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Uptake and urinary excretion of aluminum among welders

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Summary. The urinary excretion of aluminum was measured in 23 welders before and after an exposure-free interval of 16 to 37 days. In addition, the concentration of aluminum in the air was measured at the work site of 16 aluminum welders on the same workday as the first urine sample was taken. The concentration of aluminum in the urine depended on both the level and duration of exposure. The postshift urinary concentration of aluminum prior to an exposure-free interval was mainly related to the current air concentration, whereas the urinary concentration of aluminum determined after the exposure-free interval was related to total exposure duration (years). Among welders exposed for less than 1 year, the half-time for urinary concentration was about 9 days whereas welders exposed for more than 10 years had half-times calculated to be 6 months or longer. The results indicate that aluminum is retained and stored in at least two functional compartments of the body and is eliminated from these compartments at different rates.

Key words: Air concentration – Aluminum – Half-time – Urine concentration – Welding

Introduction

Aluminum has attracted a considerable degree of interest among physicians and toxicologists ever since it was associated with encephalopathy in dialysis patients [1]. Patients with severely impaired kidney function cannot eliminate aluminum in the urine, and the metal will accumulate in the body as a result of prolonged exposure. Increased levels of aluminum in the brain and bone may damage these organs [2, 7]. In a previous study of workers exposed to aluminum in different types of industries, welders were found to be one of the most exposed groups, with significantly higher blood concentrations of aluminum than non-exposed control subjects. However, their aluminum blood levels were lower than those of dialysis patients without signs of encephalopathy [8]. In another group of welders, the urinary concentration of aluminum was related to the level of current exposure as well as to the duration of exposure [9]. The purpose of the present investigation was to continue to study the uptake, kinetics, and elimination of aluminum among welders exposed to this metal.

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Subjects and materials

The study comprises 25 welders (24 men and 1 woman) who had welded aluminum for 0.3 to 21 years. The mean age of the welders was 32 years (19–59 years). Metal inert gas (MIG) welding was the most frequent method but Tungsten inert gas (TIG) was also used.

The current air exposure during a workshift was measured in the breathing zone of 16 welders. The first urine sample was taken immediately after this workshift. A second urine sample was taken from 23 of the 25 welders after an exposure-free period of 16–37 days (vacation). A further sample was taken from 8 welders 5–7 days after their last exposure. All participants were queried regarding the possibility of taking aluminum-containing drugs prior to the investigation.

Air samples. Samples of the welding fumes were collected on cellulose ester membrane filters (Millipore filter AAWP, diameter 37 mm, mean pore size 0.8 μm) in the breathing area of the subjects. A membrane filter pump (Dupont model P 2500) was used with a mean flow of 2.2 l/min (1.9–2.4 l/min). The total sampling time was at least 6 h.

Urine samples. The urine samples were collected after a workshift (t_0) in order to study the relationship between air and urine concentrations of aluminum. The second (t_1) and third (t_2) urine sample were taken after a period of nonexposure. The sampling hour of the day was arbitrarily chosen as no diurnal variation had been observed in our previous study [9].

Urine was voided into 500-ml bottles of polyethylene with lids of the same material. The bottles and lids had been carefully cleaned, soaked in 5% RBS-25 solution for at least 5 h and in 1% ethylenediaminetetraacetate solution overnight, and carefully rinsed with ion-free water.

At the laboratory the urine samples were divided into two portions, a small amount being preserved for the assessment of creatinine. To the remainder, 1.5% of 9 *M* sulfuric acid was added. The samples were stored at −20°C until analysis. Creatinine was determined by a photometric method on a reaction rate analyzer (LKB 8600).

Determination of aluminum. The aluminum was determined by electrothermal atomic absorption spectrometry using a Perkin-Elmer Zeeman/3030 system, which comprised a microcomputer-controlled spectrometer for graphite furnace analysis, equipped with a AC-Zeeman magnet, a closed cooling system, an AS 60 auto sampler, and a PR-100 printer. The detection limit was 2 µg/l. The standard deviation was 1.35 µg/l at an aluminum level of 40 µg/l and the coefficient of variation was 3.3% ($n = 10$) [10].

The welding fume samples were analyzed according to a method previously described [9]. The program for the graphite furnace was close to the program used for the urine samples. The calibration was performed by means of a standard curve and the aluminum values were calculated by the Zeeman/3030 computer.

Statistical methods. Simple as well as multiple linear regression analysis was used to study the relationship between the urinary concentration of aluminum, the air concentration of aluminum, and the exposure time.

Assuming first-order kinetics, the decline in urinary aluminum concentration was calculated from mean values of c in the equation $A_1 = A_0 \cdot e^{-c(t_1 - t_0)}$, where A_0 is the urinary concentration of aluminum at t_0 and A_1 is the concentration at t_1. The corresponding biological half-time can be calculated from $\ln 2/c$.

Results

The air concentrations of aluminum, calculated as 8-h time-weighted averages, varied between 0.2 and 5.3 mg/m^3, median 1.1 mg/m^3 and mean 1.5 mg/m^3. The aluminum levels of urine collected before the exposure-free interval varied from 6 to 564 µg/l (median 82 µg/l) and the corresponding creatinine adjusted concentrations varied from 6 to 322 µg/g creatinine (median 54 µg/g creatinine). After an exposure-free interval of 16 to 37 days, the urinary concentrations of aluminum decreased to between 3 and 434 µg/l (median 29 µg/l) or 4 and 285 µg/g creatinine (median 29 µg/g creatinine).

