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Indoor air pollution, lung cancer and solutions

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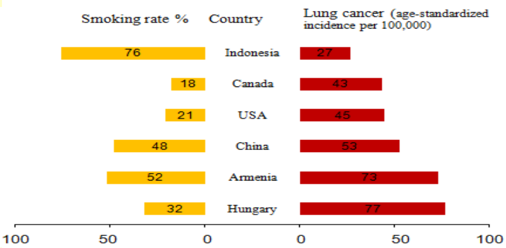
Abstract: **About 90% of our time is spent indoors where we are exposed to chemical and biological contaminants and possibly to carcinogens. These agents are highly associated with the increased rates of nonspecific respiratory and neurologic symptoms, allergies, asthma and lung cancer. We reviewed the sources, health effects and control strategies for these agents, particularly the major carcinogens from contaminated indoor air. While the fundamental approaches including quitting smoking and using natural and healthy building materials are essential of eliminating indoor air contamination, some simple measures such as increasing ventilation in the central heating, ventilation and air-conditioning systemsand daily opening windows may be realistic, convenient and cost-effective ways to improve indoor air quality and health for homeowners.**



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1. Introduction

Lung cancer is the number one cancer both in incidence and mortality for men worldwide in 2012[1]. While cigarette smoking is the dominant risk factor of lung cancer established by numerous epidemiological studies and cigarette smoking causes about 90% of lung cancers in the United States[2], lung cancer occurs in numbers of patients who have no history of smoking both direct and second hand smoking[3]. Indeed, the highest smoking rate in men (76%) is in Indonesia in 2015, but the lung cancer incidence rate in men is only 26.5 per 100,000 populations, which is much lower than that in USA (44.5 per 100,000 populations) while only 20% American adult men are smoking[4,5]. Therefore, there are more causes of lung cancer besides smoking.

Besides smoking and inherited factors, air pollution, particularly indoor air pollution may contribute the high lung cancer incidence. These indoor airborne substances include biological contaminants such as allergens and endotoxins and chemical contaminants such as combustion products and off-gassing emissions, and many of these substances are carcinogens[6]. Moreover, people are spending more time in the tight, energy-efficient buildings. For instance, adults spend about 87% of their time in buildings, 6% in vehicles and 7% outdoorsIn North America[7,8]. Typically, more time is spent indoors in very hot or cold climates. As a result, personal exposure to airborne substances is more closely related to indoor rather than outdoor pollution. Thus, improving indoor air quality may prevent environmental factors-induced lung cancer. In the present article, we reviewed the sources, health effects and control strategies for several of the most important sources of residential chemical contaminants.

2. Household air pollution and health

The most recent World Health Organization (WHO) household air pollution and health fact sheets show that 3.8 million premature deaths annually from noncommunicable diseases including stroke, ischaemic heart disease, chronic obstructive pulmonary disease and lung cancer are attributed to exposure to household air pollution, and more than 50%of premature deaths due to pneumonia among children under 5 are caused by household air pollution[9]. The major household air pollution in developing countries comes from the using open fires and simple stoves burning biomass (wood, animal dung and crop waste) and coal. In developed countries, however, household air pollution are from tobacco using, poor ventilation and building materials. Indeed, sick building syndrome (SBS), situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified, occurs over 30% of new buildings. A 1984 WHO report suggested that up to 30 percent of new and remodeled buildings worldwide may be related to the poor indoor air quality[10]. A recent study found that that SBS symptoms including throat dryness, cough, sputum, malaise, headache and wheezing were more common in women than men. Malaise and headache were the most common symptoms in women and men[11].

