Exercise induced bronchospasm and chlorine in swimming pools

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Declaration

I, Arthur Joseph Williams, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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AHR (airway hyperresponsiveness)

EIB (Exercise induced bronchospasm)

PEFR (Peak expiratory flow rate in liter/second)

FEV1 (Forced expiratory volume in the 1st second)

FEV1% (percentage fall in FEV1 when pre- and post exercise values are compared)

Abstract

Background: Swimming is often the preferred exercise prescription for asthmatics. However, there is also concern because increased sensitisation to allergens and a high rate of bronchial responsiveness to methacholine has been reported in swimmers (Drobnic, 1992). It has recently been hypothesized that chronic exposure to chlorine compounds in swimming pool water might sensitize the airways and cause exercise induce bronchospasm (EIB) in swimmers.

Objective: The purpose of this thesis was firstly to review the possible relationship between chlorine in swimming pool water and exercise induced bronchospasm, and secondly to assess whether chlorine exposure during swimming provokes EIB in well-trained swimmers with and without a history of EIB.

Review

Methods: The relationship between asthma, EIB, swimming and chlorine was reviewed. The internet-based medical literature search engine, PUBMED, was used to obtain the related articles. Copies of the original articles were collected at and through the University of Cape Town Medical Library. The possible relationship between exposure to chlorine in swimming pool water and the prevalence of EIB in swimmers is reviewed.

Results: A review of the literature confirms a relationship between chlorine and EIB in swimmers. Furthermore, the effect of chlorine on EIB must be carefully investigated because swimming per se can influence the diagnosis of EIB compared with running. Lastly, there is some evidence that the exposure to chlorine and by-products of water chlorination may have a negative effect on respiratory function in swimmers.

Conclusion: Further studies need to be conducted to test the hypothesis that forced expiratory lung functions will be decreased when swimmers are exposed to chlorinated swimming pools compared to non-chlorinated swimming pools.

Study

Methods: Twenty-one well-trained swimmers with a history of EIB [EIB subgroup] and twenty swimmers with no history of EIB [CON subgroup]) from swimming clubs in Western Cape were recruited as subjects. All subjects completed a medical and training questionnaire and were then randomly exposed to four exercise tests of the same intensity and duration: swimming in an indoor pool with no chlorine in the water (NoChl=29), swimming in a chlorinated swimming pool with low concentration of chlorine (0.5 parts per million) (Chl[0.5]=17), swimming in a chlorinated swimming pool with high concentration of chlorine (1.0 parts per million) (Chl[1.0]=30) and running or cycling (non-swimming) next to any one of the swimming pools (Non-Swim=37). Spirometry was performed with a calibrated hand held spirometer before each exercise challenge, immediately after, and at 5 minutes, 10 minutes, 15 minutes and 30 minutes after the challenge test. Forced Expiratory Volume after one second (FEV1) was measured. The percentage fall in FEV1 compared to the baseline FEV1 was used to make the diagnosis of EIB. Two cut-off points of ≥10% and ≥15% were used as a positive test.

Results: Exposure to high chlorine concentrations (>0.5 part per million) in swimming pools during exercise (6-8 minutes at 60-80% of the target heart rate) resulted in a higher risk to develop exercise-induced bronchospasm. At low levels of chlorine (less than 0.5 part per million) the risk of developing EIB were similar to exercise conducted outside the pool. There was no difference in the incidence of EIB between swimmers with or without symptoms of wheezing, coughing, chest pain or fatigue during or directly after swimming or exercise.

Conclusion: The study confirms the findings of previous investigators that a certain concentration of chlorine exposure in swimming pools causes deterioration in respiratory health and function. The higher incidence of EIB after swimming in pools with a higher range of chlorine indicates that closer monitoring of swimming pool chlorine levels is important for all swimmers to prevent EIB. Further investigation into the long-term effect of chlorine exposure and the incidence of EIB is required. Furthermore we suggest that the exposure to chlorine in swimming pools needs to be standardized during testing for the diagnosis of EIB in swimmers.

