*ERJ Express*. Published on January 14, 2010 as doi: 10.1183/09031936.00118009

# Infant swimming in chlorinated pools and the risks of bronchiolitis, asthma and allergy

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**Conflict of interest**: none of the authors has a conflict of interest to disclose

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**Running Title:** Bronchiolitis and infant swimming

**Key Words:** bronchiolitis, respiratory infection, swimming pool, infant swimming

**Abbreviations:** CPA, cumulative pool attendance; OR, odds ratio; RSV, respiratory syncytial virus

**Abstract**

**Introduction**

Recent studies suggest that swimming in chlorinated pools during infancy may increase the risks of lower respiratory tract infection.

**Objective**

To assess the influence of swimming in chlorinated pools on the risks of bronchiolitis and its late consequences.

**Methods**

We examined 430 children (47% of girls, mean age 5.7 years) in 30 kindergarten schools. Parents completed a questionnaire about the child's health history, swimming practice and potential confounders.

**Results**

Attendance at indoor or outdoor chlorinated pools ever before the age of two years was associated with an increased risk of bronchiolitis (OR, 1.68, 95% CI, 1.08-2.68, p=0.03), which was exposure-dependent for both types of pools (p for trend <0.01). Associations persisted and were even strengthened by the exclusion of other risk factors. Among children with no parental antecedents of atopic diseases or no day care attendance, ORs for bronchiolitis amounted to 4.45 (1.82-10.9) (p=0.001) and 4.44 (1.88-10.5) (p=0.007) after more than 20 hours spent in chlorinated pools during infancy. Infant swimmers who developed bronchiolitis had also higher risks of asthma and respiratory allergies later in childhood.

**Conclusions**

Swimming pool attendance during infancy is associated with a higher risk of bronchiolitis with ensuing increased risks of asthma and allergic sensitization.

This study was supported by the Belgian Science Policy (ANIMO project). Alfred BERNARD is Research Director of the National Fund for Scientific Research, Belgium.

## Introduction

Bronchiolitis is an acute infection of the small airways that affects primarily young infants, most often between the age of 2 and 24 months. The main causative agent is respiratory syncytial virus (RSV) although other viruses may sometimes be involved. The disease occurs with a seasonal pattern, peaking during winter in temperate climates and the rainy season in tropical climates [1, 2]. The disease burden of bronchiolitis is substantial and seems to have increased in most developed countries over the last decades [3]. In USA and Europe, the annual incidence of bronchiolitis during the first year of life is estimated between 10% and 20% but incidences as high as 30% have been reported in some urban areas [3, 4]. Because bronchiolitis increases the risk of childhood asthma [5,6], it also contributes to the rising incidence of chronic respiratory diseases in children.

Factors that may increase the frequency or severity of bronchiolitis are male sex, low gestational age, young or unmarried mothers, infant condition at birth (Apgar score), lack of breastfeeding, early weaning, congenital heart or lung diseases and a family history of atopic diseases. The risk of bronchiolitis is also higher for infants living with older siblings, attending a day-care centre or exposed to environmental tobacco smoke [2, 7]. Since ambient air pollution appears to play, if any, a marginal role [8], factors driving the rise of the disease in industrialized remain largely unknown.

Infant swimming is a practice that has been greatly popularized in most industrialized countries. Nystad et al. [9, 10] were among the first to draw the attention to the risks this practice may pose to the airways of infants. These authors noted that infants from atopic parents were more likely to develop wheezing or lower respiratory tract infections when they were attending swimming pools. In a cross-sectional study of schoolchildren aged 10-13 years, we also found that infant swimmers were more likely to develop asthma and recurrent bronchitis than their peers who had never attended a chlorinated pool before the age of two years. Interestingly, this poorer respiratory health of infant swimmers was associated with lower serum levels of Clara cell protein (CC16) [11,12], a protein protecting from inflammation in acute RSV infection [13]. These findings led us to postulate that chlorine used to disinfect swimming pool can cause airways changes making the lungs more sensitive to infection- and asthma-inducing agents. A Swedish study also described decreased levels of serum CC16 in children who swam during their infancy compared with those who did not [14], providing further evidence that terminals airways and in particular the Clara cells may be damaged during infant swimming.

Given these associations between infant swimming, serum CC16 and RSV infection, we hypothesize that the infant swimming practice should be associated with a higher risk of bronchiolitis. To test this hypothesis, we have explored the associations between infant swimming, bronchiolitis and its sequelae in a cross-sectional study focused on young schoolchildren. Because both outdoor and indoor pools may affect the airways of swimmers [15], we did not limit our study to baby swimming lessons in indoor pools but considered all kinds of swimming activities during infancy regardless the type of chlorinated pool and the conditions of attendance.

### *Study population*

Study participants were 5-6 years old children from thirty schools located mainly in the areas of Brussels and Liège in Belgium. These children were recruited in the frame of a prospective study on the respiratory impact of air pollution. A questionnaire and an informed consent document were distributed to children in the third kindergarten. Of the 839 children who received these documents, 430 returned the questionnaire with the informed consent document filled by the parents. The overall participation rate was 51.3% but showed a large variation between schools (between 20 and 90%). Since the participation rate did not correlate with the prevalence of the main outcomes and risk factors, we decided to retain all schools for the statistical analysis and to add the participation rate to the list of potential confounders. The ethics committee of the Faculty of Medicine of the Catholic University of Louvain approved the study protocol that complied with all applicable requirements of international regulations.

