

Indoor Air Pollution in Exercise Centers

Hajian M¹, Mohaghegh Sh^{2*}

¹Department of Community Medicine, Faculty of Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran

²Department of Sports Medicine, Loghman Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran

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ABSTRACT

As many people and athletes exercise indoor, in their homes or other sports arenas because of outdoor air pollution or other reasons, it is important for health professionals to know briefly about indoor air pollutants and its possible health effects on athletes who exercise in these environments. In this review the most common indoor air pollutants and their possible health effects on athletes are discussed.

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1. Introduction:

It is well accepted that exercising in outdoor air polluted environment causes more contacts with air pollutants and possibly more negative effects on athlete's health. However, less attention has been paid to the indoor air pollutants in exercise centers and their possible health effects. Indeed as many physiological changes which happen during exercise such as increasing in minute ventilation, air inhalation through mouth, air flow velocity, and pulmonary diffusion capacity (1), in both outdoor and indoor environments are essentially the same, one

can conclude that exercising in indoor air polluted environment can have the same importance as exercising in outdoor environment. Furthermore cardiac and respiratory patients, children, elderly people and even normal athletes are frequently advised for staying in home and not doing exercise in hazardous outdoor environmental situations which nowadays are becoming more frequent in large and industrial cities like Tehran (capital city of Iran) (2). Also it seems many citizens of this cities exercise indoor because of causes other than outdoor air pollution such as lack of time or appropriate facilities. Thus it is necessary for all physicians and other health workers involved in sports and exercise medicine to know briefly about indoor air pollutants and its possible health effects on athletes who exercise in these environments.

Corresponding author: Mohaghegh Sh, MD. Assistant Professor of Sports Medicine, Loghman Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran

E-mail: sh.mohaghegh@sbmu.ac.ir

Indoor air pollutants have different sources. Broadly they can be divided into 3 groups: 1) pollutants which are produced inside a building (internal pollutants), 2) pollutants which are produced outside a building and can penetrate indoor through windows or other pores and openings, joints, and cracks in walls, floors, and ceilings (external pollutants), and finally 3) natural radon gas that can go inside the buildings from the ground (3). An important other factor that should be considered in gymnasiums is poor indoor air quality due to gathering of large number of people in small buildings that often have poor ventilation (4). In this review we focused on the most common indoor air pollutants that people and athletes encounter with them during exercise in their homes or other indoor exercise centers.

2. Internal pollutants:

These include *environmental tobacco smoke* (ETS) and other combustion related pollutants such as carbon monoxide (CO) and nitrogen dioxide (NO₂); *biological pollutants* such as dust mites, molds, fungus, bacteria; *volatile organic compounds* (VOCs) such as formaldehyde and benzene; *inorganic chemicals* such as chlorinated substances in swimming pools; *heavy metals* such as lead and mercury; and asbestos (5-7).

Internal pollutants can accumulate inside the space when there is poor ventilation of buildings. Unless they are equipped with good ventilation facilities, buildings with the lower amount of outdoor air exchangerate may have higher pollutant levels than other buildings (6).

3. Environmental Tobacco Smoke (ETS):

ETS has complex mixture of more than 4000 identified chemicals. Many of them are toxic or carcinogenic agents. In indoor spaces non-smoker exposure to these agents can occur as a person smokes (5). Environmental tobacco smoke is a major source of indoor air pollution. Second-

hand smoke as direct smoking causes many cardiovascular and respiratory diseases and even death in children and adults. Overall increased risk of cancer (including lung and breast cancers and brain tumors), heart diseases, lung, ear, nose and throat infections (including tuberculosis), abnormalities of lung function and growth, hearing loss, asthma and allergies, sudden infant death syndrome (SIDS), tooth decay and learning difficulties (in children), Crown disease, low birth weight and premature birth and atopic dermatitis have been related to ETS (8, 9).

Reduced heart rate variability, increased heart rate, hypertension, blood carboxyhemoglobin and consequently reduction in exercise capacity in those with stable angina and in healthy people are acute cardiovascular effects of passive smoking (10, 11). Also ETS increases the risk of atherosclerosis (12).

As children's lungs are more susceptible to harmful effects from ETS (8), it is necessary for all persons and audience to pay attention completely for smoke-free laws in children gyms. It is important to know that general ventilator systems can not totally eliminate ETS (gaseous and particulate components) from the indoor spaces and the most effective method is smoking prohibition in these spaces. Also moving to another room or opening a window for smokers cannot provide enough ventilation (7).