3. Air pollutants

3.1. Biological contaminants

The biological contaminants include allergens, bacteria, viruses, fungus, molds etc. These contaminants can be recirculated and spread throughout the building. The most common indoor sources of allergens are furry pets and dust mites. Endotoxins are lipopolysaccharide components of the outer membranes of gram-negative bacteria. Increased endotoxins or gram-negative bacteria are associated with contaminated humidifiers, lower ventilation rates, presence of cats and dogs, storage of food waste and increased amounts of settled dust[12]. There are 4 major sources of mould growth in residences: leaks in building fabric, condensation, unattended plumbing leaks and household mould (e.g., mould growth on kitchen and bathroom surfaces, hidden food spills, garbages, defrost pans). Although these biological contaminants have not been established with lung cancer, increased levels of these biological contaminants in house dust have been associated with increases in asthma and other upper respiratory symptoms[13,14].

3.2. Chemical contaminants

Chemical contaminants come from both outside and inside of homes, but majorly from home building materials, cooking fuels and other materials.

3.2.1. Volatile organic compounds (VOCs)

VOCs is a mixture of over 40 chemicals including formaldehyde and benzene from building materials including wooden materials, glue and paint. VOCs have been reported as a major source of indoor air pollution, particularly in new buildings[15]. Although most VOCs are sufficiently decreased with the time in new homes, formaldehyde and a-pinene will continue emit from building materials up to 100 years at a stable rate[16]. Actually, formaldehyde is released from pressed-wood products (PWP) bound with urea-formaldehyde (UF) resins. In new homes having new PWP materials, the high emission rates of formaldehyde is from the evaporation of free formaldehyde in UF resins as well as the breakdown of easily hydrolyzed chemical bonds in the first 3 years[17]. This emission of free formaldehyde is significantly affected by temperature and relative humidity (RH). As these sources are depleted, formaldehyde is generated from further hydrolysis of the polymeric structure of UF resins. This mechanism is long-lasting over 100 years, involves low emission rates, and is likely to be controlled by diffusion from within the material to its surface[17]. In 2008, the state of California set 9μg/m^3 (7 ppb at 25^{o}C) asthe chronic reference exposure level (REL) forformaldehyde by the Office of Environmental Health HazardAssessment (OEHHA) [18]. The REL is based onpositive associations, especially among children withdiagnosed asthma, between prolonged exposures toformaldehyde and allergic sensitization, respiratorysymptoms (e.g. coughing, wheezing), or decrements inlung function[18].

3.2.2. Solid fuel smoke

About half of the world's population, particularly in developing countries, uses unprocessed biomass fuels and coal for cooking and heating. Exposure to solid fuel smoke is associated with several diseases, including chronic obstructive pulmonary disease, acute respiratory infections, and cancer, particularly lung cancer[19]. The risk of these diseases associated with household coal burning shows substantial heterogeneity by geographical location, due to the use of different coal types[20]. Recently, emissions from indoor combustion of coal has been classified as carcinogenic to humans (group 1) by the International Agency for Research on Cancer (IARC) based evidence in both humans and animals[21].

3.2.3. Secondhand smoke

Secondhand smoke is from other people's cigarettes, pipes, or cigars. When a person breathes in secondhand smoke, it is like he or she is smoking. In the United States, two out of five adults who don't smoke and half of children are exposed to secondhand smoke, and about 3,000 people who never smoked die from lung cancer due to secondhand smoke every year according to the US Centers for Disease Control and Prevention (CDC)[2,22]. During 2007--2008, approximately 88 million nonsmokers aged ≥3 years (40.1%) in the United States were exposed to secondhand smoke, although this number has been declined significantly from 52.5% during 1999-2000[23].