### *Protocol*

Parents completed a detailed questionnaire inquiring about the health of their child, respiratory symptoms, family antecedents, care during early life and all lifestyle or environmental factors known or suspected to influence the risk of bronchiolotis. Questions about respiratory symptoms were those of the International Study of Asthma and Allergy in Children [16]. Wheezing was identified as a positive answer to the question "has your child had episodes of wheezing during the 12 last months?". The questionnaire included specific questions asking whether the child had ever been diagnosed for most common diseases during childhood. Among these there were seven distinct questions about the following respiratory diseases: asthma, bronchitis, bronchiolitis, pneumonia (or broncho-pneumonia), hay fever, allergic rhinitis and sinusitis. For each question, the parents were asked to reply by “yes” or “no”. In case of a positive reply, parents were then asked to indicate the exact age when the disease was diagnosed. The questionnaire also comprised questions about sport and recreational activities. For swimming practice, parents were asked to specify the type of pool attended by their child, the type of disinfection method (even though almost all of them use chlorine), the frequency of attendance and the age when their child started to regularly attend the pool. This information served to calculate the cumulative pool attendance at indoor or outdoor chlorinated pools, separately or combined, before the age of two years (during infancy) or later over lifetime (during childhood). Children were examined in schools between 9:00 and 16:00. We measured the height and body weight. Because the examination of children in schools precluded any provocation test, screening for respiratory allergies in school was performed non-invasively by measuring specific IgE in nasal mucosa with the Rhinostick test [17]. The test was successfully performed in 372 children for whom the following allergens were screened: cat epithelium, *Dermatophagoides pteronyssinus*, *Anthoxanthum odoratum*, *Parietaria officinalis* and a mix of tree allergens containing *Betula odorosa*, *Corylus avellana*, *Carpinus betulus* and *Alnus incona*. Regarding sport and recreational activities organized by the schools, we asked the school directors to complete a questionnaire that allowed us to cross-check and complete the information given by the parents.

***Swimming pools***

In Belgium, each public swimming pool is legally required to regularly check the microbial and chemical quality of water by measuring several parameters including active (0.5-1.5 ppm) and combined chlorine (<2 ppm). In 2003, the legislation was enforced by a lowering of the standard for combined chlorine (<0.8 ppm) and the setting of a standard for trichloramine in pool air (<500 µg/m$^3$ in air sampled at 1.5 m above pool surface). Because there were no public outdoor pools in the studied areas, open-air swimming pools attended by infant swimmers were mostly residential. In Belgium like in most countries, there are no specific regulations for these privately owned swimming pools, which are disinfected according to the instructions of the chlorine supplier (active chlorine between 1 and 2 ppm).

***Statistical analysis***

Continuous variables were described as median with interquartile range. Differences between infant swimmers and their controls were assessed by the two-sided Mann-Whitney *U* test for the cumulative pool attendance indices and the unpaired *t* test of Student for other variables. Binary variables were compared by the chi-squared test or by a chi-squared test for trend for the analysis of exposure-response relationships. We used logistic regression models to assess the associations between swimming and bronchiolitis while adjusting for potential confounders Attendance at outdoor or indoor pools before the age of two years was categorized as never, >0-20 hours and >20 hours. Crude and adjusted odds ratios (ORs) for the outcomes were calculated using as reference level the occurrence of the outcome among children who never attended an indoor or outdoor chlorinated pool before the age of 2 years. We used a backward approach by including all potential control variables and removing the least significant predictor until the model only contained variables with a $p < 0.20$. A total of 24 potential predictors were tested, including among others, age, gender, parental asthma and/or respiratory allergies (hay fever or allergic rhinitis), high education level of parents (father and/or mother graduated from university or a high school), maternal smoking during pregnancy, parental smoking at home, the child's season of birth, birth weight, number of older siblings, house cleaning with bleach, breastfeeding, day-care center attendance, area of current residence (Liège vs Brussels area), having spent infancy in a urban or rural area, living in the vicinity of a polluting industry or within a distance of < 100 meters from a busy road and cumulative time spent in indoor or outdoor chlorinated swimming pools before the age of two years, separately or in combination (cumulative pool attendance, CPA). We also used a classification of CPA in tertiles. For outcomes other than bronchiolitis, we added to the potential predictors the cumulative attendance at outdoor or indoor swimming pools after the age of two years. Statistical analyses were performed by using SAS version 9.1.3 (SAS International, Cary, NC).

## Results

Table 1 compares the characteristics between infant swimmers in indoor or outdoor chlorinated pools (n=195) and children who never swam before the age of two years (n=235). On average, infant swimmers had spent 6 hours in indoor and 8 hours in outdoor chlorinated pools before the age of two years. These infant swimmers had also a greater lifetime attendance at indoor or outdoor chlorinated swimming pools (total indoor and outdoor, 132 vs 35 hours in other children, Table 1). There were no significant differences between the two groups regarding most risk factors of respiratory diseases including gender, age, BMI, birth weight, exposure to tobacco smoke and parental allergies. The social class or socio-economic status, as evaluated on the basis of parental education, and the proportions of children with parental asthma, having been breastfed or attended a day-care center were higher in the group of swimmers as compared with non-swimmers. The two groups did not differ with respect to the prevalences of wheezing and of ever diagnosed asthma, respiratory allergies, bronchitis, sinusitis and pneumonia. The prevalence of bronchiolitis was, however, significantly greater in infant swimmers than in their controls (36.4 vs 23.8 %, p=0.004).