4. Other combustion related pollutants:

These include particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_x) and others. PM consist of variety of particulates with different size and composition. They are small enough to remain in suspension for some hours or days. Fine particles <2.5 μm (PM_{2.5}) can be deposited in the lower respiratory tract. They can carry organic and inorganic (such as heavy metals) and some carcinogenic pollutants (1, 5). Exposure to particulate matter especially PM_{2.5} is a short and long-term risk factor for

cardiovascular disease and has been linked to the triggering of acute coronary syndromes within hours of exposure. Acute vasoconstriction, hypertension and arterial stiffness, vascular endothelial dysfunction, myocardial ischemia and changes in cardiac autonomic control were reported following acute exposure to concentrated ambient particles(13). In respiratory tract, exposure to PM can cause irritation and oxidative stress producing lung and airway inflammation, hyper-responsiveness, and in long-term exposures airway remodeling, emphysema and cancer. Also reduced mucociliary clearance and macrophage response was reported (5). Environmental tobacco smoke and cooking can generate high concentrations of PM in indoor spaces both in residential and commercial settings (14). It improved that more than half of world's indoor population caused by burning of biomass for heating and cooking purposes (13). In developing countries, especially in rural areas, these fuels are often burned inefficiently in open fires, leading to extremely high levels of indoor and local air pollutions. Biomass stoves (wood stoves) are also a source of indoor pollution in developed countries (5, 13). Smoke from biomass combustion is an important source of indoor pollutants including free radicals, polycyclic aromatic hydrocarbons, aldehydes, partially oxidized organic chemicals and particulate matter (13). Chronic obstructive pulmonary disease, acute respiratory infections, nasopharyngeal, laryngeal and lung cancer, cataracts and pulmonary tuberculosis are associated with the use of biomass fuels (15). In skating rinks, the operation of fossil-fueled ice rink resurfacing machines which is used for cleaning and resurfacing the ice, can lead to elevated concentrations of combustion products such as ultrafine and fine particulate matter (PM 1), nitrogen dioxide and carbon monoxide. Airborne PM 1 has been implicated in the inflammatory cascade of asthma and pulmonary function decay in ice rink athletes chronically

exposed to these pollutants. This may explain the high prevalence of exercise-induced bronchospasm (EIB) in this group of athletes (30–50%) (16).

Nitrogen dioxide (NO₂), a byproduct of combustion, is commonly known as both the outdoor and indoor air pollutant. Major sources of indoor NO₂ include gas cooking and heating, and environmental tobacco smoke (17). In enclosed ice skating arenas, the lack of air flow due to inadequate ventilation, combined with temperature inversion resulting from migration of heavy NO₂ towards the ice surface causes trapping of this pollutant near the ground (18). Acute exposure to nitrogen dioxide concentrations above 5 to 10 ppm may produce severe cough, hemoptysis, chest pain, and pulmonary edema. Exposures of healthy (non-asthmatic) individuals to nitrogen dioxide concentrations above 1000 ppb for 1 hour or longer may be causes airway hyper-responsiveness. Asthmatics, particularly children, are more susceptible to respiratory effects of nitrogen dioxide (18, 19). It is thought that the mechanism of injury to the respiratory tract is combination of NO₂ with water in the lungs producing nitrous and nitric acid. According to air quality standards for enclosed ice arenas, NO₂ should not exceed 200 ppb for a 1 hour exposure. However, asthmatic people may develop symptoms with concentrations as low as 0.1 ppm (18).

Carbon monoxide (CO) is a colorless, odorless air pollutant. It is a byproduct of the incomplete combustion of the organic fuels. After inhalation, it combines with hemoglobin (Hb) with an affinity 200 to 240 times more than oxygen to form carboxyhemoglobin (COHb). This shifts the oxyhemoglobin dissociation curve to the left, greatly impairing the ability of hemoglobin to deliver oxygen to tissues (cellular hypoxia). Headache, hypotension and syncope occur in blood carboxyhemoglobin concentrations more than 20 percent. At lower concentrations (more than 2.5 percent) vision is altered and evidence of impaired behavior may

appear. A concentration below 2.5 percent has no apparent symptoms. As many signs and symptoms of CO poisoning are nonspecific, it is probably greatly underreported (1, 18, 20). CO poisoning can impair athletic performance too. Maximum cardiac output, maximal arteriovenous difference, anaerobic threshold, maximum oxygen uptake and work output are lowered and heart rate and pulse pressure are increased following acute CO poisoning (1). Uptake of CO during exercise is three to four times greater than at rest. During exercise, there has been a linear relationship between percentage saturation of COHb in blood and exposure time and concentrations of CO in indoor air of enclosed rinks. For each 10 ppm of CO in an arena, an adult hockey player after 1.5 hours game of hockey increases his COHb concentration by 1.0%. Limits of concentration of CO proposed in arenas for 1 hour and 8 hours exposure are in the range of 25 and 12 ppm respectively. Children, elderly persons, people with cardiovascular failure, and pregnant women are more susceptible to lower concentrations (18). All patients should receive high-concentration, high-flow oxygen by tight-fitting face mask or endotracheal tube. Airway protection, breathing assistance and cardiovascular support should be done as necessary for patients with significant CNS or respiratory depression (20).

