ORIGINAL ARTICLE

Long-term effects of aluminium dust inhalation

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ABSTRACT

Objectives During the 1950s and 1960s, aluminium dust inhalation was used as a potential prophylaxis against silicosis in underground miners, including in Australia. We investigated the association between aluminium dust inhalation and cardiovascular, cerebrovascular and Alzheimer's diseases in a cohort of Australian male underground gold miners. We additionally looked at pneumoconiosis mortality to estimate the effect of the aluminium therapy.

Methods SMRs and 95% CI were calculated to compare mortality of the cohort members with that of the Western Australian male population (1961–2009). Internal comparisons on duration of aluminium dust inhalation were examined using Cox regression.

Results Aluminium dust inhalation was reported for 647 out of 1894 underground gold miners. During 42 780 person-years of follow-up, 1577 deaths were observed. An indication of increased mortality of Alzheimer's disease among miners ever exposed to aluminium dust was found (SMR=1.38), although it was not statistically significant (95% CI 0.69 to 2.75). Rates for cardiovascular and cerebrovascular death were above population levels, but were similar for subjects with or without a history of aluminium dust inhalation. HRs suggested an increasing risk of cardiovascular disease with duration of aluminium dust inhalation (HR=1.02, 95% CI 1.00 to 1.04, per year of exposure). No difference in the association between duration of work underground and pneumoconiosis was observed between the groups with or without aluminium dust exposure.

Conclusions No protective effect against silicosis was observed from aluminium dust inhalation. Conversely, exposure to aluminium dust may possibly increase the risk of cardiovascular disease and dementia of the Alzheimer's type.

What this paper adds

- Aluminium dust inhalation was used as a potential prophylaxis against silicosis in miners, including in Australia, whereas aluminium exposure may lead to long-term adverse health effects.
- This study indicates that aluminium dust exposure may possibly be related to an increased risk of cardiovascular and Alzheimer's diseases.
- No evidence was found that aluminium dust inhalation protected against silicosis.

INTRODUCTION

In the middle part of the 20th century, it was believed that inhaled aluminium compounds coated the silica particles in the lungs and inhibited the silica-induced fibrotic reactions and as such worked as a prophylaxis for silicosis.[1] Silicosis is a form of pneumoconiosis due to inhalation of respirable silica. Patent rights for the aluminium therapy were held by the McIntyre Foundation in Canada, where the 'McIntyre powder' was used in the mines for over 30 years from the mid-1940s.[2] There has however never been scientific evidence of its prophylactic effects against silicosis.