The logistic regression analysis confirmed the association between infant swimming and the risk of bronchiolitis (OR, 1.68, 95% CI, 1.08-2.68, p=0.03). Other risk factors of bronchiolitis identified included male sex (OR: 1.65, 95% CI 1.05-2.59, p=0.03), parental asthma and/or respiratory allergies (OR: 1.73, 95% CI 1.20-2.74, p=0.02), number of older siblings (OR: 1.69, 95% CI 1.07-2.67, p=0.02), maternal smoking during pregnancy (OR: 1.80, 95% CI 1.01-3.37, p=0.05) and day-care center attendance (OR: 1.87, 95% CI

1.17-3.00, p=0.009). Breastfeeding by contrast was associated with a protective effect towards bronchiolitis (OR: 0.58, 95% CI 0.34-0.97, p= 0.04). The parental education level, a surrogate of the socio-economic status, the use of bleach for house cleaning or the parental smoking at home did not emerge as significant predictors of bronchiolitis (all p>0.20).

We pursued our analysis by examining whether the risk of bronchiolitis was different when attending indoor or outdoor chlorinated pools. As shown in Table 2, the odds for bronchiolitis increased dose-dependently with the cumulative attendance of both types of swimming pool considered separately (both p for trend < 0.05). Stratification of infant swimmers into tertiles of cumulative attendance at indoor or outdoor chlorinated pools led to similar patterns of significant increases (p for trend =0.009 for indoor and p=0.03 for outdoor pools). The same pattern of exposure-related increases was found when the analysis was based on children attending only indoor or only outdoor pool at the exclusion of the other type of pool.

We also ascertained that these associations were not confounded by differences in participation rate between the schools or by other risk factors of bronchiolitis, in particular those linked to the socio-economic status of children, which indeed was higher in infant swimmers that in controls. This analysis was conducted by combining the attendance at indoor and outdoor pools in order to get sufficient subjects in the different pool attendance categories. As shown in Table 3, associations between bronchiolitis and infant swimming persisted and were very consistent (OR for CPA>20 h, 2.2 to 2.7, p≤0.03) across categories created by excluding children from schools with a low participation rate (<50%), children from parents with a lower education level, children who had not been breastfed, who had been exposed to tobacco smoke or else who had lived with older siblings or in a house cleaned with bleach. Quite interestingly, exclusion of children from parents with asthma or respiratory allergies, or of children having attended a day care center – two well known risk factors for bronchiolitis – noticeably strengthened the associations between bronchiolitis and infant swimming (OR for CPA>20 h, 4.45, and 4.44, p=0.001 and 0.007, respectively), which emerged through a particularly remarkable dose-response relationship among children having never attended a day-care center (p<0.001).

Last, we checked the temporal coherence of these associations by comparing the age of bronchiolitis occurrence with the age when the child started to attend swimming pools. Of the 71 infant swimmers who had bronchiolitis, there were 54 cases for which the parents provided us with the exact dates when their child started to swimming and developed bronchiolitis. These infant swimmers developed bronchiolitis on the average at the age of 9.6 months (SD, 5.9) and were diagnosed with asthma at the age of 21.8 months (SD, 18.6). Among these, bronchiolitis occurred after the start of infant swimming in 35 cases (65% of cases), a number consistent with the excess of bronchiolitis cases observed in the infant swimming group. Children who never swam during infancy had bronchiolitis at about the same age as infant swimmers (9.3 months, SD, 5.5) but they were diagnosed with asthma later at the age 30.6 months (SD : 10.0).

Since bronchiolitis is known to increase the risk of wheezing, asthma or allergic sensitization in subsequent years, we also compared the late consequences of bronchiolitis between infant swimmers and non-swimmers. This comparison was made by adjusting the odds ratios for the cumulative attendance of indoor or outdoor pool after the age of two years, which indeed was very different between the two groups. Table 4 clearly shows that bronchiolitis was associated with an increased risk of wheezing, doctor-diagnosed asthma and hay fever only among children who had attended chlorinated pools during their infancy. Interestingly, bronchiolitis and infant swimming also interacted to increase the risk of sensitization to house dust mite ($p=0.04$) and to pollen ($p= 0.05$). There were no differences in the odds for cat allergy and allergic rhinitis between the two groups. When considering children who never developed a bronchiolitis, there were no significant differences in the prevalences of respiratory diseases and sensitization to aeroallergens between children who swam during infancy and those who did not (Table 4, chi-squared test, all $p>0.07$).

## Discussion

The present study shows that swimming in indoor and outdoor pools during infancy is associated with an exposure-related increase in the risk of bronchiolitis. This effect is independent of other known risk factors of bronchiolitis such as day-care attendance, exposure to tobacco smoke or parental antecedents of atopic diseases. Our study also shows that among children who had bronchiolitis, only those who were infant swimmers were at greater risk of asthma and respiratory allergies in subsequent years.

