, welding $PM_{2.5}$ was found to be more toxic to nerve cells (3.5–4.5 times greater) and more likely to induce oxidative stress (2.1–7.0 times greater) than other magnetic sources of PM. Overall, the authors concluded that occupational protection is needed to reduce risks of adverse effects from welding and cutting processes in the workplace.

Galarneau *et al*. (2024) assessed reported harassment in the workplace and associations with depression and anxiety in a cohort of welders and workers in the electrical trades in Canada. A total of 1,885 workers participated in the study, with 1,101 (447 women) and 884 (438 women) in the welding and electrical trades, respectively. The authors employed questionnaires at the beginning of the study and follow-up was conducted every 6 months for 3 years (men) and 5 years (women). A final questionnaire included questions regarding harassment. About 75% of the workers completed the final questionnaire and of these 60% of women and 32% of men reported harassment. The workers reporting harassment had a higher number of episodes of depression and anxiety compared to other workers based on both questionnaire data and health records. Overall, the authors found evidence that harassment in the workplace contributed to poor mental health.

Johnson *et al*. (2024) conducted a systematic review of the associations between radiofrequency electromagnetic field (RF-EMF) exposure and adverse pregnancy outcomes including small for gestational age, miscarriage, stillbirth, low birth weight (LBS) and congenital anomalies. A literature search was conducted across various databases (MEDLINE; Embase; and the EMF Portal) and grey literature was also searched. At least two reviewers evaluated the studies and extracted data. Risk of bias and the strength of the evidence were also evaluated. A meta-analysis was conducted to estimate the overall relative risk (RR) and 95% confidence intervals (CI). The occupational studies included some welding studies. Overall, the authors did not find consistent evidence of adverse pregnancy outcomes associated with exposures to RF-EMF. Results were found to be inconsistent with a high risk of bias. More rigorous studies are needed with better exposure measurements and sound statistical analyses.

Magoha *et al*. (2024) evaluated health and training practices, reported work-related injuries and illness, and use of personal protective equipment (PPE) in 219 informal welders in this cross-sectional study in Mwanza City, Tanzania. The authors used statistical tests to assess whether improved training and site inspections would result in increased use of PPE and a reduction in workplace injuries and illness. The authors reported that education, training and awareness significantly increased PPE use. Use of PPE also reduced injuries associated with fire explosions and electrical shock. Knowledge and application of safety measures also resulted in a more positive attitude towards the workplace and safety practices in general. The authors concluded that workplaces would benefit from training programs to increase knowledge regarding occupational risks and use of PPE along with inspections and enforcement to improve the health and safety of informal welders.

Moen *et al*. (2024) conducted a literature review on the potential health effects associated with exposures to iron oxide that occurs in many workplaces including during thermal processes (*e.g.,* welding). Iron oxide particles are regarded as low toxicity, low solubility particles, but the authors hypothesized that exposures could be associated with acute or subchronic lung inflammation that could lead to lung disease. The review included one human study and several animal studies published up to February 2023, for a total of 25 studies. The authors determined that the data suggested a lower occupational exposure limit (OEL) for iron oxide based on their review of the literature. Specifically, the authors evaluated recruitment of polymorphonuclear neutrophiles (PMN) as the endpoint of interest, as this is characteristic of pulmonary inflammation. They reported that the point of departure (POD) for estimating the OEL ranged from 3 to 5 mg/m^3 based on several studies, with a single inhalation study indicating a POD of 0.75 mg/m^3.

