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Swimming facilities and work-related asthma

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Abstract

Background: Exposure to chlorinated water in swimming facilities may aggravate preexisting asthma or cause new onset asthma. This may be a particular problem for individuals who work and therefore spend prolonged time at swimming facilities. Chloramines formed by the interaction of chlorine-based disinfection products with the nitrogen in water from human sweat, urine and skin cells are the suspected causal agents. *Methods*: Cases were reviewed from the state surveillance systems in California (CA), Michigan (MI) and New Jersey (NJ) to identify individuals with confirmed work-related asthma (WRA) attributed to exposures in swimming pools, water parks or hydrotherapy spas. A standardized method was used to confirm cases. *Results*: A total of 44 confirmed cases of WRA were identified; 17 from 1994 to 2011 in CA, 15 from 1991 to 2012 in MI and 12 from 1990 to 2011 in NJ. A majority (52.2%) of the cases were new onset; 31.8% secondary to an acute exposure incident and 20.4% to repeated exposure. These represented 0.3–1.6% of all confirmed cases of WRA received during these time periods. Maintenance workers (34.9%) and lifeguards (31.8%) were the most common occupations. *Conclusions*: Swimming pool workers were identified from three states where the pool environment was either a trigger of preexisting asthma or associated with new onset of WRA. Regulations to require air monitoring and improvements in ventilation are recommended to reduce exposure levels of chloramines, the presumed etiologic agents. Clinical assessment of patients with asthma should include consideration of the effect on respiratory symptoms from exposures in a swimming pool environment.

Keywords

Choramines, chlorine, environmental trigger, epidemiology, occupational exposure

History

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Introduction

Whether swimming in chlorinated water causes or aggravates asthma is an ongoing focus of research [1]. Studies of children and elite Olympic swimmers have suggested a causal relationship between repeated swimming in chlorinated pools and the development of asthma [2–6]. The ''pool chlorine hypothesis'' states that the increased incidence of asthma in developed countries is at least partially caused by children spending more time in chlorinated swimming pools [1]. However, because many of the studies that find a risk of asthma in association with swimming are cross-sectional, an alternative explanation is that people with asthma are more likely to swim because, at least in the past, it has been a recommended form of exercise for individuals with asthma [1].

Exposures of concern related to asthma from swimming pools and similar environments are the elevated concentrations of disinfection by-products (DBPs) found in the air of indoor pools, hydrotherapy spa and hot tub venues and water parks. Examples of DBPs include the chloramines (mono-, di- and tri-), trihalomethanes and haloacetonitriles and are formed when chlorine-based disinfection products interact with the nitrogen in water from human sweat, urine and skin cells [7]. In addition, chloramines may already be present in the water used to fill pools because an increasing percentage of municipal water supplies utilize monochloramine as an alternative to chlorine for disinfection. Monochloramine is often used because, compared to water treated with chlorine, chloramine-treated water has improved taste and is less likely to convert organic material in the water to trihalomethanes such as chloroform [8]. Trichloramine is the most volatile of the three chloramine compounds and predominates at a pH of less than 8. Mono and dichloramine, which are less volatile, are likely to be released from droplets when the water surface is disturbed (i.e. splashing and water park attractions) [9].

Seven studies have been identified in the medical literature involving respiratory symptoms in pool workers [10–16]. One, from England, included specific antigen challenge testing on three pool workers [10]. In this article, we have reviewed reports of work-related asthma (WRA) associated with working at a swimming pool or water park identified

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through the WRA surveillance systems in California (CA), Michigan (MI) and New Jersey (NJ).