Our results are in concordance with the observation of Nystad et al. [9, 10] that swimming before the age of two years increases the prevalence of lower respiratory tract infection. They are also consistent with our prior study on schoolchildren [11, 12] suggesting that infant swimming may cause airways changes predisposing to asthma and recurrent bronchitis. In the present study focused on younger children, we found no significant differences between infant swimmers and the other children regarding the risk of asthma and allergies. This lack of association between infant swimming and asthma, reported by other authors on children of the same age [18-20], does not necessarily argue against the hypothesis of a causal link between infant swimming and poorer respiratory health later during childhood. Children aged 5 to 6 years are probably to young to detect associations with chronic respiratory diseases that develop and are correctly diagnosed later during childhood. This might explain why studies linking swimming pool attendance to childhood asthma were all based on children with an average age of more than 9 years [21-23]. The follow-up of our cohort of infant swimmers should provide more conclusive data regarding the long-term consequences of infant swimming.

The swimming pool factor responsible for the risk of bronchiolitis is hard to identify with certainty given the multiplicity of potential harmful agents in the swimming pool environment [20, 24]. Currently, one of the most plausible explanation is that the airways of infant swimmers are made more sensitive to infections because of the irritating effects of chlorine used to disinfect swimming pools. The fact that bronchiolitis is increased by outdoor as well as by indoor pools means that chloramines are not the sole and probably not the main irritants which might be implicated in the risk of bronchiolitis. The first reason for this is that outdoor pools attended by infant swimmers in our study were mainly residential pools. Compared to public pools, residential pools are indeed much less polluted by organic matter from bathers, in particular by urine which is the main source of nitrogen leading to the formation of chloramines. The second reason is that trichloramine, the ultimate chlorination by-product, is a highly volatile gas that is very quickly dispersed into the atmosphere once released at the surface of open-air pools, which therefore do not have the characteristic ‘‘chlorine’’ smell of indoor pools. Like for the risks of asthma and respiratory allergies associated with outdoor pools [15], we suspect that the major burden of oxidants irritating the airways of infant swimmers comes from the microaerosols or small volumes of water that they inhale when actively playing and having their head under water [12]. The risk of inhaling small volumes during submersion exercise is especially important as infants cannot control their breathing. If the infant swimming practice is considered to be safe, it is because of the laryngeal or gag reflex (closure of the larynx with the epiglottis) that is triggered when water gets into infant’s mouth. This gag reflex disappears however when the infant gets older (more than 6 month) and anyway this reflex cannot prevent small amounts of chlorinated water deposited or trapped in the upper respiratory tract to be conducted more deeply in the lungs when the infant surfaces to breathe [12].

The most reactive and concentrated chlorine compound present in the water and microaerosols of both outdoor and indoor pools is the hypochlorite/hypochlorous acid, i.e. the active chlorine itself (concentrations in the range of 1 to 2 ppm). Depending on the level of organic pollution of pool water, infants swimmers have also been exposed to chlorination by-products among which the most irritant and concentrated are the mono-, dichloro- and trichloramine as well as the dichloromethylamine [19, 20, 24, 25]. Since public pools are usually more polluted by nitrogenous substances from bathers (urine, sweat, saliva) than residential pools, irritating effects caused by the chloramines might explain why the odds for bronchiolitis are higher with indoor than with outdoor pools.

Chlorine-based oxidants such as hypochlorous acid or chloramines are known to be potent oxidants capable of damaging the endothelial and epithelial barriers [26, 27]. Studies based on lung injury markers have shown that at concentrations commonly found in indoor pools, these chemicals can affect the permeability or the cellular integrity of the deep lung epithelium. Regular attendance at chlorinated pools by schoolchildren has been associated with an exposure-dependent increase in lung epithelium permeability (lung hyperpermeability) resulting in an intravascular leakage of the surfactant-associated proteins A and B [28]. A decrease of serum CC16 has also been described in children who used indoor pools during their infancy or later in childhood, which is the reflection of a decrease of Clara cells and an ensuing decrease of CC16 production [11, 12, 14]. The latter observation is particular relevant to the present study given the experimental evidence that CC16 down regulates the inflammation during acute RSV infection [13].

Even though airways irritation by chlorine-based oxidants appears as a very likely explanation for the increased risk of bronchiolitis associated with infant swimming, other causative factors might also play a role. As a result of inadequate disinfection with chlorine, swimming pool environment can be contaminated by viruses (adeno-, noro- and echovirus), which may cause outbreaks of waterborne illnesses such as gastroenteritis, dermatitis and respiratory infections [29]. Respiratory illnesses in these incidents are rather uncommon and in most cases limited to the upper airways. Nevertheless we have no evidence allowing to exclude the possibility that swimming pool environment may increase the risks of cross-infection by RSV virus [30, 31]. Another possibility that should be considered is the inhalation of swimming pool water when infants performed submersion activities. Because of its hypotonicity, swimming pool water deposited in airways might perhaps cause some airways alterations, aggravating the toxic effects of chlorination products [32].

Our study has certain limitations. The most important one concerns the exposure assessment since we could not of course retrieve exposure data concerning the levels of chlorine in indoor or outdoor swimming pools that our children attended during infancy. We had no choice but to use the information provided by the parents. The existence of exposure-response relationships for both outdoor and indoor pools suggests that the lack of data about the actual levels of chlorine in swimming pools has not been critical to the point of distorting our analysis. Another limitation concerns the participation rate that overall reached only 51% and greatly varied between schools. The young age of children combined with the fact that the medical examination, though based on non-invasive tests, was performed in schools, has probably deterred a significant proportion of parents from participating to our study. This low participation does not seem to have biased our study too as there were no significant correlations between the participation rate and the prevalences of main outcomes and risk factors. The response rate tested along with other potential confounders did not emerge either as a significant predictor of bronchiolitis. This lack of confounding by the participation rate probably stems from the fact that parents were blinded to the tested hypothesis. Since the study was conducted in the frame of a prospective study on environmental factors affecting the respiratory health of children, infant swimming was only one of the many items addressed by the questionnaire.