Nwogueze *et al*. (2024a) conducted a case-control study to evaluate the effects of welding fume exposures in smokers on concentrations of zinc in blood serum and body composition to assess potential risks of developing cardiovascular disease. The authors recruited 40 adult men, 20 for the control group (nonsmokers and smokers with no welding exposure) and 20 for the experimental group (nonsmokers and smokers with welding exposure). The data were analyzed by comparing means and conducting an analysis of variance (ANOVA) for multiple comparisons. Compared to the control group, the body mass index (BMI) of smokers was lower and that of non-smokers was higher. The levels of zinc in blood serum were elevated only in smoking welders. The data obtained showed that the body mass index (BMI) of smokers (non-welders and welders) were slightly reduced while that of non-smoking welders was increased compared to the control. The serum zinc level increased among the smoking welders, increased high-density lipoproteins (HDL) levels was found in smoking non-welders and lower HDL was found in nonsmoking and smoking welders. Levels of triglyceride levels were increased in all groups compared to their respective control levels. The authors concluded that both exposure to welding fumes and smoking resulted in significant changes in levels of serum zinc, HDL and triglycerides and these could be early indicators of potential cardiovascular disease. Future studies should include additional biomarkers of exposure based on urine and toenail samples.

Onyeso *et al*. (2024) evaluated whether levels of aluminum in blood serum were associated with physical health indicators, cognitive function markers, and general quality of life (QoL) in welders. The authors recruited 100 men matched by age and location (50 welders and 50 controls). Serum aluminum levels (SAL) were determined using atomic absorption spectroscopy and data on blood pressure and body mass index were collected. Questionnaires were used to evaluate pain (pain rating scale), cognitive function (General Practitioner Assessment of Cognition), QoL (WHOQol-BREF), and musculoskeletal symptoms (MSS, using Nordic musculoskeletal symptoms questionnaire). Statistical tests were used to analyze the data. The authors reported higher SAL, generally lower QoL, and higher rates of MSS (neck, shoulder, upper back and knee) in welders compared to controls. In addition, they reported associations between SAL, blood pressure and body mass index, but no associations between SAL and pain, cognitive function or QoL. Adjustment for physical health and QoL resulted in a positive association between SAL and blood pressure. The authors noted that SAL may be a good biomarker for certain health effects and this warrants further investigation.

Pourhassan *et al*. (2024) conducted a risk assessment using different methodologies to assess risks associated with welding fume exposures. The authors measure concentrations of various metals including tin (Sn), zinc (Zn), aluminum (Al), iron (Fe), cadmium (Cd), lead (Pb), copper (Cu), manganese (Mn), nickel (Ni), chromium (Cr), and arsenic (As) using National Institute for Occupational Safety and Health (NIOSH) method 7300 and analysis using Inductively Coupled Plasma Mass Spectroscopy (ICP-MS). The four risk assessment methods that were applied included Malaysia's method, Control of Substances Hazardous to Health Essentials (COSHH model), Chinese OHRA standard, and the US Environmental Protection Agency (EPA) method. Monte Carlo probabilities were also used to evaluate the uncertainties in the methodology. The authors calculated risk ratios for all methodologies and reported and evaluated the consistency in the findings across methods. They reported that across all risk assessment methods exposures to hexavalent Cr were associated with the highest risk, cancer risks were found to be above acceptable levels, and the non-carcinogenic risks were highest for As exposures. Also, the authors found results to be consistent for the Malaysia method and the Chinese OHRA method and for COSHH and the Chinese OHRA method. Overall, due to the findings of elevated risks the authors concluded that engineering controls be used to reduce exposures and risks in the workplace.

Salles *et al*. (2024) evaluated the associations between blood heavy metal concentrations, including lead (Pb), cadmium (Cd), and arsenic (As) and self-reported health outcomes in women engaged in welding of jewelry (n=36), men working in a steel company (n=22) and a two control groups for each exposure group (n=28 and n=27, respectively) in Brazil. Blood samples were analyzed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and workers were tested for glucose levels (*i.e.,* to assess diabetes), elevated insulin and lipid concentrations. A questionnaire was also used to obtain background information on any household exposures and any underlying diseases. The authors reported that exposed women had higher blood concentrations of Pb, Cd, and As as well as higher blood concentration of glucose compared to controls. There was no difference between the exposed men and controls. The authors found significant associations between blood Pb and blood As levels and self-reported neurological symptoms, and significant associations between blood Cd levels and higher glucose concentrations in exposed women. The authors concluded that exposure monitoring and interventions were needed to protect workers, particularly the more "informal" workers such as women that make jewelry.

