Mucociliary clearance is humidity dependent–contrary to common belief

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ABSTRACT

Efficient mucociliary clearance (MCC) is a precondition for the moistening capacity of human noses. A review of the literature reveals that only young and healthy individuals can maintain efficient nasal MCC in low ambient humidity. Aging, concomitant diseases and stress factors, all diminish MCC and therefore the ability of maintaining homeostasis of the airways. In an aging population this finding calls for action. We cannot change the outdoor climate nor the physical laws that cause indoor dryness. But we must take responsibility for the anthropogenic indoor climate and its undesired consequences.

THE ORIGINE OF THE MISCONCEPTION

From 1971 to 1977 Anderson IB, Proctor DF and Lundquist GR investigated the effect of different humidity and temperature ranges on MCC, nasal airflow resistance and subjective responses, (I. Andersen, Lundqvist, Jensen, & Proctor, 1974; I. Andersen, Lundqvist, & Proctor, 1971; I. B. Andersen, Lundqvist, & Proctor, 1972; D. F. Proctor, 1983; Donald F. Proctor, Andersen, Lundqvist, & Swift, 1973; Donald F. Proctor, Andersen, & Lundqvist, 1977). The volunteers in a series of climate chamber experiments were all young and healthy Danish students. The study of 1977 with the intention to study the impact of extreme climate parameters (9°C to40°C, 9% to 70% relative humidity, RH) on airways of potential military personnel was supported by NATO. The overall conclusion ofthe studies was that in young and healthy people the mucociliary transport velocity (MTV) was not significantly affected by changing humidity and temperature. However, the intra- and inter-individual variability of MTV was extremely high. The mean MTV was 6-7 mm/min. with a range of less than 1mm to more than 22mm. In 65 measurements (17% of 393) the MTV was less than 1mm/min (D. F. Proctor, 1983).

The above studies became the core element of the widespread belief that dry indoor climate conditions do not significantly decrease the nasal MCC or damage the homeostasis of airways. This conclusion is not admissible since only healthy young adults were included. Nevertheless, these studies are regularly cited in discussions on suspected causal connections between indoor dryness and epidemic respiratory infections in winter of temperate climates.

Anderson IB, Proctor DF and Lundquist GR used beads, labelled with 99mTc for their studies. Quinlan (Quinlan, Salman, Swift, Wagner, & Proctor, 1969) described the used tracers as, quote "… solid, insoluble beads always less than 1mm, and usually less than 0.5 mm, in diameter". The path of the beads was observed with gamma cameras. In his original description of the technique, Quinlan observed a dependence of the MTV from RH above and below 30% and on symptoms like dry nose, congestion and respiratory infections. In view of today's knowledge and in comparison, to newer methods for the measurement of nasal or bronchial MTV, the original technique used unrealistically large particles with diameters of roughly 500µm. The particles of interest that accumulate preferably in the nose have less than 0.01µm aerodynamic diameter (deposition by diffusion) or above 1µm aerodynamic diameter up to roughly 50 µm that deposit in the nose by impaction (Kodros, Volckens, Jathar, & Pierce, 2018; Millage, Bergman, Asgharian, & McClellan, 2010). Without high air speed, particles of above 50µm have a low chance of deposition in the nose (Millage et al., 2010).