In summary, our study shows that infant swimming is associated with a dose-dependent increase in the risk of bronchiolitis. Exposure to chlorinated pools during infancy interacts also with bronchiolitis to increase the risks of asthma and respiratory allergies later during childhood, which suggests that the infant swimming practice may have more long-standing impact on the respiratory health of children.

**References**

1. American Academy of Pediatrics. Subcommittee on Diagnosis and Management of Bronchiolitis. *Pediatrics* 2006; 118: 1774-1793

2. Smyth RL, Openshaw PJ. Bronchiolitis. *Lancet* 2006; 368: 312-322.

3. Carroll KN, Gebretsadik T, Griffin MR, Wu P, Dupont WD, Mitchel EF, Enriquez R, Hartert TV. Increasing burden and risk factors for bronchiolitis-related medical visits in infants enrolled in a state health care insurance plan. *Pediatrics* 2008;122:58-64.

4. Grimpel E. Epidémiologie de la bronchiolite du nourrison en France. *Arch Pediatr* 2001; 8 : 83S-92S.

5. Lemanske RF Jr, Jackson DJ, Gangnon RE, Evans MD, Li Z, Shult PA, Kirk CJ, Reisdorf E, Roberg KA, Anderson EL, Carlson-Dakes KT, Adler KJ, Gilbertson-White S, Pappas TE, Dasilva DF, Tisler CJ, Gern JE. Rhinovirus illnesses during infancy predict subsequent childhood wheezing. *J Allergy Clin Immunol* 2005; 116: 571-577.

6 Cassimos DC, Tsalkidis A, Tripsianis GA, Stogiannidou A, Anthracopoulos M, Ktenidou-Kartali S, Aivazis V, Gardikis S, Chatzimichael A. Asthma, lung function and sensitization in school children with a history of bronchiolitis. *Pediatr Int* 2008; 50: 51-56.

7. Koehoorn M, Karr CJ, Demers PA, Lencar C, Tamburic L, Brauer M. Descriptive epidemiological features of bronchiolitis in a population-based cohort. *Pediatrics* 2008; 122: 1196-1203

8. Karr CJ, Rudra CB, Miller KA, Gould TR, Larson T, Sathyanarayana S, Koenig JQ. Infant exposure to fine particulate matter and traffic and risk of hospitalization for RSV bronchiolitis in a region with lower ambient air pollution. *Environ Res* 2009; 109:321-327.

9. Nystad W, Nia F, Magnus P, Nafstad P. Baby swimming increases the risk of recurrent respiratory tract infections and otitis media. *Acta Paediatr* 2003; 92: 905-909.

10. Nystad W, Håberg SE, London SJ, Nafstad P, Magnus P. Baby swimming and respiratory health. *Acta Paediatr* 2008; 97: 657-662.

11. Bernard A, Carbonnelle S, Nickmilder M, de Burbure C. Non-invasive biomarkers of pulmonary damage and inflammation: Application to children exposed to ozone and trichloramine. *Toxicol Appl Pharmacol* 2005; 206:185-190.

12. Bernard A, Carbonnelle S, Dumont X, Nickmilder M. Infant swimming practice, pulmonary epithelium integrity, and the risk of allergic and respiratory diseases later in childhood. *Pediatrics* 2007; 119: 1095-1103.

13. Wang S, Rosenberger C, Bao Y, Stark J, Harrod K. Clara cell secretory protein modulates lung inflammatory and immune responses to respiratory syncytial virus infection. *J Immunol* 2003; 171: 1051-1060.

14. Lagerkvist BJ, Bernard A, Blomberg A, *et al.* Pulmonary epithelial integrity in children: relationship to ambient ozone exposure and swimming pool attendance. *Environ Health Perspect* 2004; 112: 1768-1771.

15. Bernard A, Nickmilder M, Voisin C. Outdoor swimming pools and the risks of asthma and allergies during adolescence. *Eur Respir J* 2008; 32: 979-988.

16. The International Study of Asthma and Allergies in Childhood (ISAAC) Steering Committee. Worldwide variation in prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and atopic eczema: ISAAC. *Lancet* 1998; 351: 1225-1232.

17. Marcucci F, Sensi L. A new method for IgE detection in nasal mucosa. *Clinical and Experimental Allergy*1989;19: 157-162.

18. Schoefer Y, Zutavern A, Brockow I *et al.* Health risks of early swimming pool attendance. *Int J Hyg Environ Health* 2008; 211: 367-373.

19. Uyan ZS, Carraro S, Piacentini G, Baraldi E.. Swimming pool, respiratory health, and childhood asthma: should we change our beliefs? *Pediatr Pulmonol* 2009; 44: 31-37.

20. Weisel CP, Richardson SD, Nemery B, *et al.* Childhood asthma and environmental exposures at swimming pools: state of the science and research recommendations. *Environ Health Perspect* 2009; 117: 500-507.

21. Bernard A, Carbonnelle S, De Burbure C, Michel O, Nickmilder M. Chlorinated pool attendance, atopy and the risk of asthma during childhood. *Environ Health Perspect* 2006; 114: 1567-1573.

