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Environmental Influence on Trace Element Levels in Human Hair

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Trace element content of human hair depends on many factors (Valković 1977, Anke and Risch 1979, Brown and Crounse 1980, Gibson 1980, Valković 1984). It has been shown by a large number of investigators that environmental factors play an important role (Haunner et al. 1971, Valković et al. 1975). Elements from air particulates, water, shampoo or other media get incorporated into the hair structure. Here we are proposing a model in which different contributions to trace element levels in human hair are factorized and the environmental contribution to the radial and longitudinal concentration profiles can be calculated. With the proper understanding of environmental contamination, hair analysis has better chances of being used as a diagnostic tool.

MATERIALS AND METHODS

The factors influencing trace element levels in human hair can be grouped into four terms: (1) body stores, (2) genetic effects, (3) body fluids, and (4) environment. In the coordinate frame attached to a single hair (with z-axis along the hair length) the concentration of any element within a single hair can be expressed as:

$$C(x,y,z) = C_G + C_{BF} + C_{BS} + C_{ENV} \qquad (1)$$

where C_G, C_{BF}, C_{BS} and C_{ENV} represent genetic, body fluids, body stores and environmental contribution, respectively. Each of these four factors depends on many variables. In this report we shall consider only the C_{ENV}.

It is reasonable to assume that the migration of trace elements in hair is caused by the volume fluctuations of keratin molecules (Rosenbaum 1975). Then the migration of trace elements in hair is modelled by the diffusion law with the diffusion parameters depending on the chemical structures of the molecules and, in particular, on their hydrophobic and hydrophilic balances (Rattee and Brener 1977). In this report we propose a method for the determination of some diffusion parameters from experimental data on the distribution of trace element concentrations in hair and then, by using this method, we determine the radial diffusion constants of Se, Zn and Pb.

Our model of hair structure with respect to diffusion is based on the supposition of cross-sectional homogeneity as well as the longitudinal homogeneity of hair. This supposition implies nonisotropic diffusion in hair which is described by two diffusion constants. Our aim is to consider only radial diffusion in hair and to determine the radial diffusion constants of Se, Zn and Pb.

The diffusion constants of Se and Zn are determined from the measurements by Boss et al. (1983). Hair was kept immersed in a solvent (home made shampoo) containing Se and Zn during the periods of 8 hr, 24 hr and 48 hr. The analytical method used was micro-pixe, with proton beam focussed to a radius of 5 to 6 μm. The measurements of radial distribution of concentration were performed at hair cross sections for which the longitudinal gradient of trace element concentration could be neglected. This implies the axially symmetric diffusion of Se and Zn in hair, which can be described by the following system of equations:

$$C = \alpha \frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial C}{\partial r}\right), \qquad 0 < r < R, \tag{2}$$

$$\frac{\partial C}{\partial r}\Big|_{r=0} = 0, \quad \frac{\partial C}{\partial r}\Big|_{r=R} = \lambda_1 - \lambda_2 C, \tag{3}$$

where C is the concentration term denoted by C_{ENV} in eq. (1), R is the radius of hair cross section, λ_1 is a real number, and λ_2 is a positive number. This system must be supplied by an adequate initial condition.

