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Regional Aerosol Deposition in Human Upper Airways

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David L. Swift, Ph.D.

Johns Hopkins University
Baltimore, Maryland 21205

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Abstract

During the current reporting period experimental studies of aerosol deposition in replicate NOPL airways have carried out. A replicate model of a 4 week old infant nasal passage was constructed from MR scans. The model completes the age range from "newborn" to 4 years, there now being one child model for 4 different ages.

Deposition studies have been performed with unattached radon progeny aerosols in collaboration with ITRI, Albuquerque, NM and NRPB, Chilton, U.K. Overall measurements have been performed in adult and child nasal airways indicating that the child nasal passage was slightly more efficient than the adult in removing 1 nm particles at corresponding flow rates. A similar weak dependence on flow rate was observed. Local deposition studies in an adult nasal model indicated predominant deposition in the anterior region during inspiratory flow, but measurable deposition was found throughout the model. The deposition pattern during expiration was reverse, greater deposition being observed in the posterior region.

Local deposition studies of attached progeny aerosol size (100-200 nm) were performed in adult and child nasal models using "technigas" and a gamma scintillation camera. Similar to the unattached size, deposition occurred throughout the models, but was greater in the anterior region.

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Replicate Model Construction

In the previous report period it was reported that two adult sandwich replicated airway models of an adult and three child sandwich models were constructed from MR scans. These models were characterized with respect to cross sectional area, volume, lateral surface area, and flow resistance. Partial flow resistance was measured by successive removal of elements from the posterior end.

During the present report period an MR scan of a 4 week old "newborn" infant was obtained from the Johns Hopkins MRI facility. The scans were performed to examine possible functional changes elsewhere in the head and was reported to have a normal nasal passage. A sandwich model was constructed from these MR scans which included the nasal airways from nostril entrance to nasopharynx. The scan outlines were measured by planigraphy to obtain cross sectional area, volume, and lateral surface area, and the model was measured for flow resistance at characteristic flows.

Replicate models obtained either from in vivo MR scans or from post mortem negative casts are now representative of ages from 4 weeks to 53 years, including one model of an "ersatz" 6 year old obtained by scaling down the dimensions of the adult sandwich model. Oral passage replicates are only available on the PM cast and MR adult models. Methods for obtaining information on the oral passage configuration of children are now under consideration. The findings that oral passage removal of attached and unattached radon progeny particles in the adult are only about 15% smaller than for nasal passage should be compared to that in children to provide dosimetric models for children whether breathing nasally or oronasally. It can be hypothesized that upper airway infections in the child nasal passage may lead to oronasal or oral breathing in children more frequently than in adults. In the remaining period of investigation for the current year, oral passage breathing in children will be investigated.

Studies of Unattached Radon Progeny

The overall deposition of 1 nm radon progeny aerosols has been measured in adult and child MR replicate models in collaboration with Dr. Cheng, Yeh, and Su at ITRI. The previous work in cast models of the nasal and oral passage were performed down to 5 nm and the results as a function of flow rate and particle diffusion coefficient were fitted to an empirical equation in which the flow rate dependency was to the -0.125 power and the diffusion coefficient was to the 0.666 power. Extrapolation of the fitted curve to 1 nm led to a prediction at normal breathing in adults of 90-99% efficiency of removal of unattached 1 nm particles.

The experimental studies performed yielded a somewhat lower value, 75-80%, with a similar flow rate dependence. When all the sizes from 1-200 nm were taken into account, the results were better fit by a particle diffusion coefficient raised to the 0.50 power. The particles were generated by the decay of Rn^{220}, yielding progeny which could be used to quantify local deposition by their gamma omission (discussed below).

Parallel studies with the same models were performed at NRPB with Rn^{222} progeny in which overall deposition was measured as above, sampling both inlet and outlet aerosol concentration. In this case, the results gave slightly lower values of overall deposition, but still fit over the range of attached and unattached particle size range by a particle diffusion coefficient to the 0.5 power.

Local deposition studies of unattached particles have been performed at ITRI using the sandwich MR adult nasal model. Both inspiratory and expiratory flow directions were studies at a single flow rate, characteristic of resting breathing. The deposition pattern in inspiration was found to be greatest in the anterior portion of the model, but deposition was found throughout the nasal airway. The reverse was true in expiration. When the inspiratory results were normalized for lateral area, giving a local flux of aerosol particles, there was a peak deposition site about 2 cm posterior to the nostril entrance, corresponding approximately to the region just posterior to the nasal orifice.

Studies of Attached Radon Progeny

A series of measurements of the local deposition of particles in models of the nasal passage of adults and children was carried out at the Royal Free Hospital in London in collaboration with John Strong, NRPB, and John Agnew, RFH. These studies employed generation of technigas, an aerosol produced by pulse evaporation of Tc^{99m} followed by condensation to produce an aerosol of median diameter 125 nm. After exposure to the technigas aerosol at a flow rate of 15 l min^{-1}, the models were placed on the face of a gamma scintillation camera to measure the deposition patterns. In all cases, there was deposition throughout the nasal airway, but the predominant site of deposition was found to be in the anterior region, consistent with theory for diffusion controlled aerosol transport. The models used for these studies included an adult sandwich model (B), an adult post mortem cast model (C), an ersatz six year old model (scaled down adult) (E) and a child model, 1½ years old (F). The qualitative character of local deposition of the aerosol was similar in the models, as described above.

Studies of Inertial Particles

The age effect of deposition of particles in the 0.8-12 um diameter range has also been studied. The initial studies have been carried out in both adult and child models at flow rates representative of rest and exercise. In contrast to the unattached and attached radon progeny aerosols, the flow effect on deposition of these large particles is significant, consistent with particle inertial theory. When the deposition efficiency is plotted against a pseudo-Stokes number d_A^2Q, theory predicts that a single curve should be obtained for each model over a range of sizes and flow rates. Experimental observations do not confirm this, yielding rather a series of efficiency curves shifting to greater efficiency for a given size as flow rate increases.

This finding is observed both for the adult and child nasal airways and for the adult oral passage. In comparing the adult and child results, it is observed that the nasal efficiency is approximately equal for equal states of breathing, i.e., degree of rest or exercise compared to a reference state for each age. It should be noted that these findings represent only a single model for each child

age and only two adult models, thus the preliminary finding requires further confirmation.

A study of the dimensional effect of the nasal orifice was carried out on the adult MR sandwich model. Nasal orifice segments representing decongestion and congestion were produced and deposition efficiency studies were performed with the model in the three modes. The curves of deposition percent vs. d_A^2Q for each mode were compared and found to be different, the greater efficiency being found at the congested state. A Stokes number for each mode was calculated for the flow rate used, and when the three curves were replotted vs. Stokes number, the data were found to fall on a single efficiency curve. These studies suggest that at a single flow rate, dimensional changes can be accounted for with a Stokes number, employing the theory of impactor used for filters and cascade impactors.

Proposed Studies

A proposal for an additional three year period is being submitted with this report. It enlarges the activity of the research proposal with the continuation of model studies being augmented by adult human volunteer studies for confirmation of observation reported in replicate models.

The focus of the proposed studies is the variability of NOPL deposition in humans, with the objective of providing a basis for a population wide dosimetry model. For this purpose, models and adult human subjects representing a wide variety of nasal dimensions and configurations will be sought to determine under a variety of breathing conditions how variable the penetration of unattached, attached, and inertial particles is in the adult and child population. Additionally, the effect of dimensional and configurational changes on local deposition in the NOPL airways will be sought to predict what fraction of aerosol deposited in the NOPL airways is subject to a particular retention or clearance mechanism and site.

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