22. Bernard A, Nickmilder M, Voisin C, Sardella A. Impact of chlorinated swimming pool attendance on the respiratory health of adolescents. *Pediatrics* 2009; 124: 1110-1118.

23. Cotter A, Ryan CA. The pool chlorine hypothesis and asthma among boys. *Ir Med J* 2009;102: 79-82.

24. Bernard A. Chlorination products: emerging links with allergic diseases. *Curr Med Chem* 2007; 14: 1771-1782.

25. Weaver WA, Li J, Wen Y, Johnston J, Blatchley MR, Blatchley ER 3rd. Volatile disinfection by-product analysis from chlorinated indoor swimming pools. *Water Res* 2009; 43: 3308-33018.

26. Tatsumi, T, Fliss, H. Hypochlorous acid and chloramines increase endothelial permeability: possible involvement of cellular zinc. *Am J Physiol* 1994; 267: H1597-H1607.

27. Musch MW, Walsh-Reitz MM, Chang EB. Roles of ZO-1, occludin, and actin in oxidant-induced barrier disruption. *Am J Physiol Gastrointest Liver Physiol* 2006; 290: G222-G231.

28. Bernard A, Carbonnelle S, Michel O *et al.* Lung hyperpermeability and asthma prevalence in schoolchildren: unexpected associations with the attendance of indoor chlorinated pools. *Occup Environ Med* 2003; 60: 385-394.

29. Sinclair RG, Jones EL, Gerba CP. Viruses in recreational water-borne disease outbreaks: a review. *J Appl Microbiol* 2009 May 5. [Epub ahead of print]

30. Moro MR, Bonville CA, Suryadevara M, *et al.* Clinical features, adenovirus types, and local production of inflammatory mediators in adenovirus infections. *Pediatr Infect Dis J* 2009; 28: 376-380.

31. Artieda J, Pineiro L, Gonzalez MC, Munoz MJ, Basterrechea M, Iturzaeta A, Cilla G. A swimming pool-related outbreak of pharyngoconjunctival fever in children due to adenovirus type 4, Gipuzkoa, Spain. *Euro Surveill* 2009, 26; 14 pii: 19125

32. Qing J, Lidong Z, Liqing W, Hongbin J, Jianguo X. Pentoxifylline reduces indirect lung injury of fresh water drowning in canis. *Clin Chim Acta* 2006; 365: 221-229.

**Table 1** Characteristics of children having swum during infancy and their controls

| Characteristics | Swimming Infants | Other Children | p |
|---|---|---|---|
| Number of subjects | 195 | 235 | |
| Boys, N° (%) | 105 (53.9) | 124 (52.8) | 0.82 |
| School participation rate, %, mean (SD) | 54.9 ( 19.4) | 58. 3 (23.0) | 0.19 |
| Age, mean (SD), years | 5.60 (0.38) | 5.68 (0.38) | 0.79 |
| BMI, mean (SD), kg/m² | 20.9 (3.8) | 20.6 (3.5) | 0.39 |
| Parents | | | |
| Higher education level, N° (%) | 154 (79.0) | 156 (66.4) | 0.004 |
| Asthma, N° (%) | 38 (19.5) | 25 (10.6) | 0.01 |
| Asthma and/or respiratory allergies, N° (%) | 86 (44.1) | 88 (37.4) | 0.16 |
| Early life | | | |
| Birth weight, mean (SD), g | 3206 (639) | 3436 (2396) | 0.30 |
| Breastfeeding, N° (%) | 161 (82.6) | 169 (71.9) | 0.01 |
| Day-care center attendance, N° (%) | 127 (65.1) | 102 (43.4) | <0.001 |
| Exposure to tobacco smoke | | | |
| During pregnancy, N° (%) | 31 (16.0) | 32 (13.6) | 0.51 |
| Parental smoking at home, N° (%) | 55 (28.2) | 74 (31.5) | 0.46 |
| Cumulative pool attendance before two years | | | |
| Indoor, median (IQR), hours | 6 (0-21) | - | - |
| Outdoor, median (IQR), hours | 8 (0-31) | - | - |
| Total, median ( IQR), hours | 22 (8-50) | - | - |
| Cumulative pool attendance over lifetime | | | |
| Indoor, median (IQR), hours | 53 (17-129) | 18 (0-48) | <0.001 |
| Outdoor, median (IQR), hours | 50 (4-146) | 0 (0-28) | <0.001 |
| Total, median ( IQR), hours | 132 (52-202) | 35 (5-91) | <0.001 |
| Environment and lifestyle | | | |
| Number of older siblings, mean (SD) | 0.87 (0.79) | 0.92 (1.12) | 0.66 |
| House cleaning with bleach, N° (%) | 43 (22.1) | 66 (28.1) | 0.15 |
| Living at <100 m from a busy road, N° (%) | 63 (32.3) | 79 (33.6) | 0.78 |
| Exposure to pets since birth, N (%) | 85 (43.6) | 99 (42.1) | 0.76 |
| Aeroallergen-specific nasal IgE[a] | | | |
| House dust mite, N° (%) | 21 (12.2) | 22 (11.0) | 0.71 |
| Cat, N° (%) | 15 (8.7) | 14 (7.0) | 0.54 |
| Pollen, N° (%) | 27 (15.7) | 27 (13.5) | 0.55 |
| At least one aeroallergen, N° (%) | 42 (24.4) | 48 (24.0) | 0.92 |
| Respiratory symptoms and diseases[b] | | | |
| Wheezing, N° (%) | 36 (18.5) | 40 (17.0) | 0.70 |
| Asthma, N° (%) | 16 (8.2) | 15 (6.4) | 0.47 |
| Hay fever, N° (%) | 17 (8.7) | 27 (11.5) | 0.35 |
| Allergic rhinitis, N° (%) | 27 (13.9) | 25 (10.6) | 0.31 |
| Bronchiolitis, N° (%) | 71 (36.4) | 56 (23.8) | 0.004 |
| Bronchitis, N° (%) | 93 (47.7) | 111 (47.2) | 0.92 |
| Sinusitis, N° (%) | 28 (14.4) | 30 (12.8) | 0.63 |
| Pneumonia, N° (%) | 20 (10.3) | 28 (11.9) | 0.59 |