4. Carcinogens

4.1. Tobacco smoke

Tobacco smoke is a toxic mix of more than 7,000 chemicals. At least 70 chemicals from smoke are known to cause cancer in people or animals[2]. Serum cotinine, the main metabolite of nicotine, is a useful marker of tobacco smoking to measure tobacco exposure integrates different aspects of the exposure, including tobacco composition, uptake, distribution, and individual differences in metabolism. There is a strong, linear dose-response relationship between serum cotinine level and lung cancer risk among smokers and there is no clear plateau in the relative risk of individuals with high serum cotinine levels[24]. Serum cotinine levels >10ng/mL are associated with active smoking within the past few days, persons are considered nonsmokers if their serum cotinine concentration is ≤10 ng/mL and they did not report smoking within the preceding 30 days or use of any nicotine-containing product within the preceding 5 days at their physical examination. The minimum detectable level of serum cotinine concentration is 0.015ng/mL. Therefore, all persons whose serum cotinine concentration between 0.015ng/mL and 10ng/mL and did not report smoking within the preceding 30 days or use of any nicotine-containing product within the preceding 5 days are considered as victim of secondhand smoke[23]. The home is the major source of secondhand smoke exposure for nonsmokers supported by the evidence that the majority (98.3%) of nonsmoking children and youths who lived with someone who smoked inside the home had cotinine levels ≥0.05ng/mL (Figure 1), compared with 39.9% among those not living with someone who smoked inside the home[23]. Moreover, among children living with persons who smoked inside the home, the likelihood of exposure has increased during the past 20 years, which is supported that fewer than 1% of children aged 4--16 years living with persons who smoked inside the home had cotinine levels <0.05 ng/mL during 1988--1994, but this number has increased to 1.7% during 2007-2008. Thus, tobacco smoke may play important roles in the indoor air pollution associated lung cancer.

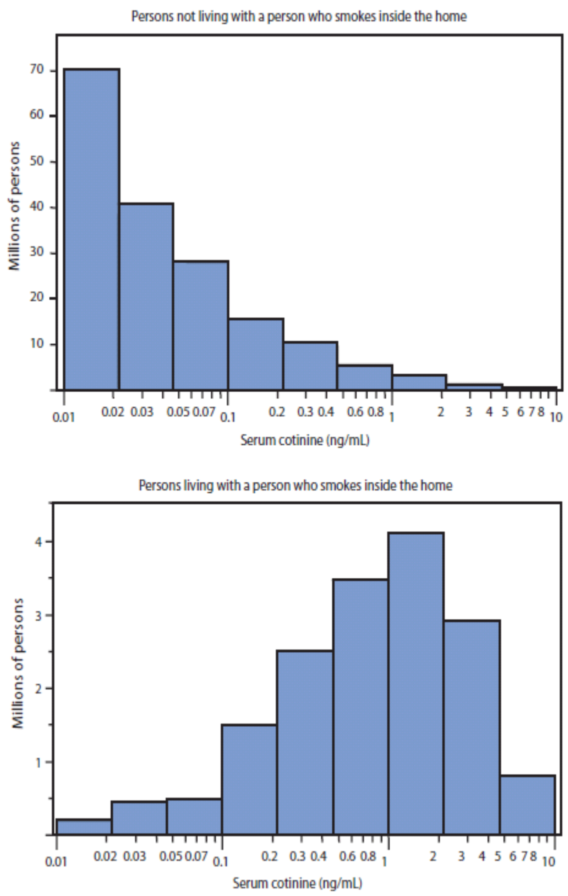

Figure 1. Secondhand smoking and serum cotinine.

4.2. Formaldehyde

Formaldehyde (FA) is also called methanol, formaldehyde gas; formic aldyhyde etc. It is colorless gas with pungent odor. It is directly used in aqueous solution (known as formalin) as a disinfectant and preservative in many applications. In fact, formaldehyde is produced worldwide on a large scale by catalytic, vapour-phase oxidation of methanol. Formaldehyde is used mainly in the production of various types of resin. Phenolic, urea, and melamine resins have wide uses as adhesives and binders in the wood-production pulp-and-paper, and the synthetic vitreous fiber industries, in the production of plastics and coatings, and in textile finishing.

Major indoor air sources of FA are building materials including wooden products as furniture, particleboard, plywood and medium-density fibreboard, consumer products and combustion processes. The International Agency for Research on Cancer (IARC) has classified FA in group 1 human carcinogen. It was based on inhalation causing squamous cell carcinoma (SCC) in rats and nasopharyngeal cancer in humans[25]. Recently, the classification has been expanded with FA causing leukaemia and limited evidence of sinonasal cancer in humans. Indoor air is the dominating contributor to FA exposure through inhalation[25]. Therefore, the World Health Organization (WHO) developed an indoor air guideline value in 2010. The critical effects were considered the portal-of-entry effects, sensory irritation of the eyes and the upper airways, resulting in a guideline value of 100μg/$m^3$of FA that should not be exceeded for any 30-min period of the day[26].