Methods

Details of how WRA cases are identified and the criteria for case confirmation and classification have been published previously [17]. All three surveillance systems are based on healthcare providers diagnosing a patient with WRA. Sixty-four percent of the WRA cases in CA, more than 80% in MI and 25% in NJ were received as reports from physicians. In MI, these reports were actively solicited. In CA, the physician reports were part of a mandatory reporting requirement linked to physician reimbursement for medical services. Additional cases were identified in MI and NJ by reviewing all hospital discharge records with the ninth International Classification of Diseases (ICD-9) code 506.0–506.9 (respiratory conditions due to chemical fumes and vapors) or with the ICD-9 code 493.0–493.9 (asthma) where workers' compensation was the primary expected payer and identifying cases where the treating physician diagnosed WRA. NJ also reviewed hospital discharges with ICD-9 codes 786.2 (cough) and 786.9 (other symptoms involving respiratory system and chest). In CA, additional cases were identified by reviewing all emergency department and hospital discharge records with an ICD-9 code 493.0–493.9 with workers' compensation as expected payer, as well as all workers' compensation cases with an indicator of asthma either in a text field or ICD-9 code of 493.0–493.9. After cases were identified, standardized follow-up questionnaires were administered by telephone in all three states to obtain additional information about workplace exposures associated with asthma symptoms, medical history and non-occupational risk factors. For each case, up to three exposures (agents) were recorded as the possible cause of asthma symptoms. Medical records in MI were also regularly reviewed for pulmonary function testing in relation to work and to record the results of that testing. Medical records were also reviewed for all emergency department and hospital discharge cases in CA. Based on the results from the interviews and medical record reviews, cases were confirmed as being work-related and were further classified as: (1) work-aggravated asthma if a person had physician-diagnosed asthma before beginning work and their asthma became worse at a particular job or (2) new-onset WRA [17]. New-onset WRA cases were further classified into asthma without a latency period between exposure and disease (reactive airways dysfunction syndrome [RADS]) if a person develops asthma for the first time immediately after an acute exposure to an irritating chemical at work, or asthma from exposure to a sensitizer or irritant after a latency period if they have a physician diagnosis of asthma and onset of respiratory symptoms associated with a particular job that then improve or are relieved when the patient is not working. For some cases, there was insufficient information obtained to be able to determine whether the individual's asthma existed prior to pool-related inhalation exposures. These latter cases were coded as ''confirmed, but unclassified''.

To identify cases where the exposure occurred at a swimming pool, hydrotherapy spa or water park, all confirmed cases of WRA reported to the CA, MI and NJ surveillance systems were reviewed. All confirmed cases in which work at a swimming pool, hydrotherapy spa venue or water park was the source of exposure were included. Exposures may have been chronic and occurred over time or they may have been acute in nature and occurred as a result of spills or improper mixing.

The Human Subjects' Review Boards of the three institutions reviewed and approved this activity.

Results

A total of 44 confirmed cases of WRA were identified: 17 from 1994 to 2011 in CA, 15 from 1991 to 2012 in MI and 12 from 1990 to 2011 in NJ. Table 1 lists the number and percentage of cases associated with swimming pools, therapy spas and water parks by asthma classification and state. Over half (56.8%) of the asthma cases were new onset. Table 2 shows gender, age and racial distribution. The cases were fairly equally distributed between men and women (52.3 and 47.7%), were generally white, non-Hispanic and the majority were less than age 35 (54.5%) with a mean age of 34.1 (range 16–71). Fifty-six percent of cases had filed for workers' compensation (Table 3). For those that filed for workers' compensation, 46.2% of the claims were approved. Most individuals had been treated in the emergency department for their asthma (79.3%); 11 had been treated once, 2 three times, 1 four times and 1 five times. Approximately one-third (34.8%) had been hospitalized; five had been hospitalized once, one three times, one four times, and one five times.

Table 1. Type, number and percentage of confirmed pool asthma cases by state.

	California No. (%)	Michigan No. (%)	New Jersey No. (%)	Total No. (%)
Work-aggravated	5 (29.4)	6 (40.0)	3 (25.0)	14 (31.8)
New onset	7 (41.2)	9 (60.0)	7 (58.4)	23 (52.2)
RADS	4 (23.5)	5 (33.3)	5 (41.7)	14 (31.8)
Sensitization/chronic irritation	3 (17.7)	4 (26.7)	2 (16.7)	9 (20.4)
Unable to classify	5 (29.4)	0 (–)	2 (16.7)	7 (15.9)
Total	17	15	12	44

Table 2. Demographics of confirmed pool asthma cases by state.

	California No. (%)	Michigan No. (%)	New Jersey No. (%)	Total No. (%)
Gender				
Men	8 (47.1)	9 (60.0)	6 (50.0)	23 (52.3)
Women	9 (52.9)	6 (40.0)	6 (50.0)	21 (47.7)
Age				
<21	0 (–)	4 (26.7)	3 (16.7)	7 (15.9)
21–34	7 (41.2)	7 (46.7)	4 (33.3)	18 (40.9)
35–49	7 (41.2)	1 (6.7)	3 (25.0)	11 (25.0)
≥50	3 (17.7)	3 (20.0)	2 (16.7)	8 (18.2)
Race (missing data on 11 cases)				
White	6 (75.0)	13 (92.9)	9 (81.8)	28 (84.8)
Other	2 (25.0)	1 (7.1)	2 (18.2)	5 (15.2)
Ethnicity (missing data on 16 cases)				
Hispanic	3 (42.9)	0 (–)	1 (14.3)	4 (14.3)
Not Hispanic	4 (57.1)	14 (100)	6 (85.7)	24 (85.7)

Table 3. Workers' compensation filing and award status of confirmed pool.

