Prevalence and characteristics of asthma in the aquatic disciplines

Margo Mountjoy, MD, CCFP, FCFP, FACSM, Dip Sport Med,[a,b,c] Ken Fitch, MBBS, MD, FACRM, FACSP, FACSM,[d] Louis-Philippe Boulet, MD, FCCP, FRCPC,[e] Valerie Bougault, PhD,[f] Willem van Mechelen, MD, PhD, FACSM, FECSS,[g] and Evert Verhagen, PhD, FECSS[g,h] *Hamilton, Ontario, and Quebec City, Quebec, Canada, Lausanne, Switzerland, Crawley and Ballarat, Australia, Lille, France, and Amsterdam, The Netherlands*

Background: Despite the health benefits of swimming as a form of exercise, evidence exists that both the swimming pool environment and endurance exercise are etiologic factors in the development of asthma. The prevalence of asthma in swimmers is high compared with that in participants in other Olympic sport disciplines. There are no publications comparing the prevalence of asthma in the 5 aquatic disciplines.

Objective: The purpose of this study is to examine and compare the prevalence of asthma in the aquatic disciplines and in contrast with other Olympic sports.

Methods: Therapeutic Use Exemptions containing objective evidence of athlete asthma/airway hyperresponsiveness (AHR) were collected for all aquatic athletes participating in swimming, diving, synchronized swimming, water polo, and open water swimming for major events during the time period from 2004-2009. The prevalence of asthma/AHR in the aquatic disciplines was analyzed for statistical significance (with 95% CIs) and also compared with that in other Olympic sports.

Results: Swimming had the highest prevalence of asthma/AHR in comparison with the other aquatic disciplines. The endurance aquatic disciplines have a higher prevalence of asthma/AHR than the aquatic nonendurance disciplines. Asthma/AHR is more common in Oceania, Europe, and North America than in Asia, Africa, and South America. In comparison with other Olympic sports, swimming, synchronized swimming, and open water swimming were among the top 5 sports for asthma/AHR prevalence.

Conclusion: Asthma/AHR in the endurance aquatic disciplines is common at the elite level and has a varied geographic distribution. Findings from this study demonstrate the need for development of aquatic discipline–specific prevention, screening, and treatment regimens. (J Allergy Clin Immunol 2015;136:588-94.)

Key words: *Asthma, exercise-induced bronchoconstriction, airway hyperresponsiveness, swimming, diving, synchronized swimming, water polo, Olympic Games, endurance training*

Swimming is a common form of exercise enjoyed around the world from the recreational to the elite level. Swimming is practiced by all age groups and has been prescribed as a recommended form of exercise for asthmatic patients for many years by respiratory and family physicians because swimming was thought to be less likely to trigger asthma symptoms[1] and is considered a safe and healthy activity.[2,3] However, evidence exists that implicates the aquatic environment itself as a cause of asthma/airway hyperresponsiveness (AHR) through exposure of the airways to irritants, such as pool chloramines.[4]

Asthma is diagnosed on clinical presentation of a constellation of recurrent symptoms, including cough, dyspnea, wheezing, chest tightness, and phlegm production. AHR is a feature of asthma in which the airways respond too much and too easily to stimuli.[5] Exercise-induced bronchoconstriction refers to the acute narrowing of the airway resulting from exercise. It often occurs in dry/cold sporting environments, such as ice-skating rink environments with poor air quality and chlorine-disinfected swimming pools. Exercised-induced bronchoconstriction can be of variable severity and can affect an athlete's performance in addition to his or her health.[5]

The presence of asthma in elite swimmers seems multifactorial. For the competitive swimmer, high ventilation rates and volumes during training are implicated in the development of asthma through airway remodeling caused by chronic inflammation, epithelial damage, or both.[6] Furthermore, exposure to the indoor aquatic environment might pose an increased risk of AHR through inhalation of chloramines, a byproduct of chlorine.[7-10] Inhaled chloramines are believed to induce disruption of the epithelial lining of the lung, promoting allergen