[a]Numbers of children who were tested for nasal aeroallergen-specific IgE were 172 in the swimming infant group and 200 in the other children. [b]Respiratory diseases were defined as doctor-diagnosed diseases at any time. Wheezing corresponds to episodes of wheezing during the 12 last months.

**Table 2:** Risks of bronchiolitis according to the cumulative attendance of indoor or outdoor chlorinated swimming pools during infancy

| CPA before the age of two years | Indoor pool attendance (all children) | | | | | Outdoor pool attendance (all children) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | OR (95% CI) | | | | | OR (95% CI) | | |
| | CPA (hrs) | N (%) | Unadjusted | Adjusted | *p* | CPA (hrs) | N (%) | Unadjusted | Adjusted | *p* |
| Never | 0 | 76/287 (26.5) | 1.0 (1.0-1.0) | 1.0 (1.0-1.0) | | 0 | 79/308 (25.7) | 1.0 (1.0-1.0) | 1.0 (1.0-1.0) | |
| >0-20 hours | 6 (2-12) | 27/92 (29.4) | 1.15 (0.69-1.94) | 0.79 (0.44-1.42) | 0.44 | 9 (5-14) | 21/54 (38.9) | 1.85 (1.01-3.38) | 1.91 (0.99-3.68) | 0.05 |
| >20 hours | 32 (25-45) | 24/51 (47.1) | 2.47 (1.34-4.54) | 2.02 (1.01-4.02) | 0.05 | 47 (30-84) | 27/68 (39.7) | 1.91 (1.1-3.3) | 1.59 (0.85-2.98) | 0.14 |
| | *p* for trend =0.006 | | | | | *p* for trend =0.006 | | | | |
| **CPA before the age of two years** | **Indoor pool attendance (no use of outdoor pools)** | | | | | **Outdoor pool attendance (no use of indoor pools)** | | | | |
| | | | OR (95% CI) | | | | | OR (95% CI) | | |
| | CPA (hrs) | N (%) | Unadjusted | Adjusted | *p* | CPA (hrs) | N (%) | Unadjusted | Adjusted | *p* |
| Never | 0 | 53/235 (22.6) | 1.0 (1.0-1.0) | 1.0 (1.0-1.0) | | 0 | 59/235 (25.1) | 1.0 (1.0-1.0) | 1.0 (1.0-1.0) | |
| >0-20 hours | 6 (2-11) | 11/50 (22.0) | 0.9 (0.43-1.88) | 0.58 (0.25-1.32) | 0.19 | 9 (4-12) | 9/27 (33.3) | 1.6 (0.68-3.76) | 1.69 (0.66-4.3) | 0.27 |
| >20 hours | 36 (24-66) | 12/23 (52.2) | 3.49 (1.46-8.34) | 3.49 (1.30-9.34) | 0.01 | 50 (39-76) | 11/25 (44.0) | 2.51 (1.08-5.85 | 2.08 (0.81-5.34) | 0.13 |
| | *p* for trend=0.01 | | | | | *p* for trend = 0.03 | | | | |

CPA, cumulative pool attendance. OR were adjusted for sex, breastfeeding, day care center attendance, older siblings, parental asthma and/or respiratory allergies, maternal smoking during pregnancy and when the analysis was performed on all children the attendance of the other type of swimming.

**Table 3**: Risks of bronchiolitis with increasing attendance of indoor and/or outdoor chlorinated pools before the age of two years for all children and separately for children categorized according to the school participation rate, parental education, parental asthma or respiratory allergies, breastfeeding, day-care center attendance and exposure to tobacco smoke, older siblings or bleach