	California No. (%)	Michigan No. (%)	New Jersey No. (%)	Total No. (%)
Filed (missing data on 17 cases)				
Yes	4 (66.7)	8 (57.1)	3 (42.9)	15 (55.6)
No	2 (33.3)	6 (42.9)	4 (57.1)	12 (44.4)
Status (missing data on two cases)				
Awarded	2 (50.0)	4 (50.0)	0 (0.0)	6 (46.2)
Denied	2 (50.0)	2 (25.0)	0 (0.0)	4 (30.8)
Pending	0 (–)	2 (25.0)	1 (100)	3 (23.0)

Table 4. Data on medical history of confirmed pool asthma cases by state.

	California No. (%)	Michigan No. (%)	New Jersey No. (%)	Total No. (%)
Emergency department visits (missing data on 21 cases)				
Yes	5 (62.5)	11 (78.6)	7 (100.0)	23 (79.3)
No	3 (37.5)	3 (21.4)	0 (–)	6 (20.7)
Hospitalized (missing data on 21 cases)				
Yes	2 (25.0)	6 (42.9)	2 (66.7)	10 (40.0)
No	6 (75.0)	8 (57.1)	1 (100.0)	15 (60.0)
Cigarette smoking (missing data on 21 cases)				
Current	0 (–)	5 (35.7)	0 (–)	5 (21.7)
Ex	3 (37.5)	4 (28.6)	0 (–)	7 (30.4)
Never	5 (62.5)	5 (35.7)	1 (100.0)	11 (47.8)

Table 5. Industry and occupation of confirmed pool asthma cases by state.

	California No. (%)	Michigan No. (%)	New Jersey No. (%)	Total No. (%)
Occupation (missing data on one case)				
Maintenance	8 (50.0)	5 (33.3)	2 (16.7)	15 (34.9)
Lifeguard	1 (6.3)	6 (40.0)	6 (50.0)	13 (30.2)
Manager/clerk	2 (12.5)	3 (20.0)	3 (25.0)	8 (18.6)
Cleaner	2 (12.5)	1 (6.7)	1 (18.3)	4 (9.3)
Medical/massage	2 (12.5)	0 (–)	0 (–)	2 (4.7)
Coach	1 (6.3)	0 (–)	0 (–)	1 (2.3)
Industry (missing data on two cases)				
Pool/water park	6 (35.3)	9 (60.0)	5 (45.5)	20 (47.6)
Hotel	2 (11.8)	3 (20.0)	1 (9.1)	6 (14.3)
Wholesale trade/service	3 (17.6)	0 (–)	4 (36.4)	7 (16.7)
Apartment/condo	1 (5.9)	3 (13.3)	0 (–)	4 (9.5)
Other (high school, junior college, Hospital, beauty salon, religious, Health and welfare fund)	5 (29.4)	0 (–)	1 (9.1)	5 (11.9)

Over half (51.7%) had smoked cigarettes and 21.7% were still smoking (Table 4). Table 5 shows the occupations and industries where the individuals worked. Maintenance occupations, which included maintaining the chlorine content of the water, were the most frequent jobs (34.1%), and lifeguards (31.7%) were the second most common occupation. Working at a pool or water park was the most common industry (47.6%). The water facility was identified as: indoor for 10 of the 17 (59%) cases, outdoor for 5 of the 17 (29%) cases and insufficient information to determine for 2 of the 17 (12%) cases in CA; 7 of the 15 (47%) cases were indoor, 6 of the 15 (40%) cases were outdoor and 2 of the 15 (13%) cases were both in MI; 7 of the 12 (58%) cases were indoor, 3 of the 12 (25%) cases were outdoor and 2 of the 12 (17%) cases were both in NJ. Even though a person worked at an outdoor pool, exposure was noted for these individuals to have occurred while mixing/handling chemicals or in a pump/mechanical room in 13 of the 14 cases and was unknown in one case, who worked at outdoor facilities.