From [a]the Department of Family Medicine, Michael G. DeGroote School of Medicine, McMaster University, Hamilton; [b]the International Olympic Committee (IOC), Lausanne; [c]Fédération Internationale de Natation (FINA), Lausanne; [d]the School of Sports Science, Exercise and Health, Faculty of Life Sciences, University of Western Australia, Crawley; [e]the Quebec Heart and Lung Institute, Laval University, Quebec City; [f]the Faculty of Sport Sciences, University of Lille; [g]the Department of Public and Occupational Health, EMGO+ Institute for Health and Care Research, VU University Medical Center, Amsterdam; and [h]the Australian Centre for Research into Injury in Sport and its Prevention (ACRISP), Federation University Australia, SMB Campus, Ballarat.

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Corresponding author: Margo Mountjoy, MD, CCFP, FCFP, FACSM, Dip Sport Med, FINA c/o Michael G. DeGroote School of Medicine, McMaster University Waterloo Regional Campus, 10-B Victoria St South, Kitchener, Ontario N2G 1C5, Canada. E-mail: mmsportdoc@mcmaster.ca.

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Abbreviations used

AHR: Airway hyperresponsiveness
BPT: Bronchial provocation test
FINA: Federation Internationale de Natation
IBA: Inhaled β_2-agonist
IOC: International Olympic Committee
TUE: Therapeutic Use Exemption
WADA: World Anti-Doping Agency

sensitization.[11] Allergen exposure in sensitized subjects results in release of inflammatory mediators and sensitization of airway smooth muscle, leading to development of airway remodeling.[12] Airway remodeling can also be seen in swimmers without evidence of AHR and is thought to be the result of fibrogenesis induced by prolonged training in a chlorinated environment.[13]

The ventilatory demands of endurance sports require the athlete to breathe at a high flow for repeated prolonged periods of time over an extended athletic career. Such ventilatory rates and volumes result in cooling and dehydration of the airway mucosa, resulting in airway smooth muscle contraction.[14] Furthermore, hyperpnea-induced mechanical stress to the airways[15] might also constitute an insult to the epithelium and can lead to airway remodeling and subsequent changes in the contractile properties of bronchial smooth muscle.[16] In addition, during daily life or if training outdoors with a high ventilatory rate, the aquatic athlete can be exposed to other inhaled particulate matter, which can also negatively affect airway integrity.[17]

Because of variations in the requirements for elite performance between the aquatic disciplines, training regimens have evolved to be discipline specific, with significant differences in physiologic demands. These different types of training exposures might translate theoretically into differences in respiratory response to the training stimuli. Although there are many studies published on the diagnosis and treatment of asthma in swimmers,[6,13,18-26] to our knowledge, there are no publications studying asthma in the aquatic disciplines of synchronized swimming, open water swimming, and diving, and there is only one study on adolescent water polo players.[27] Understanding the health risks of the practice of aquatic sports is necessary to guide team physicians in their screening programs to optimize health and performance at the elite level, as well as the recreational level. Knowledge about the prevalence of asthma in the aquatic disciplines will be helpful in determining health promotion priorities for Federation Internationale de Natation (FINA).

It is hypothesized that asthma/AHR is common in elite swimming and in other endurance aquatic disciplines. In addition, it is hypothesized that aquatic sports will have a higher prevalence of asthma/AHR than other Olympic sports and that geographic variations in prevalence will be evident at the elite level. A unique large database containing objective evidence of asthma/AHR will be analyzed to confirm the hypotheses and to formulate recommendations for future research. Therefore the purpose of this study was (1) to assess the overall prevalence of asthma/AHR in aquatic sports, (2) to assess differences in the prevalence in asthma/AHR between the aquatic disciplines, (3) to compare the prevalence of aquatic asthma/AHR by geographic continent, (4) to compare the overall prevalence of asthma/AHR between aquatic and nonaquatic athletes at the Olympic Games, and (5) to compare the prevalence of endurance versus nonendurance sport disciplines.