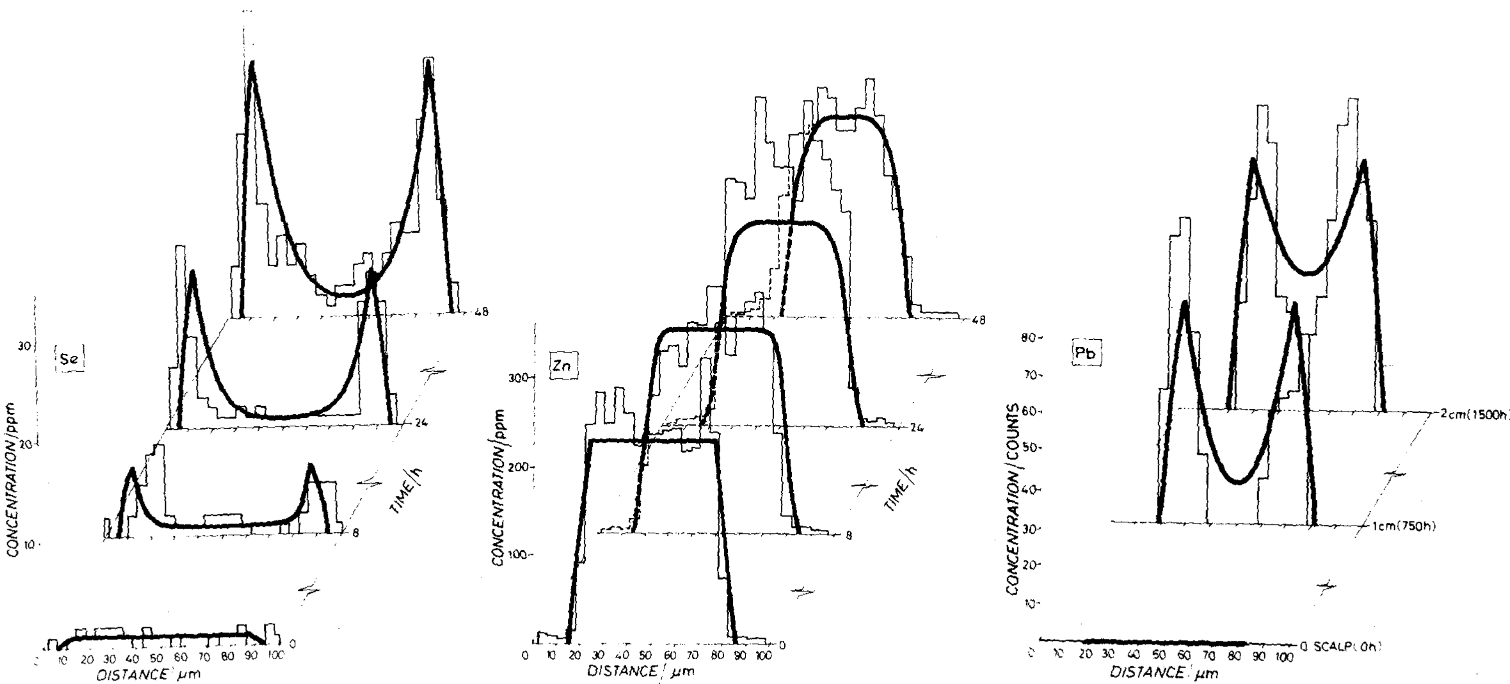

Figure 1. Distribution of trace elements across the hair diameter in different segments of the same strand of hair. (a) One segment has not been treated at all. The others were immersed for different times in an in-house made shampoo containing Se. Experimental data by Boss et al. (1983); solid lines are model prediction. (b) The same for Zn. (c) Experimental data and model prediction for Pb. Radial concentration of Pb is determined for hair contaminated by lead in air, 1 cm and 2 cm from scalp (Boss et al, 1983).

Solutions of (2) and (3) are fitted to experimental data by selecting parameters α, λ_1 and λ_2 to minimize the hi--square function. The solutions obtained with the corresponding data are presented in Fig. 1(a) and 1(b), and the calculated radial diffusion constants are presented in Table 1. (The calculated curves shown are smeared for experimental beam width).

The radial diffusion constant of Pb is determined from a measurement of hair contamination by lead in air (Boss 1984). The results obtained by the above method are illustrated in Fig. 1(c) and presented in Table 1.

Table 1. Diffusion constant for Zn, Se and Pb

Element	Zn	Se	Pb
Diffusion constant (10^4 $\mu m^2/s$)	2.28	7.33	0.25

RESULTS AND DISCUSSION

Unfortunately, the data used here are not suitable for a prediction of longitudinal diffusion constants or of saturation levels of concentration. The saturation level of concentration can be predicted as $C_{sat} = \lambda_1/\lambda_2$, where λ_1 and λ_2 are defined in eq. (3). However, a large number of measured cross sectional distributions of concentration is needed for this purpose. The longitudinal diffusion constant should be determined from experiments accordingly designed.

The obtained values of diffusion constants of Zn and Se are in a fair agreement with the results of Faucher and Goddard (1978). In this experiment, as well as in the measurements by Boss et al. (1983) analyzed in this paper, hair samples were immersed in solvents. The diffusion constant of Pb is ten times smaller than the constants of Zn and Se. This result confirms again the free-volume type of trace element transport as data on Pb were obtained from the experiment of hair contamination in air.

Among these elements which are considered here, selenium and lead have an environmental origin, while the origin of zinc is due to the remaining three effects of the model (1). Furthermore, selenium and lead are incorporated into hair, while zinc is washed out of hair. It is interesting therefore that the diffusion constants of selenium and zinc have the same order. Let us point out that the data about selenium and zinc are obtained from the same experiment.

Let us infer that cross sectional and longitudinal distributions of trace element concentration in hair can be successfully used for a prediction of trace element origin in hair if parameters of diffusion are known. For instance, the radial gradient of concentration alongside hair can be used for a reconstruction of the time distribution of a pollutant concentration in the environment if two diffusion constants, as well as the saturation level of concentration in hair, are known. The peak-type longitudinal distribution of trace element concentration can be used for the determination of a time interval of blood intoxication if the longitudinal diffusion constant is known. In general, the trace element levels in human hair can not be well understood without taking properly into account the diffusion of the elements from the environment.

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