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Diffuse Parenchymal Diseases Associated With Aluminum Use and Primary Aluminum Production

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Aluminum use and primary aluminum production results in the generation of various particles, fumes, gases, and airborne materials with the potential for inducing a wide range of lung pathology. Nevertheless, the presence of diffuse parenchymal or interstitial lung disease related to these processes remains controversial. The relatively uncommon occurrence of interstitial lung diseases in aluminum-exposed workers—despite the extensive industrial use of aluminum—the potential for concurrent exposure to other fibrogenic fibers, and the previous use of inhaled aluminum powder for the prevention of silicosis without apparent adverse respiratory effects are some of the reasons for this continuing controversy. Specific aluminum-induced parenchymal diseases described in the literature, including existing evidence of interstitial lung diseases, associated with primary aluminum production are reviewed.

Several reports of interstitial lung disease attributable to aluminum exposure have appeared in the medical literature over the past 70 years. Shaver and Riddell[1] reported pulmonary fibrosis in 46 of 344 workers engaged in the manufacturing of alumina abrasives. The disease progressed rapidly and was fatal in about 20% of the workers. This rare pneumoconiosis, named Shaver's disease or aluminosis, is an interstitial nonnodular lung fibrosis, characterized by upper lung predominance, peripheral emphysema, and frequent rupture of emphysematous blebs causing pneumothorax. Although the exact etiology was unclear, the process involved exposure to high concentrations of alumina and silica.

Goralewski and Jaeger[2] also described a similar pattern of pulmonary fibrosis, which they referred to as "aluminiumlunge" or aluminum lung among men engaged in the manufacturing of aluminum pyrotechnic flake powder used for explosives. The pyrotechnic flake powder is produced by crushing, grinding, and stamping aluminum. During stamping, the flake is lubricated with stearine, which forms a fine film of aluminum stearate on the surface of the particles and retards surface oxidation. The initial cases of aluminum lung were attributed to the absence of stearine in the process because of war-time shortage[3]; however, other reports have shown that pulmonary fibrosis can occur in the workers even when the flake is lubricated with stearine.[4] Aluminosis has since been reported in aluminum polishers,[5] workers exposed to aluminum powder in aluminum powder mills,[6] and aluminum welders exposed to aerosols of oxidized aluminum.[7,8] There are also case reports of aluminosis presenting predominantly with mediastinal lymphadenopathy, with evidence of aluminum particles in the mediastinal lymph nodes.[9,10]

Cases of aluminum-induced inflammation of the lungs, with lung biopsies showing granulomas similar to those found in sarcoidosis and chronic beryllium disease, have also been reported.[11–14] This disease differs from sarcoidosis by the identification of aluminum within the granulomas and transformation of the patient's peripheral blood lymphocytes in the presence of aluminum compounds consistent with hypersensitivity or an immune-mediated mechanism.[12] Other types of reactions reported in the literature as manifestations of aluminum-induced interstitial lung disease include pulmonary alveolar proteinosis, a rare condition characterized by the accumulation of a lipoproteinaceous material in the alveolar space[15] and desquamative interstitial pneumonia, an interstitial lung disease characterized by intra-alveolar accumulation of macrophages.[16]

There has been very little evidence of interstitial lung diseases associated with primary aluminum production (bauxite mining, alumina refining, and aluminum smelting). Cross-sectional studies of bauxite miners (exposed to bauxite dust and crystalline silica), alumina refining workers (exposed to aluminum oxide dust and caustic soda mist), and workers from an alumina-based chemical production plant in the United States have shown nonspecific airway response. These include cough and mucous production, decrement in lung function (forced expiratory volume in 1 second), and radiographic changes of scanty, small irregular opacities in the lower lung zones associated with long-term high cumulative dust exposure suggestive of pneumoconiosis.[17,18] These nonspecific changes are characteristic of dust overload, a condition where dusts, which have generally been recognized as innocuous and treated as nuisance dust, produce a diminution of dust clearance and a variety of unexpected toxicological endpoints.[19] More recent studies of Western Australian bauxite miners and alumina refinery workers did not show any consistent associations between workplace exposure and respiratory symptoms or lung function.[20,21]