METHODS

Determination of the study period

We studied historical data derived from Therapeutic Use Exemptions (TUEs) containing the objective diagnoses of AHR of all competing aquatic athletes at the 2005, 2007, and 2009 FINA World Championships and the 2004 and 2008 Olympic Games. Commencing in 2002, the International Olympic Committee (IOC) instituted legislation requiring all athletes competing at the Olympic Games and using inhaled β_2-agonists to provide objective proof of AHR.[28,29] In 2004, all inhaled β_2-agonists, including salbutamol, salmeterol, formoterol, and terbutaline, were placed on the World Anti-Doping Agency (WADA) Prohibited List requiring pre-event medical demonstration of asthma/AHR to approve a TUE. Objective tests to establish a diagnosis of asthma/AHR included demonstration of reversible airway obstruction obtained based on a bronchodilator response (significant increase in FEV_1), a positive bronchial provocation test (BPT) response, or both (Table I).[30] In 2010, the WADA removed the requirement for a TUE for salbutamol and salmeterol because urinary threshold levels for therapeutic use were established.[31] Consequently, for the major aquatic competition events during the time period of 2004-2009, TUEs for AHR are available for all participating athletes.

Definition of asthma

We considered that an athlete had asthma/AHR if he or she had an objective demonstration of airway obstruction based on spirometric or BPT result, as outlined in Table I.

Acquisition and processing of nominator and denominator data

TUEs were obtained for the Olympic Games in 2004 and 2008 through the Chairman of the IOC TUE Committee (KF). The TUEs for the 2005, 2007, and 2009 FINA World Championships were obtained from the FINA anti-doping archives. There was no major international aquatic competitive event in 2006. The Olympic TUE data were processed to isolate the TUEs for each of the aquatic disciplines of swimming, synchronized swimming, diving, water polo, and open water swimming. All TUEs from the Olympic database and the FINA database were checked against the event participation database[32,33] to confirm that the athlete with the granted TUE actually competed in the respective competitive event. TUEs for athletes who did not compete during the target competitive event were removed from the database.

TUEs granted by FINA had a duration of 4 years. As such, athlete participation in major competitive events was confirmed for the 4 years after the granting date of the TUE. For example, if an athlete was granted a TUE for asthma/AHR in 2005 and competed in 2007 and 2008, the athlete was added to the database for the subsequent years to be counted in prevalence analysis. TUEs granted by the IOC were valid for 4 years and were also considered valid for the subsequent Olympic Games. Therefore athletes with TUEs granted by the IOC in 2004 were reviewed for participation in subsequent FINA World Championships (2005 and 2007) and for participation in the 2008 Olympic Games. Athletes with TUEs granted by the IOC in 2008 were reviewed for participation in the FINA World Championships in 2009. Those athletes competing in subsequent events with a valid TUE were added to the respective database for prevalence calculations. Prevalence was defined as the proportion of athletes at the target event competing with a TUE for asthma/AHR.

The total number of competing aquatic athletes in the FINA events was determined from the respective discipline-specific results page of the Omega Web site.[32] The total number of competing aquatic athletes for each discipline in the Olympic Games was obtained from the Olympic Web site.[33]

The prevalence of asthma by geographic region for each major event was assessed. All participating athletes' countries of origin were obtained from the official results database for the aquatic disciplines for each target event.[32,33]

TABLE I. Objective criteria required for athletes' use of inhaled β_2-agonists

Objective test	Criteria to be met for permission to use β_2-agonists
Spirometry	
Bronchodilator test	≥12% Increase in FEV_1 over baseline after inhalation of an inhaled β_2-agonist
BPTs	
Eucapnic voluntary hyperpnea	≥10% Decrease in FEV_1
Methacholine aerosol challenge	≥20% Decrease in FEV_1-PC_{20} <4 mg/mL (steroid naive) or if taking inhaled glucocorticoids >1 mo with PD_{20} ≤1600 μg or PC_{20} ≤16.0 mg/mL
Hypertonic saline aerosol challenge	15% Decrease in FEV_1 after inhaling ≤22.5 mL 4.5% saline
Exercise challenge tests (field or laboratory)	≥10% Decrease in FEV_1
Histamine challenge	≥20% Decrease in FEV_1 at a histamine concentration ≤8 mg/mL during a graded test of 2 min
Dry powder mannitol challenge	15% Decrease in FEV_1 after inhaling ≤635 mg of mannitol

