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Assessment of the biological effects of welding fumes emitted from metal inert gas welding processes of aluminium and zinc-plated materials in humans

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ABSTRACT

The aim of this study was to investigate biological effects and potential health risks due to two different metal-inert-gas (MIG) welding fumes (MIG welding of aluminium and MIG soldering of zinc coated steel) in healthy humans.

In a threefold cross-over design study 12 male subjects were exposed to three different exposure scenarios. Exposures were performed under controlled conditions in the Aachener Workplace Simulation Laboratory (AWSL). On three different days the subjects were either exposed to filtered ambient air, to welding fumes from MIG welding of aluminium, or to fumes from MIG soldering of zinc coated materials. Exposure was performed for 6 h and the average fume concentration was 2.5 mg m^{-3}. Before, directly after, 1 day after, and 7 days after exposure spirometric and impulse oscillometric measurements were performed, exhaled breath condensate (EBC) was collected and blood samples were taken and analyzed for inflammatory markers.

During MIG welding of aluminium high ozone concentrations (up to 250 μg m^{-3}) were observed, whereas ozone was negligible for MIG soldering. For MIG soldering, concentrations of high-sensitivity CRP (hsCRP) and factor VIII were significantly increased but remained mostly within the normal range. The concentration of neutrophils increased in tendency. For MIG welding of aluminium, the lung function showed significant decreases in Peak Expiratory Flow (PEF) and Mean Expiratory Flow at 75% vital capacity (MEF 75) 7 days after exposure. The concentration of ristocetin cofactor was increased.

The observed increase of hsCRP during MIG-soldering can be understood as an indicator for asymptomatic systemic inflammation probably due to zinc (zinc concentration 1.5 mg m^{-3}). The change in lung function observed after MIG welding of aluminium may be attributed to ozone inhalation, although the late response (7 days after exposure) is surprising.

Introduction

Welding fumes consist of a complex mixture of magnetite-like particles that are potentially hazardous to human health as indicated by various studies (Antonini et al., 2003). Symptoms such as occupational asthma, bronchitis (Lillienberg et al., 2008), metal fume fever (Pasker et al., 1997; Antonini et al., 2003; El-Zein et al., 2003), cardiovascular effects (Scharrer et al., 2007; Cavallari et al., 2008; Fang et al., 2009, 2010b), and interstitial pulmonary fibrosis (Yu et al., 2001) have been reported. Furthermore it is discussed whether welding is associated with an increased risk of lung cancer (Ambroise et al., 2006; Sorensen et al., 2007). However, working conditions at real workplaces lead to considerably heterogeneous exposure conditions (Isaxon et al., 2009) with complex mixtures of emissions from different sources like welding, grinding, soldering or chemical solvents (Korczynski, 2000) which complicate the assessment of the workers' actual exposure. Moreover, workplace conditions like ventilation, space, individual susceptibility and the use of personal protection equipment (Oxhoj et al., 1979; Mur et al., 1985) influence the impact of welding fume exposure on workers. Furthermore, studies on welding fumes effects are often complicated and biased by the subjects' smoking habits (Ozdemir et al., 1995; Steenland, 2002).

To overcome these problems arising from real workplace conditions in field studies, the Aachen Workplace Simulation Laboratory was developed (Brand et al., 2012a,b; Gube et al., 2012) – taking into account previous considerations of the working group "effect related factors" of the "Iron and Metal I" expert committee in the employers' liability insurance association, section "Hazardous Substances in Welding and Allied Processes" – which allows

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Table 1
Anthropometric and lung function data of study population.

Parameter	Unit	Average	Median	Standard deviation	Minimum	Maximum
Age	Years	22.5	22	2.02	20	27
Height	cm	182.9	185	6.88	167	192
Weight	kg	80.7	76.5	11.70	67	110
VC	L	6.18	6.30	0.81	4.95	7.3
VC%pred		111.63	112.95	12.41	92.1	128.8
FEV1	L	4.99	4.93	0.52	4.37	6.18
FEV1%pred		107.49	105.5	9.95	94.7	125.9

performing exposure studies in human subjects under controlled conditions using the emission of one single working process and establishing exposures with controlled concentration time courses in order to assess short term effects of various workplace emissions which are comparable among different subjects. The hypothesis on which such studies are based is that even short term exposure to, for example, welding fumes may induce topic as well as systemic inflammatory reaction (Antonini et al., 1998; Hurley et al., 2003; Kim et al., 2005; Palmer et al., 2006) which may be responsible for chronic lung disease (Sobaszek et al., 2000; Fireman et al., 2008) as well as cardiovascular disease (Sjögren et al., 2002; Sjogren et al., 2006; Fang et al., 2010b) if they persist for decades. Constituents of welding fumes that may be responsible for adverse health effects are supposed to be hexavalent chromium (Milatou-Smith et al., 1997), nickel (Fishwick et al., 2004), fluoride (Sjögren, 2004), zinc (Kuschner et al., 1997), and manganese (Cavallari et al., 2008).