Case report from CA

A 24-year-old woman worked as a physical/occupational therapy aide at a large children's hospital. She reported that one day she was helping a burn patient into a hydrotherapy pool when she was overwhelmed with the strong smell of chlorine. Someone had forgotten to turn on the ventilation, allowing vapors to build up. She immediately had trouble breathing and fainted. She was a non-smoker with no previous history of breathing problems. She was sensitive to many other things, took two different asthma medications and continued to have breathing problems, eight years after the incident. She did not file a workers' compensation claim.

Case report from MI

A woman in her 20's developed cough within months and shortness of breath three years after beginning to work as a lifeguard at a water park located in a hotel. Her respiratory symptoms were worse at work. She had no prior history of respiratory problems before beginning this job. She was prescribed albuterol and a steroid inhaler for the shortness of breath. Symptoms occurred while just being in the water park area. She was treated in the emergency department once for her respiratory problems. She did not perform any maintenance activities or have any responsibility to add or check chlorine levels. She stopped working at the water park when her shortness of breath began. A year later, her symptoms were less and she had stopped using the steroid inhaler. She swam recreationally once per week after stopping work as a lifeguard and used albuterol prior to swimming. She had smoked one cigarette/day for one year, two years before her shortness of breath began. She has a sister with asthma and a prior history of allergies to cats and rabbits. Beginning at the age of 16 years she began working as a lifeguard at indoor swimming pools and was also working as a lifeguard at an indoor college pool when her coughing symptoms began, but was no longer working at the college pool when her shortness of breath began.

An enforcement inspection was conducted by an industrial hygienist from the MI Occupational Safety and Health Administration (OSHA) at the indoor water park located in the hotel where the case worked. No detectable levels of chlorine were found on five separate grab air samples. Sampling was not performed for chloramines since there is no enforceable standard. The number of air exchanges in different parts of the water park ranged from 3.7 to 13.7. This is in comparison to the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) recommendation of 4–8 air exchanges per hour [18]. Fourteen fellow workers were interviewed. Five were bothered at work by daily or weekly symptoms of shortness of breath, chest tightness or wheezing. Six were bothered at work by daily or weekly nasal symptoms, and five were bothered at work by daily or weekly ocular symptoms. The company was cited for not maintaining a log to record injuries and illnesses, lack of a hazard communication program, lack of an assessment and training on personal protective equipment and lack of an eyewash flushing station in the chlorine tank area. There were no monetary penalties.

Case report from NJ

A 19-year-old female lifeguard began experiencing respiratory symptoms within two years of starting her job at a Fitness and Wellness Center in NJ. Her job tasks included checking the chlorine and pH levels of the pool every hour. If the levels needed adjustment, she would manually apply, in half-cup increments, a chlorine-based disinfectant into the pool. Occasionally as needed, she also used a chlorine-based cleaner to clean the pool deck. She had a history of asthma. On one occasion, she had shortness of breath, chest tightness and wheezing during manual application of chlorine and was taken to the emergency room where she was diagnosed with acute asthma and treated with albuterol and methylprednisolone. As a result, she missed several days of work before returning to her job.

A walk-through survey of the pool area and equipment room and employee interviews at the Fitness and Wellness Center were conducted by the NJ Department of Health (NJDOH). The Fitness and Wellness Center was a 55 000 square foot facility that included a three-pool aquatic center. The aquatic center had an enclosed ventilation system with an automatic maintenance system, which was inspected and maintained regularly by a private contractor. Each pool had its own chlorinator and a separate exhaust system to the roof. Two other pool employees, another lifeguard and a swim instructor were interviewed during the site visit. The lifeguard complained of occasional headaches related to chlorine exposure when in the pool area. Job-specific training, including health hazard training on the chemicals, was provided to the lifeguards who were responsible for checking and maintaining the chlorine and pH levels in the pool. The Fitness and Wellness Center also required the lifeguards to use eye protection and gloves during this daily pool maintenance. The equipment room housed the more frequently used pool chemicals, including some chlorine-based liquids (<15%) and powder. Other chemicals used for annual pool maintenance were stored in a separate closet. After the site visit, the NJDOH issued a report to the Fitness and Wellness Center recommending both a written Respiratory Protection (OSHA 29CFR 1910.134) and Hazard Communication (OSHA 29 CFR 1910.1200) program be implemented. Recommendations included medical evaluations, pre-placement and periodic to ensure employees were not experiencing adverse health effects. Based on the Department's recommendation, lifeguards no longer manually add chlorine to the pool, but they were still responsible for checking the daily maintenance of the pool chlorine and pH levels. The manual addition of chlorine was now the responsibility of the Aquatic Director, but lifeguards were still required to manually add chlorine if the Aquatic Director was not available. The Aquatic Director continued to be in charge of adding chemicals during annual heavy cleanings and in cases of significant changes in chemical levels.