TABLE II. Classification of Olympic sports by endurance versus nonendurance

Endurance sports	Nonendurance sports
Swimming	Diving
Synchronized swimming	Badminton
Water polo	Judo
Open water swimming	Fencing
Triathlon	Sailing
Modern pentathlon	Equestrian
Cycling	Volleyball
Rowing	Gymnastics
Hockey	Boxing
Football	Tennis
Athletics	Shooting
Softball	Baseball
Handball	Wrestling
Canoeing	Basketball
	Table tennis
	Archery
	Taekwondo
	Weightlifting

These data were then categorized to their respective continents of Africa, Asia, Europe, North or South America, and Oceania. The TUE data for each aquatic discipline were also classified by continent by using the same procedure.

The prevalence of the nonaquatic Olympic sport disciplines was determined by extracting TUE files from the Olympic database and categorizing each file by sport. Total athlete participation at the Olympic Games in both 2004 and 2008 for each sport discipline was determined from the official results found on the Olympic Web site.[33]

Calculation of endurance versus nonendurance asthma prevalence comparisons required the classification of each of the aquatic disciplines as either endurance or nonendurance. Open water swimming, swimming, synchronized swimming, and water polo were determined to be endurance events based on the physiologic demands of these sports. Diving was classified as nonendurance. The Olympic nonaquatic sport disciplines were also classified as being either endurance or nonendurance based on unpublished WADA classification of doping risk for endurance sports (Table II; personal communication, Risk Assessment Working Group, WADA). The TUE data for both the aquatic and nonaquatic sport disciplines were also classified as endurance versus and nonendurance by using the same procedure.

Analyses

Data were processed in an Excel database. Discipline- and event-specific asthma/AHR prevalence rates and corresponding 95% CIs were calculated and compared as the number of athletes with a TUE divided by the total number of competing athletes.

RESULTS

A total of 1,811 (1,441 from FINA and 370 from the IOC) TUEs from the aquatic disciplines for the study period were processed. After removal of TUEs for athletes who did not compete at the target events in the study period, a total of 1,468 aquatic TUEs comprised the study sample. For the nonaquatic Olympic sports, 920 TUEs were included in the study. The source population of aquatic athletes participating in the major events between 2004 and 2009 totaled 9,343. The total number of athletes competing in the 2004 and 2008 Olympic Games equaled 18,515.

The comparative prevalence rates of asthma/AHR in the aquatic sports can be found in Fig 1. The prevalence of asthma/AHR in swimming in comparison with all of the other aquatic disciplines was significantly higher, except for a peak in both synchronized swimming and open water swimming at the 2008 Olympic Games with a prevalence of 22.12% (95% CI, 14% to 31%) and 26% (95% CI, 13% to 39%), respectively. There was no difference in asthma/AHR prevalence rates in relation to sex for any of the aquatic disciplines.

Comparison of the continental prevalence of asthma/AHR in the aquatic sports can be found in Fig 2. The prevalence of reported asthma/AHR in aquatic athletes from North America, Oceania, and Europe was significantly higher than in Asia for all target events. The African asthma/AHR prevalence data were significantly lower than in Oceania and Europe for all target events. Both Africa and South America had statistically significant lower prevalence rates than North America for all events, except for the 2004 Olympic Games. There were no statistical differences in the prevalence of asthma/AHR in aquatic athletes between Asia, Africa, and South America, except for the 2004 Olympic Games, where South America was higher. Likewise, there was no difference in the prevalence of asthma/AHR between Europe, Oceania, and North America, except for the 2008 Olympic Games and the 2009 FINA World Championships, where North America showed a significantly higher prevalence in comparison with Europe.