AGING, DISEASES AND STRESS FACTORS DIMINISH MCC

"Normal aging affects all physiological processes", this is the opening sentence of the publication "Age-Related Physiological Changes and Their Clinical Significance", (Boss & Seegmiller, 1981). MCC and motility of cilia, as all other parameters of lung physiology, decrease with increasing age even without concurrent diseases or stress factors like air pollution or smoking, (Ho et al., 2001; Pinto & Jeswani, 2010). The following studies showed a decline of MTV with decreasing RH, increasing age, allergic rhinitis, asthma, infections and smoking, (Ewert, 1965; Lindemann, Sannwald, & Wiesmiller, 2008; Naclerio, Pinto, Assanasen, & Baroody, 2007; Salah, Dinh Xuan, Fouilladieu, Lockhart, & Regnard, 1988; Sunwoo, Chou, Takeshita, Murakami, & Tochihara, 2006; Williams, Rankin, Smith, Galler, & Seakins, 1996; Wolf, Naftali, Schroter, & Elad, 2004). Quote, Lindeman et al: "Nasal complaints in elderly patients are a consequence of lower intranasal air temperature and humidity values combined with relatively enlarged nasal cavities due to involution atrophy of the nasal mucosa".

Table 1. Outdoor AH in winter trimester is less than half of AH in summer trimester in temperate climate.

Temperature, relative and absolute humidity quartiles in summer and winter trimester for three European cities on different geographical latitudes			
summer trimester (June – Sept.)			
	T [°C], Q 1,2,3	RH [%], Q 1,2,3	AH [g/m³], Q 1,2,3
Helsinki	14 17 20	54 68 82	6.6 8.0 9.4
Berlin	16 19 23	52 68 82	7.4 9.3 11.0
Palermo	23 25 28	60 70 80	12.4 14.2 15.7
winter trimester (Nov.- Feb.)			
Helsinki	-7.0 -3.3 1.2	77 85 95	1.9 2.7 3.4
Berlin	- 1.3 1.7 4.9	71 81 91	2.8 3.5 4.3
Palermo	10.7 12.7 14.7	60 68 77	5.4 6.2 7.0

INDOOR STRESS FACTORS "LOW RELATIVE HUMIDITY" AND "LOW ABSOLUTE HUMIDITY"

Winters in temperate climate are cold and dry. Temperatures and AH's are low, while RH is higher or at least similar to summer RH, see examples Table 1.

Heating creates comfortable indoor temperature, increases the saturation deficit, expressed as low RH, but has no impact on absolute humidity. The saturation deficit reflects the dehydration stress on body surfaces including upper airways. This explains why RH is the right parameter to describe humidity effects on skin and eyes, Figure 1, (Wolkoff, Azuma, & Carrer, 2021). But conducting airways and foremost the nose are expose to a much greater challenge. Besides maintaining the hydration of their mucosal lining, they need to humidify breathing air to full saturation at core temperature, Figure 2.

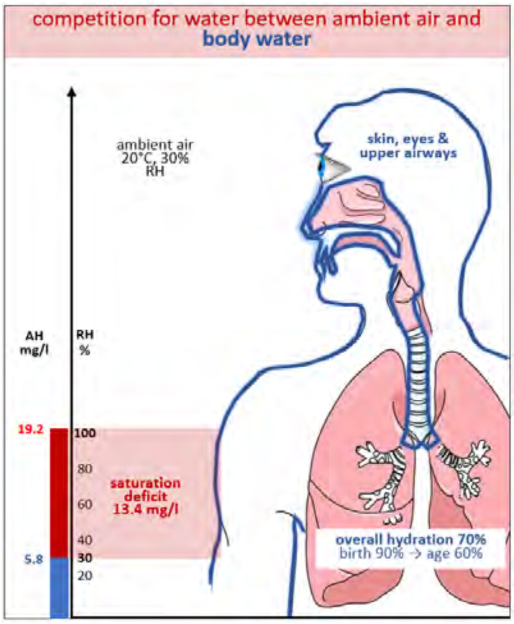

Figure 1. Saturation deficit between AH of room air and body surfaces

Noses and conducting airways of seniors and people with allergies, asthma, and chronic respiratory diseases (bronchitis, COPD) are unable to provide this vital humidification without desiccation and reduced MCC (Boss & Seegmiller, 1981; Elad, Wolf, & Keck, 2008; Ewert, 1965; Ho et al., 2001; Lindemann et al., 2008; Naftali, Rosenfeld, Wolf, & Elad, 2005; Pinto & Jeswani, 2010; Salah et al., 1988; Sun, Hsieh, Tsai, Ho, & Kao, 2002; Sunwoo et al., 2006; Wolf et al., 2004). A review on "Seasonality of Viral Respiratory Infections", (Moriyama, Hugentobler, & Iwasaki, 2020) illustrated that indoor dryness is a major factor that reduces the multilayered infection defense of the mucosa as well as the innate and acquired immune system. Low RH may completely block the immune defense against infection as a mice study has shown (Kudo et al., 2019).