Mean ambient outdoor concentration of FA is typically in the range 1–4μg/m^3, but with higher levels in polluted cities[26]. In Europe and the US, the general levels of FA in public buildings and office buildings are lower than in homes and dwellings. Salthammer et al showed that the general level of FA in homes and dwellings in Europe, Canada and the US were 10–80μg/m^3)[27]. Ahigher mean concentration of FAhas been reported in China (up to 240μg/m^3). In Japan, concentration of FA is significantly higher in homes with occupants reporting sick-building syndrome (SBS) symptom than that in homes among non-SBS reporting participants (67μg/m^3 vs. 56μg/m^3) [28]. FA was detected in all new homes and FA levels were decreased from 134μg/m^3 in the first year to 86 μg/m^3 in the third year in new homes[15]. However, FA levels were pretty stable in old homes in three years (about 86 μg/m^3)[15], which is in line with other studies that FA emits from building materials up to 100 years at a stable rate[16]. The major sources of FA are pressedwoodproducts (PWP) with UF resins including particleboard,medium-density fiberboard andhardwood plywood because theyhave high formaldehyde emission rates and are widelyused in residences for cabinetry, furniture, and houseconstruction[29]. In new homes having new PWP materials, the high emission rates of FA is from the evaporation of free FA in UF resins as well as the breakdown of easily hydrolyzed chemical bonds in the first 3 years[17]. This emission of free FA is significantly affected by temperature and relative humidity (RH). As these sources are depleted, FA is generated from further hydrolysis of the polymeric structure of UF resins. This mechanism is long-lasting over 100 years, involves low emission rates, and is likely to be controlled by diffusion from within the material to its surface[17]. Therefore, persons living in these homes/buildings are exposure to FA in all life time.

Airborne FA is absorbed mainly in the upper airways (>90 %) due to the high water solubility and reactivity of FA. In the water phase, FAforms a water addition product, FA acetal [methyleneglycol, $CH_2(OH)_2$], which reacts with glutathione (GSH),forming S-hydroxymethylglutathione (FA glutathione thioacetal;HO–CH_2–SG). This intermediate is oxidized bythe glutathione-dependent FA dehydrogenase to S-formylglutathione andhydrolyzed to GSH and formate. Formate is incorporated in metabolic products or further oxidized to carbon dioxide[30]. The halflifespan of FA in blood is about 1–1.5min. About 1 % of the inhaled FA may be delivered to the blood compartment, and react with blood proteins, including Hgb with valine as one of the binding sites. No accumulation is considered to occur over long-term exposures due to the fast metabolism of FA in blood and the reversible nature of the reaction products[31]. Thus, risk of FA exposures from indoor air may be very low.

There is sufficient evidence in humans and experimental animals that FA exposure causes cancer of the nasopharynx and leukaemia[25], however, FA-induced genotoxicity plays an important role in the development of these cancers. While the data on FA-induced lung cancer in humans are still not concluded, to our knowledge there is no long-term epidemiologic studies of indoor FA exposure and lung cancer in humans.