Studies of aluminum smelter workers have primarily shown asthma and chronic obstructive lung disease related to exposure to particulate and gaseous fluorides, sulfur dioxide, and other airborne contaminants encountered in the work environment.[22–26] Nevertheless, there have been a few case reports of aluminum smelter workers diagnosed with diffuse interstitial fibrosis. Analysis of tissues or fluids of the lungs of some of these workers showed high concentrations of aluminum fibers, raising the possibility of aluminum-induced fibrosis.[27–29]

A comparison of radiographic studies and pulmonary function tests of a cohort of aluminum smelter workers to regional controls who worked as pipefitters reported more irregular opacities, which were uniformly distributed in the lungs and fewer pleural abnormalities in the chest radiographs of the aluminum workers compared with the pipefitters. However, the forced vital capacity and total lung capacity were not significantly different between the two groups, and it should be noted that both groups were exposed to asbestos.[30]

Beryllium sensitization—an immune-mediated response—and chronic beryllium disease—an immune-mediated granulomatous interstitial lung disease—have also been reported in aluminum smelter workers arising from natural beryllium contamination of the bauxite ore and further concentration of the beryllium in the cryolite bath in aluminum potrooms.[31]

Despite these reports, aluminum-induced diffuse parenchymal disease has remained controversial because of the relatively uncommon occurrence of interstitial lung diseases in aluminum-exposed workers. Given commonly occurring concurrent exposure to other fibrogenic fibers in these work environments, fibrogenic lesions observed in aluminum-exposed workers have been attributed

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The author declares no conflicts of interest.

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DOI: 10.1097/JOM.0000000000000054

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to exposure to a mixture of other dusts such as silica and asbestos rather than aluminum.

The use of finely ground aluminum powder, called McIntyre powder, as a prophylactic agent against silicosis by Ontario miners for many years with no apparent adverse respiratory effects[32] is commonly cited as evidence that aluminum dust is harmless. Experimental studies in animals have not been very helpful in clarifying the controversy. Localized granulomatous and fibrotic lesions can develop sporadically if sufficiently large amounts of aluminum-containing particles are introduced into the respiratory tract. However, the observations differ depending upon the animal model chosen, the route of exposure (inhalation vs intrathecal), and the form of aluminum used in these experiments.[33–35] Therefore, the relevance of the experimental animal data to humans remains unclear.

For the aforementioned reasons, aluminum dust is commonly treated as a nuisance dust in the workplace. Nevertheless, in some aluminum-exposed workers with evidence of interstitial fibrosis and absence of asbestos bodies and silicotic nodules on biopsy, mineralogical analysis of bronchoalveolar lavage or lung tissue has shown predominantly high concentration of aluminum fibers. This suggests that the aluminum fibers are the primary cause of the pulmonary fibrosis.[5,27,29,36]

It has also been assumed that Shaver's disease, or aluminosis, is of historic interest only and is unlikely to occur under current work conditions. However, a recent cross-sectional study of workers from plants producing aluminum powder used high-resolution computed tomography and detected parenchymal changes in 24.2% of the workers.[37] These parenchymal changes, characterized by small rounded opacities predominantly in the upper lung region, were consistent with aluminosis, suggesting that aluminum-induced parenchymal changes—although very rare—continue to occur in some workers.

In summary, aluminum-induced diffuse parenchymal disease is very rare, yet some evidence suggests that exposure to aluminum dusts and fumes may cause diffuse parenchymal changes, characteristic of aluminosis, granulomas, pulmonary alveolar proteinosis, and desquamative interstitial pneumonia. Nevertheless, interstitial lung diseases are not commonly associated with primary aluminum production.

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