Key words

Exercise induce bronchospasm, swimmers, chlorine, asthma, indoor swimming pools, indoor pools chlorination

Chapter 1

INTRODUCTION AND SCOPE OF THE THESIS

Swimming is often advised as the most appropriate form of exercise for asthmatic children, mainly on the grounds that inhaling moist air is less likely to trigger exercise-induced bronchoconstriction (Bar-Or O, 1992). However, there are also indications that swimmers have a higher prevalence of airway hyper responsiveness (AHR) or asthma than other athletes (Hellenius, 1998; Drobnic, 1992). It has recently been hypothesised that chronic exposure to chlorine compounds in swimming pools might sensitise the airways and cause exercise induced bronchospasm (EIB) in swimmers (Carbonelle, 2002; Bernard, 2003). It has been suggested that swimming in chlorinated pools presents a hazard which can cause pulmonary damage, and could even be responsible for the recently observed increase in the prevalence of asthma in the Western society (Carbonelle, 2002). This evidence has brought into question the advice that swimming is the most appropriate exercise prescription for asthmatics. The effect of chlorine and by-products such as trihalomethanes and chloramines in the air above the water on bronchial responsiveness has been investigated (Bernard, 2003; Nemery, 2002; Helenius, 2000; Carbonelle, 2002; Aggazzotti, 1990, 1995, 1998; thicket, 2002; Langdeau, 2001). In these studies, an increase in EIB in swimmers has been documented and the reason for this may be damage to pulmonary epithelium caused by the by-products of swimming pool chlorination. Furthermore, no long-term prospective study has been conducted to weigh the beneficial effects of swimming against the possible hazardous effects of exposure to chlorination products on respiratory health.

The main focus of the thesis was to study the relationship between the exposure of well-trained swimmers to different concentrations of chlorine in swimming pools and the incidence of EIB. In addition, this study compared lung function parameters in swimmers with and without a history of EIB. These parameters were compared when these swimmers performed a similar exercise challenge (cycling or running) next to the swimming pool.

In chapter 2 the relationship between chlorine and exercise induced bronchospasm is reviewed. The relationship between asthma and EIB is described and how EIB can be diagnosed is presented. The main focus of the literature review is to explore the possible relationship between the exposure to chlorine in swimming pool water and EIB in swimmers.

In chapter 3 the details of a research study are presented. The aim of the study was to determine whether increased chlorine concentration in swimming pool water is associated with EIB in swimmers. The results of the study are discussed in relation to findings in previous studies.

In chapter 4 the summary and conclusion of the thesis is described. The results of the review and the study confirm that further investigation is required in swimming pool chlorination and respiratory health in swimmers. It also confirms that chlorine exposure above a certain concentration in swimming pool water causes a higher incidence of EIB in both swimmers with or without a past history of EIB.

Chapter 2

Chlorine and exercise induced bronchospasm: A review

Submitted to (insert Journal) for publication

INTRODUCTION

Asthma is the commonest chronic disease in children (Anderson, 1997). Asthma is defined as a clinical syndrome that is characterized by an increased response of the trachea and bronchi to a variety of stimuli (Motala, 2000). This increased response leads to a transient narrowing of airways. Asthma can be triggered by viral infections, environmental factors, allergens and exercise. The main symptoms of asthma are episodes of dyspnoea, wheezing and cough and can range from mild and intermittent to severe and continuous (American Thoracic Society, 1987). The main pathological components of asthma include variable airflow obstruction and airway hyper responsiveness (AHR). Airway responsiveness is the normal tendency for airways to constrict under the influence of non-sensitising physical stimuli such as cold air and exercise, chemical substances such as methacholine and histamine, or sensitising agents such as allergens, in sensitised individuals. AHR could then be defined as the increase above normal in the degree to which the airways will constrict upon exposure to these stimuli (Cockcroft, 1997). Airway inflammation is the dominant pathophysiological process underlying asthma (Anderson, 1997: Langdeau, 2001). AHR may be observed in asymptomatic individuals and some patients with asthma may have normal airway responsiveness when not exposed to a specific sensitising agent (Cockcroft, 1997). Asthma is a clinical diagnosis and a grading system to determine severity of asthma is necessary to determine intervention in asthma treatment (Allergy Society of South Africa, 2000, Bethesda, 1995; NHLBI, 1997).