| | Cumulative pool attendance before the age of 2 years (hours) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Never | | >0-20 | | >20 | | |
| Children | N (%) | OR (95% CI) | N (%) | OR (95% CI) | N (%) | OR (95% CI) | p for trend |
| All | 56/235 (23.8) | 1.0 (1.0-1.0) | 29/95(30.5) | 1.24 (0.69-2.23) *p=0.46* | 42/100 (42.0) | 2.25 (1.32-3.85) *p=0.003* | <0.001 |
| From schools with response rate >50% | 35/146 (24.0) | 1.0 (1.0-1.0) | 17/59(28.8) | 1.24 (0.57-2.7) *p=0.59* | 23/58 (39.7) | 2.25 (1.1-4.59) *p=0.03* | 0.03 |
| From parents with high level of education | 36/156 (23.1) | 1.0 (1.0-1.0) - | 22/72(30.6) | 1.31 (0.67-2.57) *p=0.43* | 34/82 (41.5) | 2.26 (1.22-4.18) *p=0.009* | 0.003 |
| From parents with no asthma or respiratory allergies | 17/115 (14.8) | 1.0 (1.0-1.0) | 13/38 (34.2) | 4.31 (1.55-12.0) *p=0.005* | 18/45 (40.0) | 4.45 (1.82-10.9) *p=0.001* | 0.001 |
| No breastfeeding | 19/66 (28.8) | 1.0 (1.0-1.0) | 7/12 (58.3) | 1.06 (0.55-2.06) *p=0.86* | 12/22 (54.6) | 2.10 (1.11-3.98) *p=0.02* | 0.008 |
| No day-care center attendance | 21/133 (15.8) | 1.0 (1.0-1.0) | 9/32 (28.1) | 2.35 (0.87-6.38) *p=0.09* | 15/36 (41.7) | 4.44 (1.88-10.5) *p=0.007* | <0.001 |
| No maternal smoking during pregnancy | 46/203 (22.7) | 1.0 (1.0-1.0) | 21/77 (27.3) | 1.27 (0.65-2.49) *p=0.48* | 34/87 (39.1) | 2.16 (1.2-3.9) *p=0.01* | 0.005 |
| No exposure to parental smoking | 38/161 (23.6) | 1.0 (1.0-1.0) | 19/65 (29.2) | 1.16 (0.57-2.35) *p=0.61* | 32/75 (42.7) | 2.21 (1.18-4.17) *p=0.01* | 0.004 |
| No older siblings | 16/99 (16.2) | 1.0 (1.0-1.0) | 13/45 (28.9) | 2.26 (0.87-5.88) *p=0.09* | 16/47 (34.0) | 2.72 (1.13-6.56) *p=0.03* | 0.01 |
| No use of bleach for house cleaning | 48/201 (23.9) | 1.0 (1.0-1.0) | 28/87 (32.2) | 1.37 (0.75-2.51) *p=0.30* | 36/87 (41.4) | 2.22 (1.25-3.95) *p=0.007* | 0.003 |

ORs were adjusted for breastfeeding, gender, older siblings, area of residence, day care center attendance, maternal smoking during pregnancy and parental antecedents of atopic diseases (except when the factor was excluded). High level education means that the father and/or the mother had been graduated from the university or a high school

**Table 4**: Risks of respiratory diseases and sensitization to aeroallergens associated with bronchiolitis in swimming infants and their controls

| | Controls | | | | | Swimming infants | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bronchiolitis | | OR (95% CI) | | | Bronchiolitis | | OR (95% CI) | | |
| | No (n=179) | Yes (n=56) | Unadjusted | Adjusted | p | No (n=124) | Yes (n=71) | Unadjusted | Adjusted | p |
| Wheezing | 28 (15.6) | 12 (21.4) | 1.47 (0.69-3.13) | 1.29 (0.47-3.54) | 0.62 | 18 (14.5) | 18 (25.4) | 2.0 (0.96-4.16) | 2.49 (1.13-5.49) | 0.03 |
| Asthma | 11 (6.2) | 4 (7.1) | 1.18 (0.36-3.85) | 0.91 (0.23-3.70) | 0.90 | 5 (4.0) | 11 (15.5) | 4.36 (1.45-13.1) | 8.27(2.3-29.6) | 0.001 |
| Allergic rhinitis | 16 (8.9) | 9 (16.1) | 1.95 (0.81-4.70) | 2.08 (0.79-5.40) | 0.14 | 13 (10.5) | 14 (19.7.) | 2.10 (0.92-4.76) | 4.65 (1.42-15.2) | 0.01 |
| Hay fever | 19 (10.6) | 12 (21.4) | 1.40 (0.58-3.41) | 0.96 (0.34-2.70) | 0.94 | 6 (4.8) | 11 (15.5) | 3.61 (1.27-10.2) | 4.7 (1.52-14.5) | 0.007 |
| Pollen nasal IgE[a] | 24 (15.7) | 3 (6.4) | 0.39 (0.11-1.38) | 0.57 (0.15-2.10) | 0.40 | 14 (12.8) | 13 (20.6) | 1.86 (0.80-4.3) | 2.63 (1.01-6.8) | 0.05 |
| HDM nasal IgE[a] | 15 (9.8) | 7 (14.9) | 1.62 (0.62-4.25) | 2.05 (0.62-6.75) | 0.24 | 9 (8.3) | 21 (33.3 ) | 2.59 (1.02-6.55) | 2.86 (1.07-7.8) | 0.04 |
| Cat nasal IgE[a] | 11 (7.2) | 3 (6.4) | 0.89 (0.24-3.32) | 0.90 (0.20-4.18) | 0.90 | 8 (7.3) | 7 (11.1) | 1.56 (0.54-5.54) | 1.26 (0.4-3.96) | 0.69 |

[a]Number of children tested for nasal aeroallergen-specific IgE who did not develop or developed bronchiolitis were in controls 153 and 47 and in swimming infants 109 and 63, respectively. HDM, house dust mite. Outcomes were defined in Table 1. Bronchiolitis was diagnosed at a mean age of 9.6 months (SD, 5.9) in infant swimmers and of 9.3 months (SD, 5.5) in the other children. Prevalences of respiratory diseases and of sensitization to aeroallergens among children who never developed a bronchiolitis were not significantly different between swimming infants and their controls (all $p>0.07$, chi square test).