Discussion

Asthma associated with work at swimming pools, hydrotherapy spas and water parks was identified in 0.3% (17/6415) of the confirmed WRA cases in CA over a 19-year period and 0.5% (15/2943) and 1.6% (12/768) of the confirmed WRA cases in MI and NJ, respectively, over a 22-year period. The types of jobs that people performed varied. Maintenance activity that involved regulation of chlorine disinfectant levels was the most common occupation (34.9%) identified. Confirmed cases occurred among individuals who were within the pool area throughout the day (i.e. lifeguards (30.2%)) as well as those with intermittent exposure such as cleaning crews or management staff (Table 5). Industries where cases had worked varied because pools could be free standing, located at hotels, apartments or were included with ''other organizations'' (i.e. schools; Table 5). The most common types of WRA identified were work-aggravated asthma (31.8%) and RADS from an acute exposure (31.8%). New-onset asthma from exposure to either a sensitizer or irritant without acute exposure, non RADS, occurred in 20.4% of individuals (Table 1).

How does the WRA surveillance data from CA, MI, and NJ contribute to the literature on the effect of chlorinated swimming pools on respiratory health? The fact that a third of the cases had aggravation of their previous asthma suggests that, by extension, swimming in chlorinated pools may not always be an appropriate therapeutic intervention for asthma patients and that healthcare providers should consider swimming pools as a possible asthma trigger among their patients with asthma. Six previous cross-sectional studies of swimming pool personnel were identified and are consistent with our finding of aggravation of pre-existing asthma. These studies have been conducted in France [11], Italy [12], the Netherlands [13], Sweden [14], Switzerland [15] and the United States [16]. All of these studies have shown increased ocular and upper respiratory symptoms, and all but the French and Swiss studies [11,15] found increased lower respiratory symptoms in individuals who work at pools. Some studies found a correlation between symptoms and exposure levels of trichloramine [12–14]. None of these cross-sectional studies performed peak flow or spirometric measures in association with work, nor did they identify whether individuals with pre-existing asthma had more symptoms after beginning work in a pool setting in comparison to before working at a pool.

Acute exposure to chlorine and other disinfectants used in pool areas is known to be associated with the development of RADS, and it is not surprising to identify that 14 of 44 (31.6%) of cases were RADS in a population that is required to handle and mix these substances. Engineering controls, labeling, training and attention to work practices are important to minimize these occurrences. These cases of RADS have less relevance for recreational swimmers who would not be involved in handling these materials, although there has been one incident reported from India where a chlorine leak in a public bathing pool at a temple caused respiratory symptoms in 64 bathers of whom 12 required hospitalization and three developed RADS [19].

Finally, we identified nine confirmed cases of new-onset WRA that were not RADS, which could have involved an immunological or irritant-based mechanism, although we cannot exclude the possibility that these individuals did not coincidentally develop adult onset-asthma while they were working in a pool environment and then had their asthma aggravated rather than caused by their work [20]. These cases are the most relevant to the ''pool chlorine hypothesis'' that states that the increased occurrence of asthma is associated with increased use of chlorinated swimming pools and repeated exposures to chlorine-based by-products in these areas [1]. In the report from England, two lifeguards and a swimming instructor developed occupational asthma and tested positive to specific antigen challenge testing [10]. The swimming instructor had a positive peak flow test in relation to work, and a positive-specific antigen challenge test to trichloramine with an early and late response, but she had a negative response to a specific antigen challenge test with chlorine. The second case had a positive peak flow test in relationship to her work as a lifeguard, and a positive early response to a specific antigen challenge with trichloramine, but a negative result with challenge to chlorine. The third individual was a lifeguard who was unable to complete peak flow testing because he became too breathless in the pool area. He had a positive-specific antigen challenge test to trichloramine. The cases presented in this study did not have the same level of documentation as the English report, but the presumed etiologic agents of exposure in these cases were chloramines.