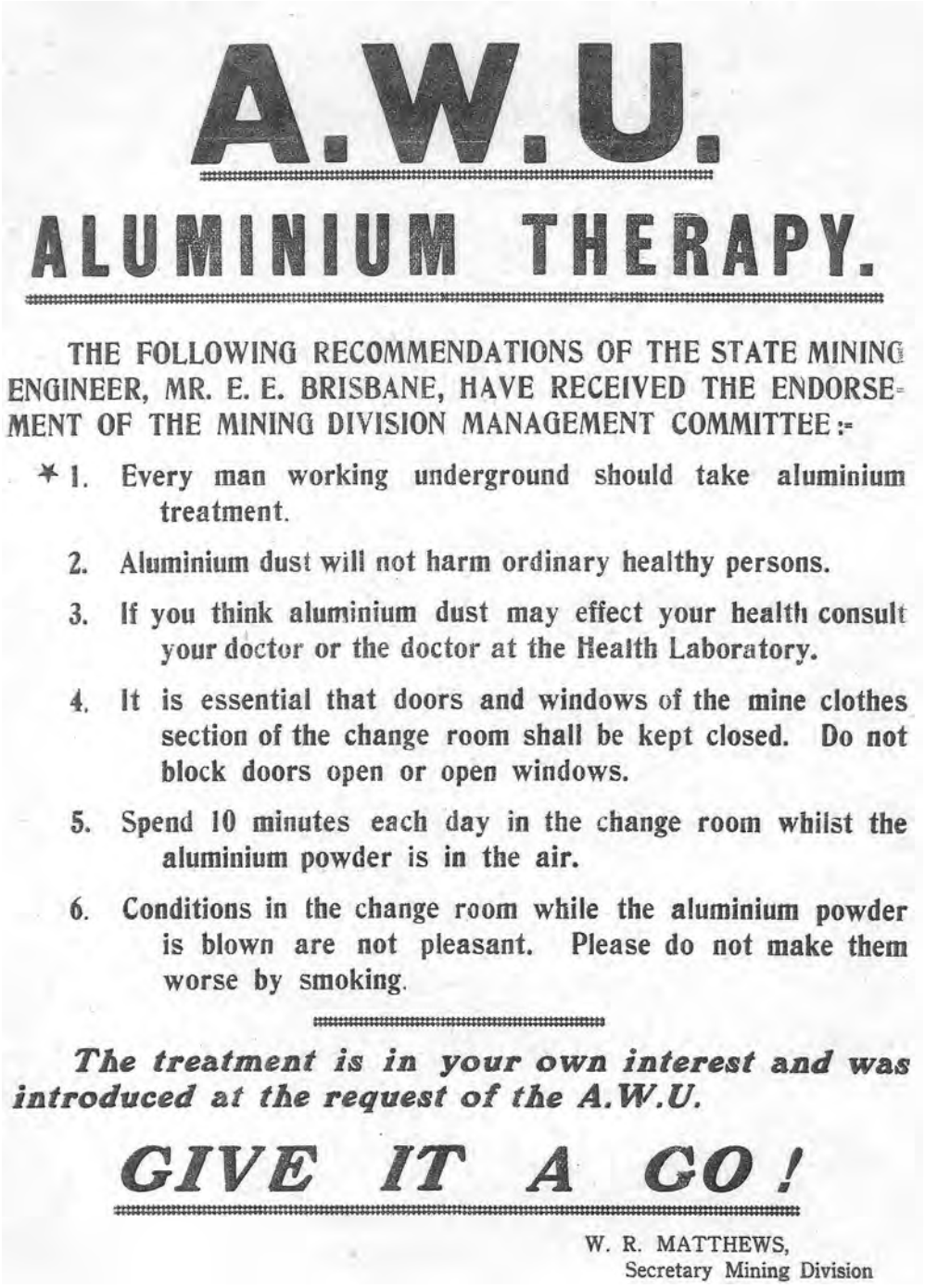
Nowadays, occupational exposure to aluminium dust occurs mainly in the aluminium industry.[3–5] Several long-term adverse health effects of aluminium exposure have been described. Increased risks of Alzheimer's disease[6] and cerebrovascular disease mortality[4] have been suggested in industrial cohorts and some indication of an association with cardiovascular disease has also been reported.[4]

Epidemiological evidence of an association between Alzheimer's disease and occupational exposure to aluminium is inconsistent as case-control studies found no associations.[7] The general population may also be exposed to aluminium via drinking water or diet.[5 8 9] Associations between such environmental exposure to aluminium and Alzheimer's disease have been suggested, but evidence is as yet insufficient.[9] The relationship between aluminium and Alzheimer's disease has been particularly controversial.[10] However, aluminium has been reported to accumulate in brain tissue in a region-specific manner implicating its involvement in Alzheimer's disease.[10]

From 1950 onwards, all underground miners in Western Australia were encouraged to inhale aluminium dust on a daily basis (figure 1). The dust was administered to the workers in the change rooms, where they had to inhale the aluminium particles for 10 min.[11] This practice ceased in the late 1960s in Western Australia.