4.3. Radon

Radon, a radioactive gas, comes from the natural decay of uranium in soil. The radiation decay products ionize genetic material, causing mutations that sometimes turn cancers. Radon is the second-most common cause of lung cancer in the USA after smoking[32]. People may ingest trace amounts of radon with food and water. However, inhalation is the main route of entry into the body for radon and its decay products. Radon decay products may attach to particulates and aerosols in the air we breathe (for example, cooking oil vapors). When they are inhaled, some of these particles are retained in the lungs[33]. Radon typically moves up through the ground to the air above and into the home through cracks and other holes in the foundation. The level of radon on the first floor of a home may be less than half of the level in the basement. The home traps radon inside, where it can build up. Any homes, new and old, well-sealed and drafty, and with or without basements have the risk of radon accumulation. Well water and building materials are not common sources. The average outdoor level of radon is about 37Bq/m^3. A study by the US Environmental Protection Agency that included homes in 50 states reported a mean indoor air radon concentration of 46Bq/m^3, ranging between 54Bq/m^3 in single-family homes to 24Bq/m^3 in multi-family homes. One in 15 homes in the US has radon levels above the recommended guideline of 148 Bq/m^3 and the highest measured level of radon from home is 74,000Bq/m^3[33]. There is no safe level of radon any exposure poses some risk of cancer. The National Academy of Sciences (NAS) estimated that 15,000-22,000 Americans die every year from radon-related lung cancer[33]. Moreover, smoking combined with radon is an especially serious risk of lung cancer by increasing almost 10 times of the radon only risk[34].

According to EPA, the first step is to test radon level in the home. If the radon level is above the EPA recommended level 148Bq/m^3, actions have to take to reduce radon. There are five principal methods for reducing a high indoor radon concentration are: 1) reducing the radon supply by reversing the pressure difference between the building and the soil; 2) raising the resistance of the foundations to soil gas entry; 3) removing the radon sources such as water or underlying soil; 4) diluting the concentration by increasing the ventilation rate; and 5) reducing the concentration of radon progeny by filtering and increasing the circulation of indoor air. Buildings which have a radon concentration higher than 200Bq/m^3 should be investigated by the national authorities. The best method for reducing radon in home is depending on how radon enters the home and the design of the home. For example, sealing cracks in floors and walls may help to reduce radon, but is not sufficient. There are also systems that remove radon from the crawl space or from beneath the concrete floor or basement slab that are effective at keeping radon from entering the home[33]. Before a permanent remedy can be effected, simple temporary precautions such as increasing ventilation by opening windows may be efficient to reduce indoor radon level[35].

4.4. Asbestos

Asbestos is a mineral fiber that occurs in rock and soil. Because of its fiber strength and heat resistance it has been used in a variety of building construction materials for insulation and as a fire-retardant. Asbestos has been used in a wide range of manufactured goods, mostly in building materials (roofing shingles, ceiling and floor tiles, paper products, and asbestos cement products), friction products (automobile clutch, brake, and transmission parts), heat-resistant fabrics, packaging, gaskets, and coatings.

Elevated concentrations of airborne asbestos can occur after asbestos-containing materials are disturbed by cutting, sanding or other remodeling activities. Improper attempts to remove these materials can release asbestos fibers into the air in homes, increasing asbestos levels and endangering people living in those homes. When asbestos fibers are inhaled, most fibers are expelled, but some can become lodged in the lungs and remain there throughout life. Fibers can accumulate and cause scarring and inflammation. Enough scarring and inflammation can affect breathing, leading to respiratory cancers (cancer of the lungs and mesothelioma) in humans[36]. Although most asbestos-induced cancer cases are from workers whose occupation involving low-level chrysotile exposure, there is report that clothing-derived asbestos exposure may cause health problem. This is very important that asbestos is still widely used in such commonly used products like clothing, pipeline wraps, vinyl floor tiles, millboards, cement pipes, disk brake pads, gaskets and roof coatings[37]. In addition, studies have shown an increased risk of lung cancer among smokers who are exposed to asbestos compared to nonsmokers[38].

5. Improving indoor air quality

While quitting-smoke, eliminating PWP with UF resins to build homes and systematically sealing cracks of floor may fundamentally remove these air pollutants as mentioned above, alternative approaches have to be used to decrease these air-borne carcinogens in old homes and persons who cannot quit smoking. The most effective and realistic method is to supply more fresh air to replace exhaust indoor air in the building, which is called ventilation. Indeed, when more outdoor air is provided (increasing ventilation rate), either through a mechanical ventilation system containing fans, or by increased opening of doors and windows, the indoor air concentrations of pollutants from indoor sources are decreased and are associated with fewer adverse health effects and with superior work and school performance[39].