For minimizing the exposure to air pollutants in ice arenas, regular and proper installation, adjustments, and operation of ice resurfacing machines are necessary. If possible, replacement of fossil-fueled ice resurfacing machines with more expensive electric ones is an effective solution. Otherwise it is recommended that resurfaces fuelled by propane should be used instead of gasoline resurface. Propane resurfaces emit the least pollutants. An effective ventilation system for the evacuation of polluted air and delivery of a supply of fresh air is essential in arenas. Regular monitoring (a minimum of once weekly) of the ambient CO and NO₂ at a

fixed time (hour, day) corresponding to the times of greatest use of the resurface is necessary. Education of rink staff, coaches, athletes and patrons of ice rinks about symptoms of CO and NO₂ poisoning for early detection and proper management must be done (18).

5. Biological pollutants:

These include bacteria, molds, viruses, products from men and pets, house dust, mites, cockroaches, other pests or insects and pollen. Also microbial products such as endotoxins, microbial fragments, peptidoglycans and varied allergens are included in this category. Many of these pollutants are small inhalable particles and are often found in wet areas, such as cooling coils and humidifiers. Dust collection in mattress, draperies, carpet, and other areas in gyms may accumulate biological pollutants (21).

Some biological pollutants cause allergic reactions including hypersensitivity pneumonitis, allergic rhinitis, and asthma in significant percents of people. Contaminated central air handling systems can become breeding grounds for *Legionella* and other biological contaminants such as mold, mildew, and can then distribute these pollutants through the indoor spaces. Tuberculosis, measles, *staphylococcus* infections, chicken pox and influenza are other infectious diseases known to be transmitted by air (5, 22). Humidifier fever, a flu-like illness but with shorter duration of symptoms, has been related to exposure to bacterial endotoxins and other biological contaminants found in humidifier reservoirs, air conditioners, and aquaria. The attack rate may be more than 25 percent (7).

For reducing exposure to biological pollutants inside gyms, keeping these places clean and dust free, providing adequate ventilators and good maintenance of heating, are very important. Keeping the relative humidity of indoor spaces between 30 to 60% (up to 50 percent in underground gyms) are necessary (21). Also controlling insect numbers especially

in moist spaces such as swimming pools can reduce exposure to these air contaminants. Cleaning humidifier's appliances according to manufacturer's instructions and refilling it with fresh water daily are important. Complete cleaning and drying of floor of gyms and mats are important. Water-damaged building materials must be repaired. They can be the origin of mold and bacteria. If gyms are located underground, cleaning and disinfecting the basement floor drain regularly are necessary (23).

6. Volatile organic compounds (VOCs):

These are emitted gases from many organic solid or liquid products at ordinary room temperature. Some examples from thousands of products are paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, glues and adhesives, varnishes, wax, many cleaning, disinfecting, cosmetic and hobby products and fuels (24).

VOCs include a variety of organic chemicals (e.g. formaldehyde, benzene, and perchloroethylene) (7). Some common organic compounds are mainly indoor pollutants and their concentrations inside buildings are 2 to 5 times higher than outside, both in rural and or highly industrial areas. Indoor levels may be 1,000 times more than outdoors during and immediately after certain activities, such as painting (23). Formaldehyde based resins are widely used in mobile and conventional home construction as components of building materials (subflooring, paneling) and as components of furniture and cabinets, permanent press fabric, draperies, and mattress ticking (7). Some of VOCs may have short and long term adverse health effects. Acute signs and symptoms of VOCs toxicity include eye and upper respiratory irritation, rhinitis, nasal congestion, rash, pruritus, headache, nausea, memory impairment, fatigue, dizziness, vomiting, dyspnea, and in the case of formaldehyde vapor, epistaxis. Pesticides poisoning can cause

muscular weakness and twitching (for example in the case of cyclodiene pesticides). People with asthma or hyper reactive airways may be more susceptible to VOCs (7, 23). Some organic compounds are known carcinogens in animals and humans (for example Methylene chloride, perchloroethylene (23) and benzene (24)); some are still suspicious as carcinogen in humans (such as formaldehyde (7)). The extent and severity of the health effects depend on many factors including level of exposure and length of time exposed. In the body, Methylene chloride is converted to carbon monoxide and can show symptoms and signs of carbon monoxide poisoning. Methylene chloride can be found in products such as paint strippers, adhesive removers, and aerosol spray paints. Damage to the liver, kidneys, endocrine and nervous systems are known adverse effects of chronic exposure to some pesticides (25).