The study presented here is part of a research project on health effects of welding fume particles which was designed in close cooperation with the Expert Committee "Metal and Surface Treatment" of the employers' liability insurance association which supported this study. The aim of these studies is to investigate possible health effects of various welding techniques and materials. In the study presented here, the effect of two process variants of metal inert gas welding (MIG welding of aluminium and MIG soldering of zinc coated steel) were investigated in respect to their ability to induce inflammatory reactions in healthy human subjects. Subjects were exposed for 6 h to concentrations of the two different welding fumes which were in agreement with the German workplace threshold limits. Topic and systemic inflammatory reactions were assessed by measuring inflammatory markers in exhaled breath condensate (EBC) (nitrate, nitrite, malondialdehyd) and in the blood (C-reactive protein, blood cell counts, coagulation factor VIII, ristocetin co-factor) up to one week. Additionally, lung function was measured using spirometry and impulse oscillometry.

Methods

Subjects

Twelve healthy male subjects participated in this study (mean age 22.5 years). They were non-smokers and had no history of asthma or any other lung or cardiac disease. Table 1 shows the anthropometric and lung function data of the study population. Subjects had no signs of any infections during the study period and used no anti-inflammatory medication. They did not report any unusual exposure to smoke or other hazardous substances.

The protocol of the study was approved by the ethics committee of the medical faculty of RWTH Aachen University. Informed written consent was obtained from each subject prior to inclusion.

Study design

The study was conducted in a threefold cross-over design in the Aachener Workplace Simulation Laboratory (AWSL). Each subject underwent three different exposures on three different exposure days. Time interval between each exposure was one week. The order of exposure was randomized in blocks of 4 subjects. The three different exposure scenarios were:

- Exposure for 6 h with filtered ambient air as control.
- Exposure for 6 h with an average concentration of 2.5 mg m^{-3} of welding fume from MIG welding of aluminium.
- Exposure for 6 h with an average concentration of 2.5 mg m^{-3} of fume from MIG soldering of zinc coated steel using a copper containing welding wire.

Endpoint parameters were measured before exposure, directly after exposure, 24 h after the beginning of exposure, and seven days after the beginning of exposure. Except for the third exposure week, the measurement after seven days was simultaneously the baseline measurement of the next exposure. Subjects entered the exposure laboratory with a time lag of about 30 min.

Exposure technique

The Aachen Workplace Simulation Laboratory AWSL consists of two different units: the emission room, in which the welding fumes are generated, and the exposure lab, in which the test subjects are exposed. Both units are connected by a ventilation system which regulates the fume concentration in the exposure lab (Brand et al., 2012b). Every 60 min, each subject cycled inside the exposure lab for 15 min on a bicycle ergometer at 80 W in order to simulate a workout as it would occur during a work shift.

The welding fumes were generated using metal inert gas welding (MIG):

1. *Metal inert gas welding of aluminium substrates* (MIG aluminium), base material: aluminium EN 573-2: EN AW-5754 (AlMg3), filler metal: aluminium (DT-AlMg3, Dratec, Germany), shielding gas: Argon, pulsed arc mode.
2. *Metal inert gas soldering on zinc plated base material* (MIG soldering), base material: hot-dip zinc coated steel sheet EN 10346: DX51D+Z275, filler metal: copper (96%), manganese (1%), silicium (3%) (CuSi3Mn) (Bercoweld S3, Bedra, Germany), shielding gas: Argon.

An experienced welder performed the welding below a funnel shaped fume hood. In order to simulate realistic concentration profiles welding was performed for 40 s every 10 to 20 min. Time intervals between each welding episode were chosen so that the average particle mass concentration was 2.5 mg m^{-3}. The maximum particle mass concentration was below 6 mg m^{-3}.

To keep the exposure dose similar among the 12 subjects the time integral (Expo) of exposure mass concentration C_{mass} was calculated online for each individual subject:

$$\text{Expo} = \int_{t_0}^{t} C_{\text{mass}}\,dt$$