Viegas *et al*. (2024) evaluated biomonitoring data on exposures to hexavalent chromium [Cr(VI)], as part of the multicenter study across the European Union. The study described results from the Portuguese center. The authors collected urine samples to estimate workers' exposure to Cr(VI), air and hand wipe samples were also collected. A questionnaire was employed to obtain information on risk management practices, demographic information (e.g., age, gender) and smoking habits. Several occupational activities were included in the study such as plating, welding and painting. Results were compared to controls taken from the general population. The authors reported that the highest exposure group was painters, with elevated urinary Cr(VI). Use of respiratory protection helped to reduce exposures. Exposures to Cr(VI) in painters were associated with higher levels of DNA and chromosomal damage in blood cells. The authors concluded that there was a need for improved risk management practices, particularly for painters.

Zeng *et al.* (2024) used different occupational health risk assessment approaches to evaluate the risks related to noise in a vehicle manufacturing facility in Tianjin, China. They conducted an occupational health survey and then applied a health risk assessment, the health risk index method, and an Australian hazard risk assessment method to estimate the risks associated with noise in the facility. The authors reported the average noise level across all four workshops was 82.9 dB (A), and noise levels exceeded detection in 22% of samples taken. The levels of noise were highest in the welding workshop compared to other work areas. All risk assessment approaches yielded similar results with the assembly and painting workshops rated as having a level 4 risk (possible risk) and the stamping and welding workshops rates as risk level 3 (significant risk). The authors concluded that the facility should implement risk reduction measures in all workshops to reduce noise-related risks.

4.2 Animal Studies

We identified two studies in animals that assessed health effects related to welding fume exposures.

Kiss *et al*. (2024) assessed the effects of exposures to metal oxide nanoparticles from metal arc welding fumes on different hormone receptors in the brains of mice. The selected hormone receptors play an important role in protective and inflammatory processes in the brain. The authors collected samples from different parts of the mice brains 24 and 96 hours after exposure. They analyzed expression levels of estrogen receptors (ER), thyroid hormone receptors (TR), and peroxisome proliferator-activated receptors (PPAR). The authors reported changes in the hormone expression depending on the region of the brain. In particular, they found significant changes in the hypothalamus (HT) and olfactory bulb (OB). Elevated expression of ER was found in the OB after 24 hours of exposure, and in the HT after 96 hours. Similar changes were found for TR. For PPAR, there were increases after 24 hours in the HT, then decreases in other regions. The authors concluded that the results suggest that hormone changes are a response to inflammation in the regions of the brain from the welding fume exposures and support the transport of metal oxide particles from the lungs via the blood-brain barrier to the different regions of the brain.

Shoeb *et al*. (2024) evaluated the effects of welding fume exposures in Sprague-Dawley rats and DNA damage (telomere alteration) in peripheral blood mononuclear cells (PBMCs) and in lung tissue. The authors exposed rats to 2 mg/rat of manual metal arc-stainless steel (MMA-SS) welding fume particulate or saline (control) *via* intratracheal instillation. Cells were obtained 30 days after exposure. The authors reported that welding fume exposure resulted in telomere elongation and alteration of Shelterin complex. Telomeres are protective DNA sequences at the ends of chromosomes and the Shelterin complex of proteins plays a key role in maintaining the integrity of the telomeres. Alteration of telomeres is associated with various diseases including cancer. The authors concluded that results suggest that alteration of the telomere length and associated proteins could be indicative of welding fume damage and could be a useful as an early biomarker for disease, however, more research is needed to confirm this.

4.3 Mechanistic/cell/*In vitro*

We identified 8 mechanistic/cell/*in vitro* study that evaluated the potential health effects of welding fume exposures.