The Western Australian Kalgoorlie gold miners' cohort was established in 1994, consisting of all male miners who attended workplace health surveys between 1961 and 1975. Previous analyses in this cohort have focused on respiratory outcomes, including lung function, radiographic silicosis, chronic obstructive pulmonary disease and lung cancer.[12–15] Recently, the mortality data for this cohort have been updated up to December 2009 and cancer mortality has been described.[16]

About a third of the Kalgoorlie underground miners inhaled aluminium dust as a prophylaxis for silicosis. The cohort therefore offered the opportunity to examine potential long-term effects of the aluminium inhalation. We aimed to describe the association between aluminium dust exposure and



A.W.U.

ALUMINIUM THERAPY.

THE FOLLOWING RECOMMENDATIONS OF THE STATE MINING ENGINEER, MR. E. E. BRISBANE, HAVE RECEIVED THE ENDORSEMENT OF THE MINING DIVISION MANAGEMENT COMMITTEE:-

* 1. Every man working underground should take aluminium treatment.

2. Aluminium dust will not harm ordinary healthy persons.

3. If you think aluminium dust may effect your health consult your doctor or the doctor at the Health Laboratory.

4. It is essential that doors and windows of the mine clothes section of the change room shall be kept closed. Do not block doors open or open windows.

5. Spend 10 minutes each day in the change room whilst the aluminium powder is in the air.

6. Conditions in the change room while the aluminium powder is blown are not pleasant. Please do not make them worse by smoking.

The treatment is in your own interest and was introduced at the request of the A.W.U.

GIVE IT A GO!

W. R. MATTHEWS,
Secretary Mining Division

Figure 1 Australian Workers' Union (AWU) poster advertising aluminium therapy, circa 1950s (Source: Fitzgerald[25]).

mortality rates from cardiovascular, cerebrovascular and Alzheimer's diseases. Additionally, we tested the effect of the aluminium therapy on preventing pneumoconiosis.

METHODS

Kalgoorlie is a Western Australian mining town, 550 km east of the capital city of Perth. A cohort of 2294 male gold miners was established from surveys of respiratory symptoms, smoking and lung function performed in 1961, 1962, 1974 and 1975 in Kalgoorlie. Detailed information on smoking was collected via questionnaires during these surveys and an additional questionnaire that was sent to all subjects still alive in 2000.

Miners were required to have annual chest X-rays for as long as they were still employed as miners. Full employment details, including dates of employment at each mine and job descriptions, were recorded at each presentation on so called 'miners' health record cards'.[14] The chest clinic physician also asked each miner at the annual X-ray examination if he was having aluminium therapy. If so, the letters 'AL' were stamped on the miners' health record card for that particular job. The information from these cards was linked to the survey data.

Duration of aluminium exposure was calculated by summing the years a subject worked in a job where he indicated the inhalation of aluminium dust. The number of months worked underground for each miner was assigned based on the job descriptions.

In total 1894 miners ever worked underground and 400 were surface-only workers. We have limited our analyses to ever-underground miners.

The cohort was linked to the Western Australian Registrar General's Mortality Database. The end of mortality follow-up was 31 December 2009. Expected numbers of deaths were estimated using age-specific and period-specific mortality rates calculated for the Western Australian male population in 5-year periods from 1970 to 2009. Mortality rates for the period 1970–1974 were used to calculate expected rates from the person-years accumulated for the first period of 1961–1969 as period-specific rates were not available for those years. The vital status of 283 individuals was unknown in December 2009. Therefore, these individuals were treated as alive until the last date of observation and then censored. Causes of death were coded according to the International Classification of Diseases (ICD) revision in force at the time of death.

SMRs were calculated as the ratio of the observed deaths to expected deaths. The general male population in Western Australia was the reference. SMRs were calculated for mortality from cardiovascular diseases (ICD9 410–429; ICD10 I20–52), cerebrovascular diseases (ICD9 430–438; ICD10 I60–69) and Alzheimer's disease (ICD9 331; ICD10 F00, G30). For the latter we also searched the free text field of the death certificates for the word 'Alzheimer', in an attempt to include those who had the disease, but where it was not coded as the primary cause of death. This was done for the cohort and the reference population. Classifications used for pneumoconiosis were ICD9 500–508 and 515, and ICD10 J60–65. SMRs and corresponding 95% CIs were estimated using Stata V.12.0 (StataCorp LP, College station, Texas, USA). SMRs were estimated for the full cohort, as well as stratified by ever or never exposure to aluminium dust.