Fig 3 illustrates the prevalence of asthma/AHR for all Olympic sports during the 2004 and 2008 Olympic Games. Sport disciplines requiring aerobic endurance training have a higher prevalence of asthma/AHR than those sports whose physiologic

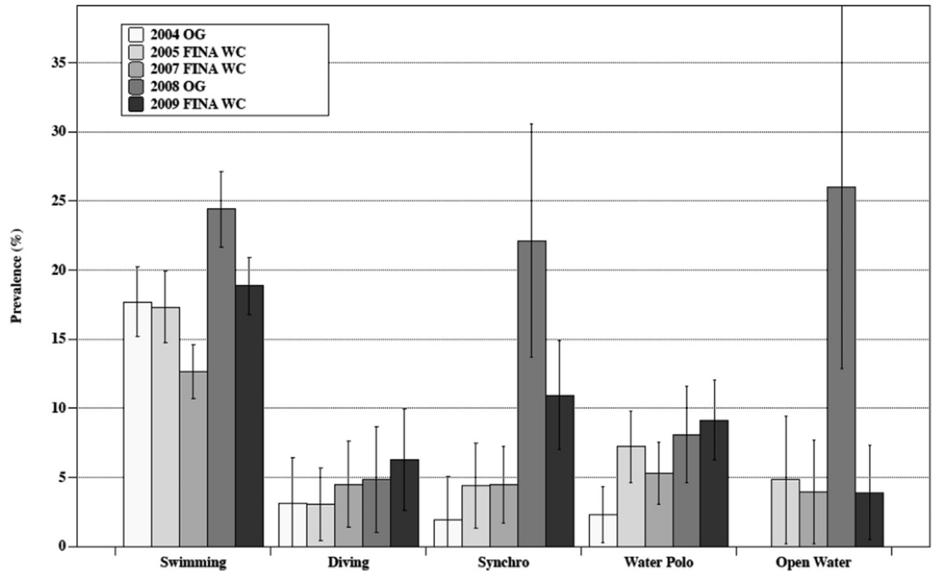

FIG 1. Prevalence of asthma in the aquatic disciplines for the 2004 and 2008 Olympic Games *(OG)* and the FINA World Championships *(WC)* in 2005, 2007, and 2009.

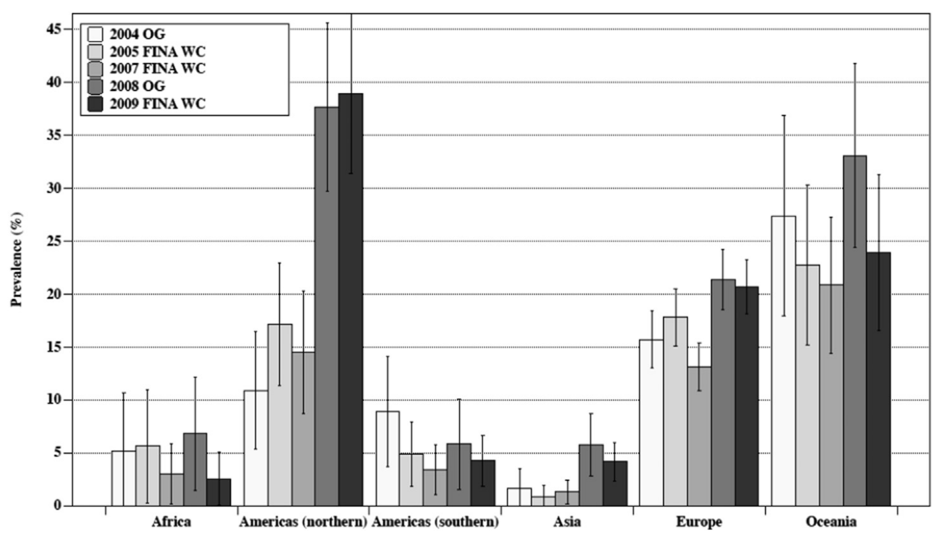

FIG 2. Prevalence of asthma in the Olympic sports of the 2004 and 2008 Olympic Games. *OG*, Olympic Games; *WC*, FINA World Championships.

demands are nonendurance in nature. When comparing the prevalence of asthma/AHR in the endurance versus nonendurance aquatic disciplines, the endurance disciplines were consistently higher for all of the target events in comparison with the nonendurance discipline of diving. Likewise, the endurance Olympic sports had a significantly higher prevalence of asthma/AHR than the nonendurance Olympic sports. The prevalence of asthma/AHR in the aquatic endurance disciplines was statistically higher than in the nonendurance Olympic sports (Fig 4).