Burns *et al.* (2024) assessed the toxicity of particles generated by a double-wire arc thermal spray, specifically metals in the form of a wire that are melted onto an object to enhance the surface properties. The wires used in the testing included zinc (PMET540), iron and chromium (PMET731), and nickel (PMET885). The authors exposed human bronchial cells to the particles generated using the various wires at concentrations ranging from 0 to 200 µg/mL to assess cytotoxicity, oxidative stress, DNA damage and levels of protein markers for an inflammatory response. The authors reported that PMET540 was associated with the highest cytotoxicity, DNA damage, antioxidant concentrations and protein markers of inflammation (interleukin-6 and interleukin-8) even at the lowest concentrations (25 µg/mL). The protein marker endothelin-1 was elevated after cells were exposed to 100 µg/mL of PMET885. The authors concluded that the results suggest effects on cellular responses to metals associated with thermal spray applications, but these are dependent on the metal and concentration.

Dauter *et al*. (2024) evaluated the correlations between mild steel welding fume exposures and changes in blood proteins that are associated with increased risk of cardiovascular disease. In this study the authors collected serum samples, respirable dust concentrations (adjusted for use of personal protective equipment), welding years, and a cumulative exposure estimate at two timepoints six years apart in a cohort on 338 non-smoking men (171 welders, 167 controls), of these 174 (78 welders, 96 controls) provided data at the two exposure points. A panel of 92 proteins were evaluated and linear mixed models were applied. The author reported median respirable dust concentrations of 0.7 mg/m^3 at both time points. They identified seven key proteins that were significantly elevated and associated with elevated dust concentrations in welders compared to controls. These included FGF23, CEACAM8, CD40L, PGF, CXCL1, CD84, and HO1. One protein remained significant after adjustment for other variables (CD84). The authors concluded that the use of these biomarkers as early warning for potential cardiovascular disease should be considered. They noted that effects were observed at levels of respirable dust below European occupational standards (1-5 mg/m^3), and the proteins identified are associated with effects on blood pressure, damage related to clogged blood vessels and chronic inflammation.

Ghanem *et al.* (2024) evaluated the bioaccessibility of heavy metals in stainless steel welding fume (WF) under different experimental conditions as well as their oxidative potential (OP). Metals were generated in a lab and collected on filters. Two different solutions were used to extract the metals, representing pulmonary conditions, a phosphate buffer and Hatch's solution. The authors also investigated effects of different extraction times, storage duration of samples, and atmospheric conditions (temperature and pressure). They observed that experimental conditions impacted bioaccessibility as well as OP. Higher solubility was found for chromium, copper and nickel in Hatch's solution. Solubility of manganese did not vary for the two solutions tested and it was found to have the greatest OP. An extraction time of 30 minutes was optimal for determining OP. In addition, storage time and temperature both affected the OP results as well as metal solubility. Potential artifacts could be minimized by storing samples under nitrogen gas, or using alternative methods for measuring OP.

Kono *et al*. (2024) investigated the effects of welding fume exposures on skin cells, focusing on measuring the impact on interleukin-24 (IL-24), which is a cytokine associated with different skin conditions such as dermatitis and psoriasis. The authors reported increased levels of IL-24 and increased expression compared to control samples. Use of effective treatment of oxidative stress pathways that suppressed expression and production indicate that this is a likely pathway for increased IL-24 expression. Increased IL-24 expression was also associated with protective effects on skin cells from welding fume exposures. The authors concluded that increased expression of IL-24 may be an adaptive response to welding fume exposures in order to protect the skin.

Nwogueze *et al*. (2024b) conducted a case-control study to evaluate the effects of welding fume exposures in smokers on concentrations of zinc (Zn) and copper (Cu) in blood serum and oxidative stress biomarkers. The authors recruited 40 adult men, 20 for the control group (nonsmokers and smokers with no welding exposure) and 20 for the experimental group (nonsmokers and smokers with welding exposure). The authors reported overall higher concentrations of Zn and Cu in blood and increased biomarkers of oxidative stress in smokers compared to respective nonsmokers. In welders, there was an overall decrease in antioxidant capacity, but the decrease was not statistically significant compared to nonwelders. The authors concluded that result suggest that smoking can exacerbate the oxidative stress associated with exposures to welding fume.