Cox proportional hazard models were fitted to examine the risk of aluminium dust exposure on mortality from the diseases of interest within the cohort, using PROC PHREG in SAS V.9.3 (SAS Institute, Cary, North Carolina, USA). HR and 95% CIs were calculated for the whole cohort. Number of years of aluminium inhalation was modelled as a time-dependent variable. All HRs were adjusted for year of birth. Smoking was considered as a potential confounder in all models, but in none of the models smoking changed the risks by more than 5% and it was therefore not included.

RESULTS

The median year of birth of the underground gold miners was 1913 (ranging from 1887 to 1959). Their work histories ranged from 1902 to 1993. Of all underground miners, 647 (34.2%) indicated they inhaled aluminium dust for silicosis prophylaxis for a job they held for at least 1 year. Aluminium inhalation was reported for jobs held between 1951 and 1968 and the duration for the individual workers ranged from 1 year to 15 years, with a median of 10 years.

In total 1577 deaths were observed among 1894 underground miners during 42 780 person-years of follow-up. Cardiovascular diseases were the most common cause of death, with 508 cases (table 1). The SMR was 1.31 (95% CI 1.20 to 1.43), and was similar in the groups with or without aluminium dust exposure. One hundred and thirty-six deaths caused by cerebrovascular disease were reported, resulting in an SMR in the overall cohort of 1.38 (95% CI 1.16 to 1.63). Sixteen cases of Alzheimer's disease were identified. The SMR for Alzheimer's disease in the overall cohort was 1.08 (95% CI 0.66 to 1.76). The SMR was highest among miners who inhaled aluminium dust, although not significantly increased compared with the general population (SMR=1.38, 95% CI 0.69 to 2.75). SMRs for pneumoconiosis were significantly increased for all underground miners, whether they inhaled aluminium dust or not.

Internal analyses showed a borderline significantly increased cardiovascular disease mortality among underground miners who inhaled aluminium compared with workers who did not (HR=1.19, 95% CI 0.99 to 1.44), and indicated a duration-response relationship (HR=1.02, 95% CI 1.00 to 1.04 per year of exposure) (table 2). There was no increased risk of cerebrovascular disease with the duration of aluminium inhalation. There was a hint of an increased mortality from Alzheimer's disease with aluminium exposure (HR=2.76), but it was not statistically significant (95% CI 0.88 to 8.82). Mortality from pneumoconiosis was reported for 73 gold miners and was significantly associated with duration of work underground (HR=1.004, 95% CI 1.002 to 1.006 per month). Rates did not differ between the miners who inhaled aluminium dust and those who did not (results not shown).

DISCUSSION

Mortality from cardiovascular and cerebrovascular diseases was increased in the gold miners' cohort compared with the general male population of Western Australia. A hint towards a possible association with aluminium dust inhalation was observed for cardiovascular disease in the internal analysis, but not in the external comparison. An indication of increased mortality from Alzheimer's disease following aluminium exposure was found in both analyses.

Our findings for Alzheimer's disease were in the same direction as previous observations among workers exposed to aluminium dust in an industry-based cohort study.[6] In a case-control study on Alzheimer's disease in the UK, no association with occupation in the aluminium industry was observed (OR=0.95, 95% CI 0.5 to 1.9).[17] Non-significant associations were reported in two other case-control studies, performed in the USA and Australia.[18 19]

Table 1 SMRs overall and by exposure to aluminium dust among underground gold miners (1961–2009)