It is necessary to increase ventilation when using products that emit VOCs. Attention to any label precautions of the products is important. As one of the main indoor sources of benzene is environmental tobacco smoke, elimination of smoking within the gyms is very important. Using a sealant on all exposed surfaces of paneling and other furnishings can reduce exposure to formaldehyde. Formaldehyde levels can be readily measured in exercise spaces to identify, and if possible, remove the source of it. Although no standards have been set for VOCs in non-industrial settings, it can be advised to reduce formaldehyde levels that are present at levels higher than 0.1 ppm. By using integrated pest management techniques, the need for pesticides can be reduced in gyms (23).

7. Inorganic chemicals:

In swimming pools, chlorine-containing agents are used frequently for disinfection of pool water. However, the rapid reaction of chlorine with nitrogen-containing organic compounds brought into water by pool users (such as urea, sweat, skin squama, cosmetics, urine, nasal discharge, fecal matter, etc.) can lead to the formation

of a large variety of by-products (disinfection by-products) such as inorganic chloramines (CAMi) among them, chloramines and particularly nitrogen dichloride (NCL₃) which is volatile and the main chloramines found in the air above chlorinated pools, can give rise to acute disruption of the airway epithelium and significant eye and respiratory irritation in swimmers and pool attendants (26). Chloramines'-related outbreaks of respiratory irritation are thought to be common but seldom reported (27). Case of severe chemical epiglottitis and laryngotracheobronchitis was reported after exposure to toxic levels of chloramines (28). NCL₃ has a strong odor and forms more rapidly in water with low pH (29). When the water splashes, it causes chloramines to be aerosolized from the water surface and rising of their levels in the air. Chloramines are mainly responsible for smell and irritant properties of swimming-pool air (30). In lifeguards and swimming teachers, occupational asthma due to exposure to chloramines was reported (31). Also a high prevalence of respiratory symptoms and airway hyper-responsiveness (AHR) to direct or indirect stimuli in elite swimmers has been reported and attributed partly to the inhalation of large amounts of chlorine by-products during repeated intense training. In addition of swimming pool workers and elite swimmers, recreational swimmers particularly susceptible individuals exposed to high levels of chlorine products may be affected overtime (32). Young children may be more susceptible for the new onset allergic sensitization and airway inflammation after early age swimming in chlorinated pools (33). Repeated exposure to chlorination by-products in the air of indoor swimming pools has caused lung epithelial hyper-permeability in children and adults. Regular attendance at chlorinated pools by young children is associated with increase in the risk of developing exercise-induced broncho-constriction, especially in association with other risk factors (34). Also it has been

reported that there is associations between rise in prevalence of childhood asthma in European countries and increasing availability of indoor chlorinated swimming pools in these countries (35). However in a recent systematic review of swimming training in mostly chlorinated swimming pools for asthmatic children and adolescents aged 18 years and under, authors concluded that there was no evidence that swimming training caused adverse effects on asthma control in children and adolescents with stable asthma (36).

NCL₃ concentration below 0.3 mg/m³ in the air of pool is recommended for prevention of short-term changes in lung function or airway epithelial permeability in swimmers (26). However, respiratory symptoms with concentrations as low as 0.017mg/m³ were reported (37). For chlorine gas the concentration of 1.5mg/m³ in the air of indoor swimming pools was established as the limit for the risk of irritating effects (38). Acute intoxication with high levels of chlorine gas (for example from explosions of chlorine gas supply) is common and may cause laryngeal edema, asthma attacks and chemical burns of the upper and lower airway mucosa, and even chemical pneumonitis and acute respiratory distress syndrome (ARDS). Patients may present with oral, nasal, and pharyngeal pain in addition to drooling, mucosal edema, cough, or stridor. Conjunctival irritation or chemosis, as well as dermatologic irritation, is often noted. Following moderate exposure, there may be only mild initial symptoms and main clinical symptoms occur after a substantial time delay, typically several hours. This is due to the intermediate solubility characteristics of this gas. Management of patients with acute respiratory tract injury begins with meticulous support of airway patency, and maintaining oxygenation. Supplemental oxygen, bronchodilators, and airway suctioning should be used if clinically indicated. Systemic or inhaled corticosteroids, designed to reduce the

inflammatory host-defense response, can be used (39).