Sporting activities that involve exercise at high exercise intensity or in cold and dry environment have the potential to provoke bronchospasm in susceptible persons. This form of bronchospasm is also known as exercise-induced asthma (EIA) or exercise-induced bronchoconstriction (EIB). EIB can be defined as the transient narrowing of airways following vigorous exercise, usually of 6 minutes duration or more (Anderson, 1997). EIB is often associated with symptoms such as shortness of breath, cough, wheeze and chest pain during of after exercise (Mahler, 1993). However, EIB can also occur without symptoms, and there is no predictable association between symptoms and presence or absence of EIB (Rundell, 2000, 2001).

RELATIONSHIP BETWEEN ASTHMA AND EIB

The relationship between EIB and asthma is well known. EIB is well recognised in asthmatics. Before the widespread use of inhaled corticosteroids, the prevalence of EIB in known asthmatics was reported to be between 40 and 90 %. This was similar in adults and children (Nastasi, 1995; Freed, 1995; Sinclair, 1995). The prevalence of EIB in asthmatics that are treated with inhaled corticosteroids has not been well documented, and needs further investigation. The prevalence of EIB in children (non-athletes) in the United Kingdom was documented between 7 and 12% (Busquets, 1996) and was more prevalent in asthmatics (Jones, 1996). In a study of 850 Australian school children, 153 (18.3%) children were found to have EIB (defined as a fall in FEV1>15% after exercise). Of these children, more than half had a history of asthma.

Thus, the prevalence of EIB in the general population is between 5-20% and more than half of those who suffer from EIB have a history of asthma (Busquets, 1996; Jones, 1996; Nastasi, 1995; Freed, 1995; Sinclair, 1995). The prevalence of EIB in athletes is higher at 23-35% (Wilber, 2000; Mannix, 1999) and the prevalence of EIB in swimmers appears to be even higher, ranging from 36-79% (Helenius, 1998; Langdeau, 2000). Therefore, there are indications that swimmers have a higher prevalence of asthma than other sports persons (Hellenius, 1998; Drobnic, 1992). This raises the question as to why there is a higher prevalence of EIB in swimmers.

SWIMMING, EIB AND ASTHMA

The relationship between swimming and asthma is well described. Swimming is often advised as the most appropriate sport for asthmatic children, mainly on the grounds that inhaling moist air is less conducive to triggering exercise-induced bronchoconstriction (Bar-Or O, 1992). But, as mentioned earlier, there are indications that there is a higher prevalence of EIB and asthma in swimmers.

Swimming, as any other exercise, can provoke symptoms of EIB. The proposed stimulus whereby swimming and other exercise activities provoke airways is the loss of water by evaporation from the airways. This loss occurs as a result of the need to humidify the inspired air to body conditions. When the inspired air is fully humidified at body temperature, the incidence of EIB is reduced (McFadden, 1988). As EIB occurs in hot (>37° Celsius), dry conditions it is thought that the osmotic effects of water loss are more significant than the thermal effects that are absent under these conditions. Thus, the intracellular events following cell shrinkage, because of water loss, are thought to be critical for mediators to be released and subsequent narrowing of airways (Anderson, 1997, 2000). There are many factors that can cause EIB in swimmers, therefore the pathophysiological process of EIB in swimmers needs careful investigation.

DIAGNOSIS OF EIB

The diagnosis of EIB needs to be confirmed in athletes with a clinical history of shortness of breath, coughing, wheezing or chest pain after exercise. The use of β_2-agonists in athletes with EIB needs objective testing to confirm the diagnosis. Response to bronchodilators and exercise challenge tests are commonly used to confirm the diagnose EIB. An increase of 12% or more in FEV1 in response to bronchodilators or a reduction of 10% or more in FEV1% from baseline in response to an exercise challenge confirms the diagnosis of EIB. Because of the increase in number of athletes competing in Olympic games notifying use of β_2-agonists, from 1.7% at Los Angeles (1984) to 5.5% at Sydney (2002), their was a need to objectively evaluate the evidence submitted for approval to use β_2-agonists. Bronchial provocation tests were also used in the diagnosis of EIB in athletes. A methacholine challenge test (Anderson, 2003) and a eucapnic voluntary hypernea test using the dry gas mannitol (Anderson, 2002) were used to objectively evaluate the evidence handed in by candidates using β_2-agonists at the Winter Olympic Games. Those taking inhaled corticosteroid for more than 3 months were candidates to be tested by the methacholine challenge test. Methacholine at a dose of less than 200 microgram (2 mg/ml) or histamine at a dose of less than 1320 microgram (13.2 mg/ml) is used by the candidate to inhale. The test is positive for the diagnosis of EIB when there is a fall of more than 20% in FEV1 (Anderson, 2003). The provoking dose of mannitol to identify a positive response to eucapnic voluntary hyperpnea was 202mg with a sensitivity of 96% and specificity of 92%. The reason for using the provocation tests is that it is objective, less expensive and easily portable (Anderson, 2002).