DISCUSSION

This study is the first to report the comparison of asthma/AHR prevalence between the aquatic disciplines in the elite athlete population and in contrast with other Olympic sports. The predominant finding of a high prevalence of TUEs for inhaled β_2-agonists (IBAs) in swimming compared with the other aquatic disciplines is consistent with published data demonstrating a higher prevalence of asthma in swimmers than in the general population.[18,20,34] There is only one published study[27] on asthma prevalence in water polo, which showed no statistical difference between water polo, football, and basketball in adolescent athletes. However, asthma in this study was defined by a decrease in FEV_1 of greater than 10% after an exercise challenge involving running in a small sample size (n = 30), and as such, the prevalence is likely underestimated.[27] The high prevalence of asthma/AHR in swimming relative to the other aquatic disciplines points to an etiologic factor other than environmental exposure, such as training intensity, type, and/or duration. This finding underscores the necessity for further research to

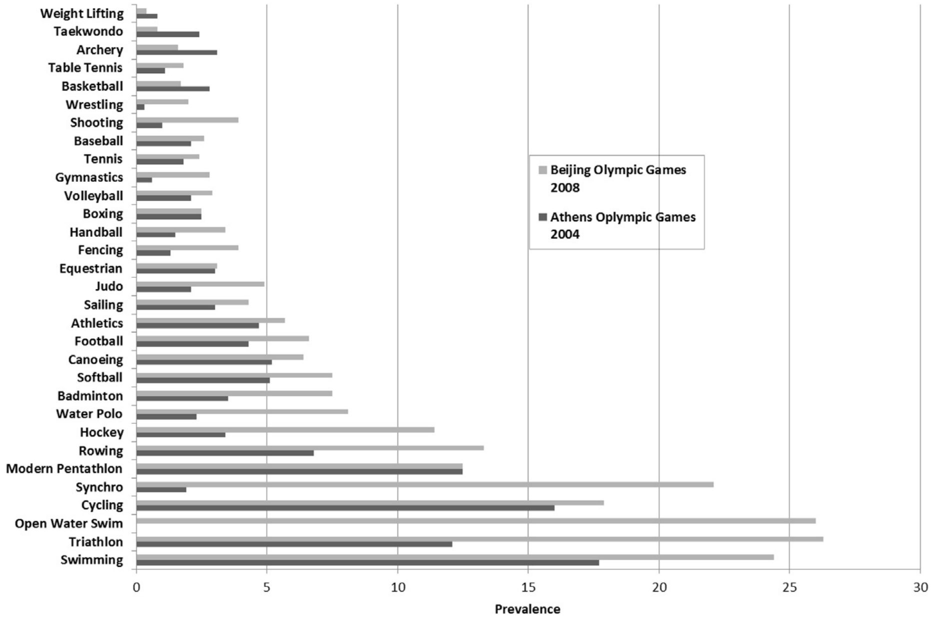

FIG 3. Comparison of the prevalence of asthma in the aquatic disciplines by continent for the 2004 and 2008 Olympic Games and the FINA World Championships in 2005, 2007, and 2009.