There are limitations to our data. Reporting of WRA, although mandated in all three states, is incomplete and cases reported may not be representative of all work-related cases. MI has previously estimated that 53–87% of WRA cases are not reported to their system [21]. The confirmed cases in our surveillance systems did not have specific antigen challenge testing nor breathing or other physiological testing such as measurement of nasal eosinophils to confirm the temporal association of symptoms with work in a pool to confirm the cause of the patient's asthma. This may have led to the over diagnosis of cases because history is known to be sensitive but not specific [22]. The confirmation process used included a history of when the patients' asthma began and the temporal relationship of the patient's symptoms with work. The confirmation process we used reflects the standard of care in the United States for diagnosing WRA where specific inhalation challenge testing is not available for testing chemical exposures and physicians rarely do breathing tests in relationship to work. This limitation of probable over diagnosis of cases is counterbalanced by under diagnosis of WRA by physicians and the incomplete reporting of cases to the surveillance systems in the three states, which would lead to under diagnosis. A third important limitation is the absence of air measurements for chloramines at the work locations where the cases occurred. Such measurements are not performed by OSHA or employers. We presumed that chloramines were the agents of concern based on the medical literature related to pool exposures but have no actual air measurements to support this assumption.

OSHA has a workplace standard of one part per million for chlorine exposure in an eight-hour day, but no standard for any of the chloramine compounds. The World Health Organization has recommended a standard of 0.5 mg/m^3 for trichloramine, based on the studies showing an association between an increasing prevalence of eye, nasal and respiratory irritation, along with increasing airborne concentrations of trichloramine. A study of 30 indoor pools in Switzerland recommended allowable levels of trichloramine be no higher than 0.2–0.3 mg/m^3 [15]. Based on the occurrence of irritant symptoms of the eyes and respiratory system experienced by users and spectators at indoor pools, it appears that better controls for respiratory irritants are needed.

Controlling DBP formation is challenging. It is common practice to attempt to reduce nitrogen infusion so as to reduce chloramine formation by posting signs requiring swimmers/bathers to shower before entering the pool and advising swimmers not to urinate in the pool. Keuten et al. (2012) reported a 60-second shower was optimal for removal of pollutants on the skin surface prior to swimmers entering the pool [23]. Showering will reduce urea concentrations in the pool, but urea from skin accounts for only 5% of the total nitrogen input. Having bathers adhere to rules not to urinate in the pool would reduce the nitrogen load by 31%. Since 64% of the urea contribution in swimming pools comes from sweat –simply modifying swimmer/bather hygiene will not eliminate trichloramine production [24]. Other means of controlling DBP production include the control of pool-water pH, use of non-chlorine based disinfectants, exposure of water to UV lights, carbon filtration and a shift toward salt-water systems. These methods have been utilized in recent years and require strict adherence to maintenance protocols but still may be unsuccessful in the control of appreciable concentrations of airborne DBPs [25–27].

ASHRAE develops and publishes consensus standards to guide the building technology industry. ANSI/ASHRAE Standard 62.1 – 2013 Ventilation for Acceptable Indoor Air Quality established the minimum outdoor air flow rates in many types of occupied buildings, including indoor pools [28]. While the standard did not establish ''maximum'' concentrations for indoor air contaminants typically found in buildings, it was designed to attempt to control them through dilution with outdoor air. However, the minimum ventilation rate given for swimming pools, 0.48 cubic feet per minute per square foot (of pool and deck), does not allow for humidity control. Nor does the ANSI/ASHRAE standard differentiate by type of facility, such as swimming pool, water park or hot water venues [28]. Finally the ANSI/ASHRAE standard does not differentiate between ''flat'' (i.e. still water) and ''agitated'' (i.e. water park) pools, thus limiting applicability of the standard in water park settings for control of indoor air contaminants such as trichloramine [28]. Water parks are a particular challenge due to the nature of the building construction, number of bathers and attractions such as spray features and waterslides that disturb the water surface, leading to increased airborne DBPs [29]. Similarly, hot water venues, such as those with hot tubs or heated spas, release more DBPs into the air per square foot than any other aquatic venue due to increased evaporation and increased introduction of waste.