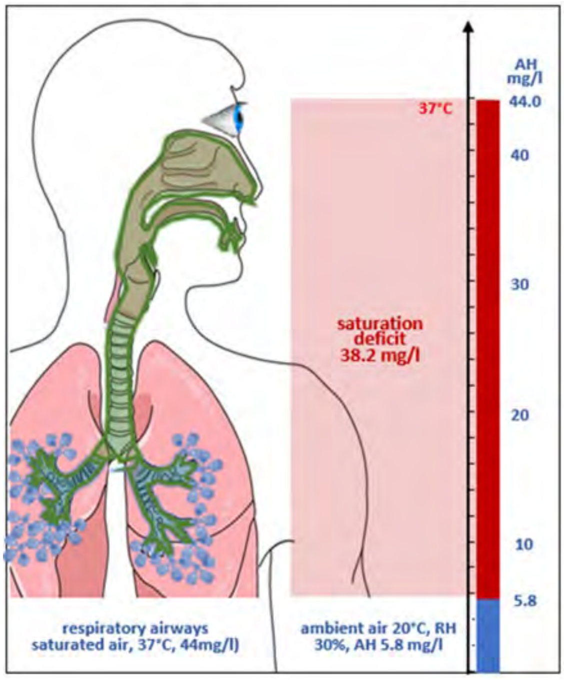

Figure 2. Saturation deficit between AH of room air and AH at 37°C determines the humidification requirement that conductive airways (green) must deliver

Continuously measured outdoor climate data for a bunch of parameters, including humidity, are available in high resolution for almost any location on earth. In contrast, data on indoor climate, to which most of us are exposed for 90% of our lifetime, are almost inexistant or kept in secret. Although indoor comfort climate is a hot topic, datasets that include humidity and cover a whole winter season, are scarce. Here two of the rare published datasets. Measurements in forty residential apartments in New York and in six high-quality commercial buildings in the Midwest, showed median indoor AH of 2.7 to 4.9 g/m³ and indoor RH of 12 to 24% in winter trimester (Quinn & Shaman, 2017; Reynolds et al., 2001).

The industrial revolutions forced most people to an indoor lifestyle. They are exposed to an indoor climate that a majority perceives as comfortable. However, for the conducting airways, especially the most challenged nose, indoor climate in winter is more stressful than almost all outdoor climates in terms of AH. The measured AH's in the study of Quinn were lower than the mean AH in the two most stressful climates, studied by Maddux SD, (Maddux, Yokley, Svoma, & Franciscus, 2016). The annual means of AH in "cold-dry" climates were 6 g/m^3, in "cold-wet" climates 7,5 g/m^3. At room temperature of 22°C, RH's below 40%, converted in AH, are at the same level or below the above mentioned annual means of stressful outdoor climates.

CONCLUSIONS

We need widespread continuous recordings of indoor climate parameters, including humidity. The correlation with epidemiological data and transmission events would give us more insight into the climate effects on the multilayered mucosal defense system and infection rates.

A growing aging population in temperate climate zones is overstressed by low indoor AH in winter. It is suspected that dryness favors seasonal epidemics, typically occurring in winter and affecting elderly people disproportionally. Recent findings underline the need for new research on links between seasonal epidemics of respiratory infections, indoor dryness and reduced mucosal infection defense.

ACKNOWLEDGMENTS

The author is scientific advisor of Condor Group SA.

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