Pavel *et al*. (2024) assessed the concentration of heavy metals in blood and urine in a cohort of 117 stainless steel welders and controls and the association between these exposure biomarkers and genotoxicity including total chromosomal aberrations (CAs), chromatid-type (CTAs) and chromosome-type (CSAs) aberrations. The authors reported that welders had higher concentrations of chromium (Cr), nickel (Ni), and manganese (Mn) in blood and urine compared to controls, and smokers had even higher concentrations. In urinary samples adjusted for creatinine (which adjusts for variable results related to diet and hydration levels), Cr and Mn were significantly higher in the control groups compared to welders. Significantly higher genotoxicity markers (CAs) were observed in welders compared to controls. The authors also reported significant associations between CAs and Cr, Ni and Mn in blood and urine adjusted for creatinine. The authors concluded that results suggest higher genotoxicity associated with metal concentrations in blood and urine as a result of welding exposures. There was also some evidence that exposures could be altering the excretion of metals from the body.

Saber *et al*. (2024) evaluated exposures to hexavalent chromium (CrVI) in a cross-sectional study of 28 workers and 8 apprentices recruited from six facilities and a vocational school, and 24 controls. The authors collected inhalable CrVI and total chromium (Cr) in personal air samples, Cr concentrations in urine and CrVI in blood, and questionnaires were used to collect information related to risk prevention measures. They also conducted genotoxicity tests. Inspections of the facility were conducted, and authors found that there was generally good compliance with occupational health and safety measures for some areas of the facilities (*e.g.,* chromium bath plating), but less compliance in the stainless steel welding areas. The authors reported geometric average concentrations of CrVI of 0.26 $\mu g/m^3$ (95% confidence interval (CI): 0.12-0.57) in workers and 3.69 $\mu g/m^3$ (95% CI: 1.47-9.25) in the apprentices. The exposed workers and apprentices had higher concentrations of Cr in urine and CrVI in blood as well as higher levels of genotoxicity compared to controls. Results in exposed workers were: urinary Cr (2.42 µg/L, 5th-95th percentile 0.28-58.39), CrVI in blood (0.89 µg/L, 0.54-4.92) and genotoxicity (1.59 %, 0.78-10.92), and in controls: urinary Cr: 0.40 µg/L, 0.16-21.3, CrVI in blood: 0.60 µg/L, 0.50-0.93,genotoxicity: 1.06 %, 0.71-2.06). In general, CrVI levels and corresponding genotoxicity were significantly higher in workers engaged in bath plating compared to welders. In fact, the authors noted that for welders, the authors did not find significant increases in CrVI exposures or associated genotoxicity compared to within company controls. Overall, the authors noted that more could be done to protect workers from CrVI exposures using preventive measures, particularly for workers conducting Cr plating.

Ying *et al*. (2024) assessed oxidative damage associated with exposures to ultra-fine particles (UFP) from metal inert gas (MIG) and manual metal arc (MMA) welding. The authors exposed human bronchial epithelial 16HBE cells to concentrations of metal UFPs (1-1000 $\mu g/cm^2$) and evaluated cell cytotoxicity, oxidative damage, and production of cytokines. Concentrations of about 33 $\mu g/cm^2$ of MIG/MMA UFP resulted in a 25% decrease in cell viability after 4 hours of exposure. Oxidative damage was also observed in the form of increased lactate dehydrogenase (LDH) leakage and increased reactive oxygen species (ROS) concentrations. Significant increases in interleukin 6 (IL-6) and 8 (IL-8) were also observed after exposure. The authors concluded that exposures to welding fume UFP are associated with oxidative stress and antioxidant production to counter the damage.

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