	Full cohort (n=1894)			Never aluminium (n=1247)			Ever aluminium (n=647)		
	42 780 person years			30 033 person years			12 747 person years		
Cause of death	n	SMR	95% CI	n	SMR	95% CI	n	SMR	95% CI
Cardiovascular disease	508	1.31	1.20 to 1.43	285	1.26	1.12 to 1.41	223	1.38	1.21 to 1.57
Cerebrovascular disease	136	1.38	1.16 to 1.63	82	1.43	1.16 to 1.78	54	1.30	1.00 to 1.70
Alzheimer's disease	16	1.08	0.66 to 1.76	8	0.89	0.44 to 1.78	8	1.38	0.69 to 2.75
Pneumoconiosis	73	16.1	12.8 to 20.2	36	13.5	9.76 to 18.8	37	19.6	14.2 to 27.1

Table 2 HRs for duration of aluminium dust inhalation among underground gold miners

	Never aluminium (reference)	Ever aluminium			1–9 years aluminium			10+ years aluminium			Continuous (years of aluminium dust exposure)	
	30 033 person years	12 747 person years			6782 person years			5965 person years				
Cause of death	n	n	HR*	95% CI	n	HR*	95% CI	n	HR*	95% CI	HR*	95% CI
Cardiovascular disease	285	223	1.19	0.99 to 1.44	121	1.23	0.99 to 1.54	102	1.15	0.91 to 1.45	1.02	1.00 to 1.04
Cerebrovascular disease	82	54	0.89	0.63 to 1.27	25	0.79	0.51 to 1.25	29	1.01	0.65 to 1.55	0.99	0.96 to 1.03
Alzheimer's disease	8	8	2.79	0.88 to 8.82	4	2.37	0.63 to 8.88	4	3.59	0.88 to 14.7	1.11	0.99 to 1.24

*All HRs are adjusted for year of birth.

Despite the small numbers of cases, however, industrial cohorts may be more appropriate by design to study occupational risk factors of Alzheimer's disease, as all information has generally been collected before diagnosis. In previous case-control studies, occupational information was collected from the next of kin, who may have been unaware of aluminium-related occupations of the patient.

A major issue with Alzheimer's disease is poor reporting on the death certificate. This disease is often not mentioned on death certificates, although it may be the proximate cause of death.[20 21] There is limited ICD coding available for dementia of the Alzheimer's type (ICD9 331 or ICD10 F00 and G30), despite numerous complications that can be directly attributed to the disease.[20] In our study, we attempted to take into account all Alzheimer's deaths by searching through the free text of the death certificates. This additional search doubled the number of identified cases. However, as Alzheimer's disease is not always recognised or registered on death certificates, these numbers are most likely still an underestimation. Zilkens and colleagues estimated that 47.5% of Western Australian men with a dementia diagnosis during their life had no documentation of dementia on their death record.[21] The coding issue will have affected the numbers of Alzheimer's deaths among the exposed cohort members and the general population in the same proportion, since we have used the same method of case identification in both groups. Therefore, the observed association between aluminium dust exposure and the disease would probably not be affected. However, more accurate figures of the number of cases would have provided more statistical power for the current analyses on Alzheimer's disease.

A high mortality rate for the Kalgoorlie gold miners' cohort was estimated for pneumoconiosis, with an SMR of 16.1 (95% CI 12.8 to 20.2) for the ever-underground miners (table 1). This is consistent with the SMR of 11.2 (95% CI 8.4 to 14.8) reported for the full cohort when it was followed up until December 1993.[14] The SMR for underground miners who never inhaled aluminium was slightly lower (SMR=13.5) compared with those exposed to aluminium dust (SMR=19.6). This difference may represent a difference in level of exposure to silica. Further, cancer mortality was also increased in the Kalgoorlie gold miners' cohort (SMR=1.27, 95% CI 1.16 to 1.39), which was mainly driven by lung cancer among ever-underground miners (SMR=1.82, 95% CI 1.56 to 2.13).[16] These causes of death may all be considered competitive causes when studying mortality from cardiovascular, cerebrovascular and Alzheimer's diseases.

