Mechanical alterations in airway smooth muscle after interaction with indoor pollutant – A mathematical model

Mac Gayver S. Castro, Wagner S. Nishitani, Adriano M. Alencar

USP - SP - Brasil

The viscoelasticity of mammalian lung is determined by the mechanical properties and structural regulation of the airway smooth muscle (ASM). The exposure to polluted air may deteriorate these properties with harmful consequences to individual health. Formaldehyde (FA) is an important indoor pollutant found among volatile organic compounds. This pollutant permeates through the smooth muscle tissue forming covalent bonds between proteins in the extracellular matrix and intracellular protein structure changing mechanical properties of ASM and inducing asthma symptoms, such as airway hyperresponsiveness, even at low concentrations. In the experimental scenario, the mechanical effect of FA is the stiffening of the tissue, but the mechanism behind this effect is not fully understood. Thus, the aim of this study is to reproduce the mechanical behavior of the ASM, such as contraction and stretching, under FA action or not. For this, it was created a two-dimensional viscoelastic network model based on Voronoi tessellation solved using Runge-Kutta method of fourth order. The equilibrium configuration was reached when the forces in different parts of the network were equal. This model simulates the mechanical behavior of ASM through of a network of dashpots and springs. This dashpot-spring mechanical coupling mimics the composition of the actomyosin machinery of ASM through the contraction of springs to a minimum length. We hypothesized that formation of covalent bonds, due to the FA action, can be represented in the model by a simple change in the elastic constant of the springs, while the action of methacholine (MCh) reduce the equilibrium length of the spring. A sigmoid curve of tension as a function of MCh doses was obtained, showing increased tension when the muscle strip was exposed to FA. Our simulations suggest that FA, at a concentration of 0.1 ppm, can affect the elastic properties of the smooth muscle fibers by a factor of 120%. We also analyze the dynamic mechanical properties, observing the viscous and elastic behavior of the network. Finally, the proposed model, although simple, incorporates the phenomenology of both MCh and FA and reproduces experimental results observed with in vitro exposure of smooth muscle to FA. Thus, this new mechanical approach incorporates several well know features of the contractile system of the cells in a tissue level model. The model can also be used in different biological scales.

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