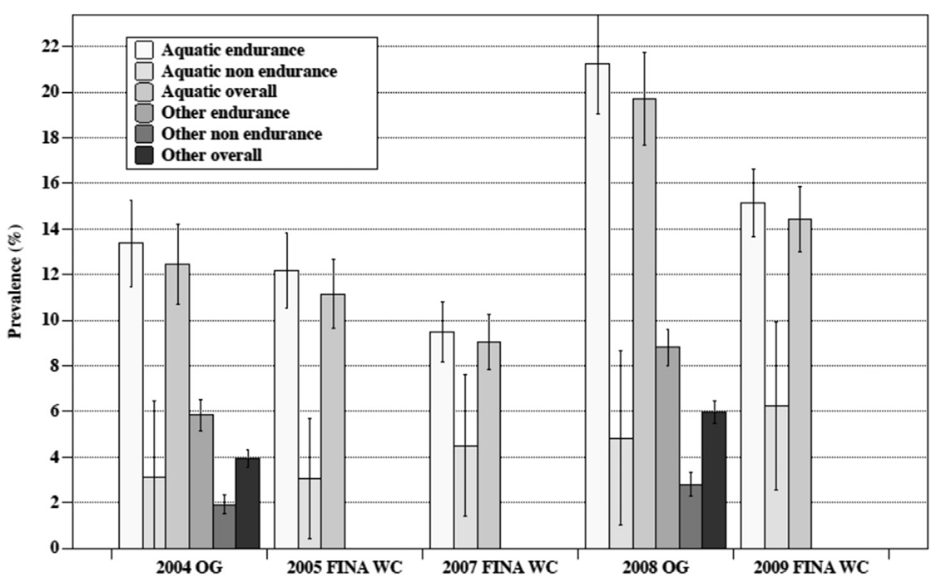

FIG 4. Comparison of the prevalence of asthma in endurance versus nonendurance aquatic and nonaquatic Olympic sports for the 2004 and 2008 Olympic Games and the FINA World Championships in 2005, 2007, and 2009.

determine the etiologic mechanism of asthma/AHR in swimming. A longitudinal study would be useful to ascertain the distinction between athletes with asthma who self-select to swimming and those who have asthma as a result of exposure to endurance-training practices. Although asthma is more common in women than in men in the general population, the lack of a sex difference in asthma prevalence in this elite athlete population is attributed to the fact that both sexes are equally exposed to the cause of asthma, namely endurance training and environmental irritants.

Using a retrospective design of TUE analysis does not provide information about the natural history of asthma/AHR in the elite aquatic disciplines. Given the high prevalence of asthma/AHR demonstrated in this study, the potential health burden in this population is important to ascertain. Knowledge of the long-term health repercussions for the aquatic athlete after retirement is scarce. A study by Bougault et al[6] demonstrated some reversibility in AHR after a 2-week or longer rest period. Helenius et al[35] studied 42 Finnish swimmers prospectively over 5 years, showing some reversibility. However, further study in this area is required.

The use of TUE data to diagnose asthma/AHR has inherent limitations and potential bias. TUE data might underrepresent the

actual prevalence for athletes who do not have access to respiratory diagnostic facilities or to sports physicians knowledgeable of the WADA TUE program. On the other hand, there are published data to suggest that TUE data might overestimate the diagnosis of asthma/AHR. Published data demonstrate that BPTs according to the WADA TUE criteria identified AHR in asymptomatic swimmers.[18,25,36,37] It is postulated that exercising in the warm, humid ambient environment of the swimming pool might mitigate the triggers of asthma symptoms.[37,38] Given the design of this current study, which evaluates a very large database of TUEs over an extended period of time on a worldwide scale in elite aquatics, these biases are likely not significant.

Although there are differences in the prevalence of asthma/AHR in different geographic locations in the general population globally because of environmental influences and varying medical awareness and practices, the findings of this study raise questions for the elite aquatic athlete that warrant further evaluation.[39] Is the lower prevalence in Asia and Africa due to a lack of access to diagnostic equipment, or does it represent a geographic variation in medical practice? Is there a racial genetic protection for asthma/AHR that correlates with athletic performance? Another explanation is that there might be geographic variations in pool environmental regulations for chlorination, thus resulting in geographic prevalence differences. A final postulate is that the lower prevalence of asthma/AHR in Africa might be due to the fact that Africa has a lower participation rate in elite aquatics (except for South Africa); however, this postulate is not applicable to Asia, which enjoys a high participation rate in elite swimming.

An interesting finding of this study is the increased prevalence of TUE applications during the 2008 Olympic Games in Beijing, China. This spike in prevalence was likely due to an increased awareness among the medical staff of the relatively high levels environmental air pollution in the region, prompting concern for extraneous environmental triggers for asthma, an increasing familiarity of the TUE process, or both. Why then does Asia have a relatively low TUE prevalence in comparison with other geographic regions when air quality is a concern in the region? Anti-doping rule violations for IBAs during this time period were rare, resulting in only 2 for terbutaline from France (2007 and 2009) and 2 for formoterol in 2009 from China and Australia, demonstrating that athletes were not being treated for asthma/AHR without valid TUEs.[40] Further study in these geographic regions is warranted to evaluate the cause of these findings.

