A compartment model for the simulation of fiber-cell-interaction in the alveolar region of the human respiratory tract

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Numerous medical studies performed during the past decades (e.g. Lippmann, 1990; Heesterberg & Hart, 2001) have demonstrated that exposure to airborne mineral fibers, and especially to asbestos fibers, presents a significant health hazard. Accumulation of fibers in the lung enhances the risk of lung diseases, such as asbestosis, pneumoconiosis, and asbestos-induced lung cancer. The highest damage by fiber deposition and accumulation occurs in the alveolar region, where the particles are subject to various clearance mechanisms. The efficiency of these mechanisms depends primarily upon two factors, the size of the deposited material, and its degradability due to biological processes (Lippmann, 1990).

In this contribution, a compartment model is presented, which aims to describe the interaction between biopersistent fibers and alveolar cells and tissues (Fig. 1). Inhaled mineral fibers deposited in the alveolar region may hit the surface of the alveolar epithelium which is lined by a thin blanket of the so-called surfactant. Independent of their length all fibrous particles undergo endocytosis by alveolar macrophages. Those fibers exceeding the dimension of the macrophages will not be cleared from their sites of deposition, whilst small fibers will be evacuated along two paths: (1) towards the conductive airways and, in further consequence, to the gastrointestinal tract, and (2) towards the lung parenchyma (interstitium) (ICRP, 1994). Fibers accumulated on the alveolar walls or taken up by macrophages may provoke inflammatory reactions, resulting in a hyperactivity of fibrocytes, while fibers accumulated in the parenchyma and mesothelium may act as serious carcinogens.

Alveolar fiber deposition was simulated using the stochastic deposition model of Koblinger & Hofmann (1990), assuming light-work breathing conditions (ICRP, 1994). Fibrous particles included in the computations had a uniform diameter of 0.5 µm, a density of 2.6 g cm$^{-3}$ (mean density of asbestos), and an aspect ratio of 10 and 100, resulting in fiber lengths of 5 and 50 µm. Rate constants of the compartment model were estimated from published medical and histological data.

As shown in Fig. 2, small fibers are subject to a significant clearance by alveolar macrophages, but also to an accumulation in the parenchyma. The first process occurs within several weeks to months, whilst the second process takes presumably much longer due to the penetration of numerous cell layers by the fibrous material. In contrast, large fibers are partly taken up by the macrophages, but are not effectively cleared due to their sizes. This results in an accumulation of the material on the epithelial surface.


Figure 1. (a) Sketch exhibiting the basic cellular components included in the model; (b) Definition of the model compartments and associated rate constants.

Figure 2. Preliminary results obtained by the compartment model. Computations were carried out for two size classes of biopersistent asbestos fibers.