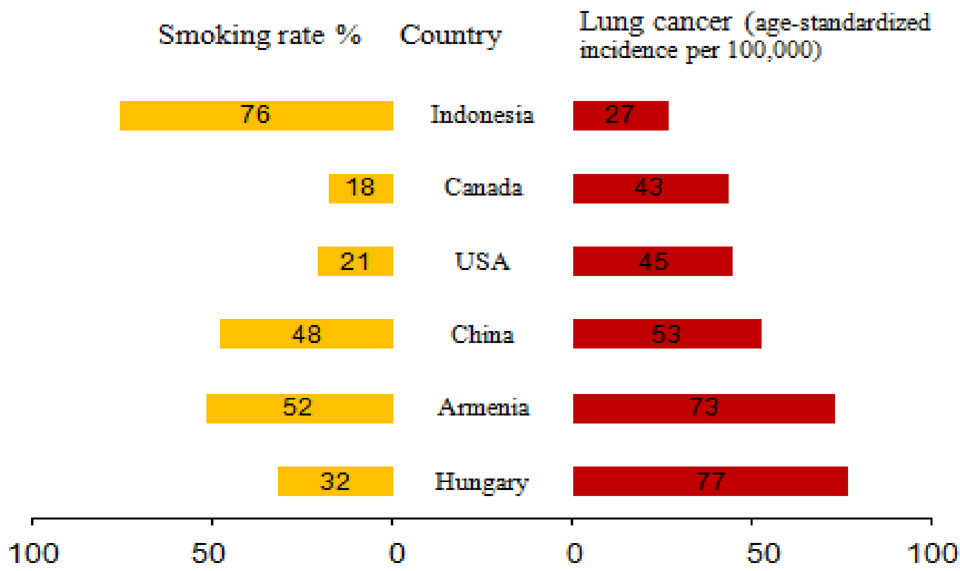

Figure 2. Lung cancer incidence and smoking rate in adult men.

Opening widows is oldest and most used way to improve indoor air quality. In most developing countries where central heating, ventilation and air-conditioning systems (HVACs) is not prevalent, opening widows is the only way to get fresh air if the climate is allowed and opening windows really increased indoor air change rate in homes[40]. This is supported by the fact thatthe highest smoking rate in men (76%) is in Indonesia in 2015, but the lung cancer incidence rate in men is only 26.5 per 100,000 populations, which is much lower than that in USA (44.5 per 100,000 populations) while only 20% American adult men are smoking (Figure 2)[4,5]. One possible interpretation is that opening windows is much common because of the high temperature and low rate of HVACs in Indonesia, on the contrary, Americans do not like to open widows because HVACs are installed in almost every building/house.

Removal or modification of the pollutant source can be carried out by a routine maintenance of HVAC systems, replacing water-stained ceiling tiles and carpets, using stone, ceramic or hardwood flooring, proper water proofing, avoiding synthetic or treated upholstery fabrics, minimizing the use of electronic items and unplugging idle devices, venting contaminants to the outside, storing paints, solvents, pesticides and adhesives in close containers in well-ventilated areas and using these pollutant sources in periods of low or no occupancy. Allowing time for building material in new areas to off-gas pollutants before occupancy and smoking restrictions are some measures that can be used.

6. Conclusion

Indoor air contaminations include cigarette smoking, FA and other VOCs as well as radon in homes and working spaces. Building materials such asPWP are the major sources of FA and VOCs, and these materials may release these toxic chemicals over 100 years. While FA was banned in Europe and few countries, these materials are still widely used in the building of houses worldwide. To our knowledge, long term comprehensive studies, particularly clinical/epidemiological studies on these building materials-derived chemicals on health are still lacking. While the fundamental approaches including quitting smoking and using natural and healthy building materials are essential of eliminating indoor air contamination, some simple measures such as increasing ventilation in the central HVAC systems or daily opening windows may be realistic, convenient and cost-effective ways to improve indoor air quality and health for homeowners.

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