Findings from this study demonstrating the high prevalence of asthma/AHR in endurance versus nonendurance sports are consistent with those of previously published studies showing that endurance training itself is an etiologic factor in the development of asthma.[6,30,41] This finding raises the question of whether prolonged endurance training leading to the development of asthma has a negative effect on performance. A study evaluating athlete performance with a TUE for IBAs in the 2000 Sydney Olympic Games showed that the 5.7% of athletes with a valid TUE for IBAs were responsible for winning 7.2% of the medals. Likewise, in a study of TUEs in the 2004 Athens Olympic Games, McKenzie and Fitch[42] demonstrated that 4.2% of all athletes with a TUE for IBAs won 5.4% of all individual medals. Fitch[29] looked specifically at swimming results in the 2008 Beijing Olympic Games and reported that the 19.3% of swimmers with a TUE for IBAs won 32.9% of all aquatic medals. Clearly, asthma/AHR in the elite swimmer does not have a negative effect on performance; indeed, this study demonstrates that athletes with TUEs for asthma/AHR perform better.

There are many possible theories for why athletes with asthma perform better than athletes without asthma. Is this phenomenon due to a longer training period, resulting in the development of asthma along with more efficient swimming skills? Does this represent a genetic predisposition for asthma and superior aquatic performance? This also raises the question of whether the use of IBA or inhaled corticosteroid therapy is performance enhancing. Kuipers et al,[43] Kinderman,[44] and Pluim et al[45] have shown that neither substance, when used in therapeutic doses, is performance enhancing. Could there be a perceived placebo effect of performance enhancement with IBAs? Couto et al[46] demonstrated that the prevalence of asthma/AHR declaration decreased by half when the mandatory objective measures required by WADA were implemented, suggesting that before the WADA TUE requirements, athletes were using IBAs without an accurate diagnosis of asthma/AHR, potentially for the falsely perceived performance benefit of the drugs. However, a study of asthma/AHR prevalence in the British swimming team showed the opposite, with an increase from 41% in the 2000 Sydney Games in contrast to 44% in the 2004 Athens Olympic Games.[47] Findings from this current study also showed an increase in the prevalence of asthma/AHR in the aquatics disciplines from the 2004 to the 2008 Olympic Games. Could the perceived performance advantage be the reason for the peak in asthma/AHR prevalence in the 2008 Beijing Olympic Games seen in swimming, synchronized swimming, and open water swimming? It is more likely that concerns about air quality in Beijing prompted team physicians to pursue TUE application even in asymptomatic athletes.

The outcomes of this study demonstrate the need for FINA to develop educational initiatives for aquatic team physicians addressing prevention, screening, and treatment of asthma in swimming. In addition, host medical services for aquatic competitions should plan to have rescue β_2-agonists available at all competition and training venues.

In conclusion, the key finding from this study is that swimming has a higher prevalence of asthma/AHR relative to the other aquatic disciplines. In addition, the data also support the hypothesis that elite endurance athletes have a higher prevalence of asthma/AHR than nonendurance athletes. Geographic variations in asthma/AHR prevalence in aquatic sports raise many questions requiring further investigation.

The high prevalence of asthma/AHR in swimmers in comparison with the other aquatic disciplines and Olympic sports underscores the need for FINA to develop strategies to prevent, identify, and treat asthma/AHR in this athletic population. Further research is required to better delineate the pathophysiologic mechanisms for the development of asthma/AHR in the aquatic athlete and the natural history of the disease after retirement to assess long-term health consequences for athletes who have asthma as a result of aquatic endurance training. Despite the increased risk of asthma in elite swimming, the physical, mental health, and lifestyle benefits of participation in the sport are numerous when compared with the health of the general population.[48] With attention to the findings and recommendations resulting from this study, healthy

participation in swimming at the elite level can be improved and enjoyed.

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Clinical implications: Analysis of prevalence data in the aquatic disciplines demonstrates the necessity to improve the air quality of the pool environment and to educate aquatic team physicians on asthma management.

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