For prevention of exposure to chloramines, together proper ventilation and good maintenance of swimming pool in regard of water quality, it is necessary to pay attention to public hygiene for reduction of human nitrogen-containing organic compounds in the water. Some important interventions are showering with soap before entering the pool, wearing a swim cap, using a swim suit reserved exclusively for swimming, respecting personal hygiene precautions before entering the pool, bare feet zones, and removing make up and other cosmetics (26). Using indoor pools treated with combined chemical treatments (e.g. ozone) can reduce direct exposure to disinfection byproducts and their negative effects on respiratory function compared to chlorinated pools (40).

The ventilation system of pool must be able to remove contaminants and moisture and provide good exchange rate with outdoor air. Condensation on windows and walls (fog/wetness) are indications of poor air quality (41). A well maintained pool should have little or no chlorine odor and should not cause burning of eyes in swimmers (28). pH of water should be preserved between 7.2 and 7.8. Free chlorine in water should be kept between 0.8 ppm and 3ppm. Combined chlorines (chloramines) in water should be <0.2 ppm (41). Water in public swimming-pool should be clean and clear with a clearly visible main drain (28).

8. External pollutants:

These include pesticides and outdoor air pollutants (6). Some pollutants can be considered as both internal and external pollutants such as carbon monoxide (CO) and nitrogen dioxide (NO₂). Infiltration efficiency is the fraction of outdoor pollution that penetrates indoors. Reducing air exchange between outdoor and indoor (for example by closing the windows), can effectively reduce infiltration (42). Infiltration rate of particulate matter

increases with decreasing aerodynamic diameter of the collected particles. Indeed it has been shown that air in the school gyms located near major roads with high traffic densities was significantly polluted by fine aerosol (less than 2.5 micron) infiltrating from outdoors. Concentrations of coarser suspended aerosol (PM_{10-2.5}) in these gyms have been associated with the movement of people reflected by the number of exercising pupils and/or the number of physical education hours performed in gyms (43).

9. Radon:

Radon is an odorless, invisible and naturally occurring radioactive gas produced from radium, which is the product of radioactive decay of uranium in the ground. It penetrates through buildings via leakage sites in the foundations and in underground portions of the walls. Radon can be exhaled from building materials or contaminated tap water too. The radon concentration of a building depends mainly on the amount of uranium and radium in the underlying soil and construction materials, the degree of penetration through a building, climatic conditions (more in cold seasons), the pressure gradient between the subsurface air and the interior of the building and whether it is removed from indoor air by air exchange or ventilation. It is not related to the aging of the buildings and presence or absence of the basement in it. However, the concentration usually declines with increasing elevation above the ground. Radon is a well-known carcinogen due to high level of alpha irradiation and can cause lung cancer, probably in a linear dose-response relationship with no threshold value. Radon exposure after smoking is the second main cause of lung cancer in the general population without occupational exposure (44, 45).

It is necessary to keep radon concentrations as low as possible in indoor spaces where people are present for more than merely transient periods of time (45). This is true for ordinary people who live

and exercise at their homes or elite athletes who spend a large time in gyms. Although there is not mentioned any standard level for radon in gyms, it is recommended for fixing homes with radon levels at or above 4 pCi/L (44). This is done by eliminating leakage sites of radon in the building, by improving natural or artificial methods of ventilation and gas removal, and by regulating pressure relationships between indoor space and subsurface air. Also it is important to make buildings radon-proof from the beginning (45).

10. Ventilation and air quality in gyms:

Ventilation is a combination of processes which results in the supply and removal of air from inside a building (46). Of the different ventilation systems (natural, air conditioning or mixed), mixed systems are the most effective. There have been reported a clear relationship between the different ventilation systems and indoor air contaminant levels. CO₂ levels are considered a good parameter for assessing indoor ventilation quality in enclosed settings like schools; levels above the threshold of 1000 ppm would imply poorly functioning ventilation systems (47). More specifically, exercise centers and gyms require higher ventilation rates than offices and living places and should maintain the lowest CO₂ concentration practically possible. An indoor level of 650 ppm CO₂ is needed for satisfaction of 90% of users with air quality (48).

Although indoor pollutant exposure can also be lowered through the use of air cleaners (such as high-efficiency particulate air (HEPA) filter air cleaners), clinical studies investigating the health benefits of air cleaner use have not confirmed these findings yet (42).

11. Discussion:

Using low-emission building materials, regularly cleaning and use of low-dust floor coverings, clean ventilation and air conditioning systems, and sufficiently high fresh air ventilation rate are key factors for

controlling exposure to indoor pollutants in exercise centers (48).

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