The urinary concentration of aluminum was dependent on the level of current exposure as well as the duration exposure. The postshift urinary excretion of aluminum before an exposure-free interval was mainly related to the current air level, whereas the urinary excretion of aluminum measured after the exposure-free interval was related to the total number of exposed years.

A linear relationship was found between postshift urinary concentrations and current air concentrations of aluminum, U-Al (µg Al/l) = 29.6 + 25.0 × air-Al (mg/m^3), $n = 16$, $r = 0.72$ and U-Al (µg Al/g creatinine) = 30.2 + 13.5 × air-Al (mg/m^3), $n = 16$, $r = 0.47$, respectively. When all subjects exposed for 1 year or more were excluded, the slope of the regression line became steeper: U-Al (µg/l) = 24.5 + 34.7 × air-Al (mg/m^3), $n = 9$, $r = 0.92$ and U-Al (µg/g creatinine) = 30.7 + 18.5 × air-Al (mg/m^3), $n = 9$, $r = 0.57$.

The linear relation between the urinary excretion of aluminum after an exposure free interval of 16 to 37 days and the total number of aluminum welding years was U-Al (µg Al/g creatinine) = 9.4 + 8.7 × exposed years, $n = 23$, $r = 0.85$. Without the adjustment for creatinine, the linear equation was U-Al (µg Al/l) = 8.9 + 11.9 × exposed years, $n = 23$, $r = 0.74$.

Two welders had taken aluminum-containing drugs before the exposure-free interval. The relationships described were not significantly influenced if these two subjects were excluded. The number of exposed years influenced the rate of elimination, c, in the equation $A_1 = A_0 \times e^{-c(t_1 - t_0)}$. Among welders with less than 5 years aluminum exposure, the mean of the elimination constant (c) was 0.040 based on unadjusted urine samples and 0.032 based on creatinine-adjusted samples. The corresponding half-times for these c values are 17 and 22 days, respectively. Among welders with 10 or more years of aluminum exposure, the c value for unadjusted urine was 0.0057 and for creatinine-adjusted urine 0.0016, with corresponding half-times of 122 and 433 days, respectively.

Urine samples were collected three times from eight subjects: (1) a postshift sample during exposure (t_0); (2) after an exposure-free interval of 5–7 days (t_1); (3) after 18–30 further exposure-free days (t_2). The means of the elimination constants (c) between t_0 and t_1 were 0.026 and 0.056 based on unadjusted and creatinine-adjusted samples, respectively, with corresponding half-times of urinary concentrations of 27 and 12 days. Five of the eight welders had been exposed for a shorter period than 1 year. The half-times for these were calculated to be 8 and 9 days. The means of the elimination constants between t_1 and t_2 for unadjusted and creatinine-adjusted urine samples were 0.026 and less than 0.001, respectively, corresponding to half-times of 27 days and more than 2 years.

Discussion

Aluminum welders are exposed to levels of aluminum that often exceed 1 mg Al/m^3. MIG welding of aluminum generates particles with a mass median diameter of about 0.4 µm and TIG welding generates somewhat smaller particles [4]. This means that most of the particles produced in these welding processes are respirable [12].

The urinary concentration of aluminum was dependent on the level of current exposure as well as on the duration of exposure; this is in accordance with one of our previous studies [9]. Among welders exposed to aluminum fumes for a period shorter than 1 year, the following relationship was observed between postshift urinary concentrations and current air concentrations of aluminum: U-Al(µg/l) = 34.7 × air-Al (mg/m^3) + 24.5. A similar equation has previously been reported in an Italian study on welders exposed to aluminum, with a short period of exposure [6]: U-Al (µg/l) = 36 × air-Al (mg/m^3) − 16.

In addition, a relationship was observed between the urinary concentration of aluminum after an exposure free interval of 16 days and the number of exposed years: U-Al (µg/l) = 8.9 + 11.9 × exposed years. The postshift urinary concentration of aluminum can thus be expressed as a function of two variables: air concentration of aluminum and duration of aluminum exposure [9]. When the result from this study is combined with that from a previous study of welders exposed to aluminum [9], the following relationship will emerge: U-Al (µg/l) = 41.7 × air-Al (mg/m^3) + 6.7 × exposed years −4.6, $n = 25$, $R = 0.89$. Both coefficients of regression differ significantly from zero ($P < 0.05$).

We found that the urinary concentration of aluminum by welders with a short exposure time (< 1 yr) decreased by 50% within 8–9 days, whereas in welders with more than 10 years of exposure, the half-time was calculated to be half a year or longer. In one of our previous studies [9], three volunteers were exposed to aluminum-containing welding fumes for 1 day. The urinary half-time in these previously unexposed subjects was calculated to be about 8 h. Mussi and co-workers [6] assessed aluminum in the urine from four welders exposed to aluminum fumes for 6 months. The mean of the calculated half-times was 4 days.

The calculations of half-times of urinary concentrations of aluminum are not precise due to the relatively great variation between individuals. The results nevertheless indicate that inhaled aluminum is stored in the human body in at least two functional compartments, one with a relatively rapid rate and another with a slow rate of elimination. The compartment with the slow rate of elimination is not yet located, but the lungs and the skeleton are likely candidates: the lungs, as inhaled metal particles can be retained for a considerable period [3, 5]; the skeleton, as bone contains a rather high concentration of aluminum, and about 40% of the total aluminum in the body is stored in the skeleton [11]. We assume that aluminum is eliminated slowly from one of these organs, or both, and that this will explain the slow decrease of the urinary concentration of aluminum seen among welders exposed to aluminum for many years.

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