The Centers for Disease Control and Prevention, working with public health and industry representatives across the United States, is developing a Model Aquatic Health Code (MAHC). When it is released, it will serve as a guideline for ''local and state agencies needing to update or implement swimming pool and spa code, rules, regulations, guidance, law or standards governing the design, construction, operation, and maintenance of swimming pools, spas, hot tubs, and other treated or disinfected aquatic facilities'' [30]. Importantly, the proposed MAHC Ventilation Code section takes into consideration control of DBPs [30]. An early version of the proposed MAHC ventilation requirements was designed to take aquatic venue type as well as occupant density into account for calculating outdoor airflow rates [29]. The earlier version, using ASHRAE 62.1 [28] as a starting point, outlined additional fresh air requirements for flat water and even more fresh air requirements for agitated water (e.g. water parks) and hot water. Peak occupant densities were also factored into the air requirement calculation. However, the MAHC Steering Committee received a significant number of negative comments about the increased equipment and operation costs and, in the current MAHC draft, decided to defer to the ASHRAE 62.1-2013 minimum outdoor air requirement of 0.48 cfm/ft^2 with no enhancements for venue type or occupant density. The MAHC language with the higher airflow rates has been moved to an appendix in the proposed MAHC Ventilation Code [31].

Another approach to contaminant control would be the use of a local exhaust ventilation strategy that takes into consideration the process of trichloramine formation and volatilization. Formation of trichloramine – the most volatile of the chloramines – occurs at or just above the pool surface, and if enough nitrogen is present in the water, forms independent of the pH of the water [26,32,33]. This ''trichloramine bubble'' remains suspended above the surface of the water and in the breathing zone of swimmers until dispersion or active removal occurs with the aid of forced air ventilation systems. The highest concentration(s) of DBPs are expected to be at the surface of the water where agitation and splashing/mist production occurs. From the water surface, dispersion continues and is influenced by sources of natural and dilution ventilation. Unfortunately, at present, ventilation systems for most indoor pools and water parks are not designed or intended for contaminant removal at the source, since exhaust vents are typically suspended from the ceiling and within walls well above and away from the contaminant source. Recently, recommendations have been published that propose a ''source capture and exhaust strategy'' for trichloramine (and other DBP) removal that is similar to ventilation systems found in industrial settings designed to capture and remove airborne contaminants at the source [34]. The recommendation describes a ventilation system in which strategically placed supply and return vents move the surface trichloramine ''bubble'' horizontally across the pool toward a capture hood at the surface of the water that then exhausts the DBPs to the outside air, out of the air recirculation system so that there is no recirculation [34]. If done effectively, DBPs would be captured or removed *prior* to accumulation at the surface or diffusion into the indoor pool space. As removal would occur essentially at the point of generation, exposures would be expected to be dramatically reduced for swimmers, workers and spectators. We are not aware that this proposed system has been installed; however – a simulation system has been constructed, demonstrating control of test vapors [27]. The proposed MAHC also appears to recognize the benefit of this type of ventilation system design in the section covering performance requirements for air handling systems. It specifies that both new construction and retrofits of existing structures that return air intakes be placed near aquatic venue surfaces to remove DBP contaminated air and that the air handling system be designed to create airflow across the water for removal of DBPs [31]. One drawback for this type of ventilation system is that it would have limited utility for agitated water venues such as water parks or pools with spray features. Temporary fixes that utilize portable air handling units have been developed for placement around the pool deck allowing for directional movement of air and DBP capture/exhaust.

Consideration should be given to the development of an OSHA standard for air levels of trichloramine and the other DBPs. Such a standard would be useful for pool and water park owners to be able to evaluate the effectiveness of existing control strategies. Any proposed OSHA standards must take into account levels that are relevant to asthma causation. Adoption of the enhanced MAHC ventilation requirements, perhaps, where possible, implemented with an effective ''source capture and exhaust strategy'', would be a vital step toward controlling DBPs and should be implemented in concert with education and enforcement of rules regarding showering and urinating, as well as with maintaining strict adherence to existing pool facility operation and preventative maintenance protocols. In the absence of remodeling existing ventilation and disinfection systems, the latter control methods – education, rule enforcement and proper pool operation – will have a limited role in improving water/air quality and thus reducing exposure to potentially harmful DBPs.

Clinicians need to be aware of the potential adverse effect that indoor swimming pools and water parks may have on both causing the onset of new asthma and aggravating pre-existing asthma. Attention to swimming pools and water parks as potential triggers for asthma may, for selected patients, be an important factor in asthma management. The American College of Chest Physicians has developed a consensus statement for the diagnosis and management of WRA that clinicians can refer to when evaluating adult patients with asthma [35].

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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