The significantly increased mortality rates for cardiovascular and cerebrovascular diseases among underground gold miners compared with the general population may point towards unhealthy work conditions in the mines. However, it may also be attributed to lifestyle factors. For example, 85% of the cohort had ever smoked. At the time of the first survey in 1961, 68% of the miners indicated to be a current smoker. In comparison, the smoking rate in the general male population of Western Australia in 1945 was estimated to be 72% and dropped to 58% in 1964.[22]

Aluminium dust inhalation did not affect the risk of cerebrovascular disease, while there was some indication of an increased risk of cardiovascular mortality among miners with a history of aluminium dust exposure over those who never inhaled aluminium. Risks of aluminium dust inhalation may have been overestimated if the diseases under study are associated with other conditions of working underground. Possible increased risk of cardiovascular disease due to silica exposure has been reported.[23 24] Based on the higher SMR for pneumoconiosis among miners exposed to aluminium, the levels of exposure to silica may have been somewhat higher for the aluminium dust exposed group. However, we did not observe any association between duration of work underground, as a proxy for silica exposure, and risk of cardiovascular disease. Moreover, the inhalation of aluminium dust appeared to have no effect on the overall cancer mortality or lung cancer specific mortality among the Kalgoorlie underground miners (data not shown). This suggests that confounding by indication does not explain our observation of increased mortality of cardiovascular disease among miners exposed to aluminium dust.

Aluminium inhalation was seen as a 'quick fix' for silicosis in Western Australian mines, which was less costly than the implementation of interventions to reduce silica dust exposures and would reduce the costs of compensation for occupational disease in miners.[11] The benefits of aluminium inhalation were, however, subject to debate due to the lack of scientific evidence. Therefore, the inhalation of aluminium dust never became compulsory for underground miners in Western Australia. Our results provide no evidence that aluminium dust protected against silicosis.

The aluminium therapy was not enthusiastically embraced by the miners themselves. The dust irritated their throats and bronchioles. Reports of inspections state that many miners simply arrived early for the shift and changed their clothes before the powder was dispersed, others inhaled the dust for less than a minute, or the door was opened when the weather was hot. Nevertheless, it has been suggested that miners would state at their annual health check that they inhaled the aluminium dust in order to avoid the possibility of losing compensation money.[25] Among the miners in our cohort who worked underground during the years 1950–1969, 38.4% reported having inhaled aluminium dust. Despite the probability that some miners falsely claimed to be exposed to aluminium dust,

the proportion non-exposed indicates that it was not common practice. Hence, aluminium exposure and calendar time were not interchangeable in our cohort.

The only information available for each miner is whether he indicated the inhalation of aluminium dust during a particular job. We could not check how often he actually did this. As a result, the duration of aluminium dust inhalation may not be accurately assessed for all miners and observed trends are questionable. Moreover, we had no indication of levels of exposure. Rifat and colleagues estimated an annual alveolar burden of 375 mg aluminium for miners receiving the treatment according to the recommendations.[2] The actual exposure levels will have been lower given the aversion of the miners to the aluminium therapy. On the other hand, the comparison between miners ever and never exposed to aluminium dust will be more reliable. Potential exposure misclassification will have been random and therefore resulting in risk attenuation rather than a spurious association between aluminium dust exposure and diseases under study.

In conclusion, our results show a tendency towards a possible association between aluminium dust exposure and an increased risk of mortality from cardiovascular disease and dementia of the Alzheimer's type. No increased risk of cerebrovascular disease was observed following aluminium exposure among underground gold miners.

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Contributors SP analysed the data and drafted the manuscript. NdK and AWM were involved in the establishment of the cohort. SP, AR, LF, NdK and AWM were involved in the design and analysis of the study and all authors have provided critical input into the manuscript.

Competing interests None.

Ethics approval University of Western Australia's Human Research Ethics Committee.

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