FACTORS THAT AFFECT BRONCHIAL HYPER-REACTIVITY

Bronchial hyper-reactivity during exercise is affected by temperature, humidity, specific types, intensity, and duration of exercise performed and by the interval since the last attack of EIB (Mc Fadden, 1988; D'Urzo, 1995). During testing protocols, factors that affect EIB, have to be controlled for. The factors that may play a role in the diagnosis of EIB are:

1. Clinical history of asthma or symptoms of asthma or EIB during or after exercise
2. Type and intensity of exercise

3. Environmental factors (humidity, air and water temperature)
4. Use of medication to treat and prevent bronchospasm
5. Chlorine exposure during swimming

These factors will now be discussed in more detail.

1. Clinical history in the diagnosis of EIB

The clinical history of the athlete (symptoms of wheezing, shortness of breath, coughing or chest pain within 30 minutes after exercise or poor performance) can be suggestive of EIB in athletes. Athletes with a history or diagnosis of asthma have a higher incidence of EIB (Busquets, 1996; Jones, 1996; Nastasi, 1995; Freed, 1995; Sinclair, 1995). Athletes with these symptoms need objective testing to confirm the diagnosis of EIB.

2. Type and intensity of exercise in the diagnosis of EIB

The choice of the exercise protocol and the measurement of spirometry are important to make the diagnosis of EIB. Exercise is a physical stimulus that can provoke EIB. The commonly used exercise protocol is to exercise the subject on a treadmill or cycle ergometer at 90%-95% of predicted maximum heart rate for the age range and sustain the exercise for 4-6 minutes (Sterk, 1993). Exercise on a treadmill for 6 minutes at an intensity of 6-8 km/hour (or 6 minutes of swimming at a heart rate of 80% of target heart rate for age) are commonly used as exercise challenge tests. The Bruce protocol (Baba, 1997) and the standard fixed time test (Busquets, 1996; Matsumoto, 1999) have also been used as exercise challenge tests in the diagnosis of EIB.

The effect of different types of exercise on EIB has also been investigated. A comparison between running and swimming and their effect on EIB has been investigated in a number of studies (Bar-Yisha, 1982; Bundgaard, 1982; Nishima, 1981; Penny, 1983; Reggiani, 1988; Schnall, 1982). In general, swimming causes a lesser fall in FEV1. The reasons why swimming causes a lesser fall in FEV1, and is thus less asthmogenic, are twofold:

(i) The minute ventilation (Ve) determines the extent of EIB and during swimming the Ve is less, thus may cause a lesser degree of EIB (Oded Bar-Or, 1992).

(ii) The higher humidity of inspired air during swimming causes a lesser degree of airway reactivity (Oded Bar-Or, 1992).

However, it has been documented that the prevalence of EIB in swimmers is higher and therefore the decreased asthmogenic nature of swimming does not explain this. Further investigation is required as to why there is a higher prevalence of EIB in swimmers.

The exercise challenge test for the diagnosis of EIB is with spirometry. Spirometry is referred to as the measurement of forced expiratory volume in one second (FEV1), forced vital capacity (FVC) and the ratio between these two volumes (FEV1/FVC) expressed as a percentage. These parameters are measured during a forced expiratory manoeuvre (Quanjer, 1993). A percentage fall in FEV1 of either more than 10% (post exercise values are compared to the pre exercise values) or a >15% fall in peak expiratory flow (PEF) are commonly used as diagnostic cut-off points for EIB (Anderson, 1997; Weiler, 1996). During these tests a subject has to exercise at a ventilation rate of at least 20 times the resting FEV1 and exercise must be sustained for at least four, but preferably six minutes (Anderson, 1997). A cut off point of more than 15% reduction in both FEV1 and PEFR has been used in some laboratory studies reported in the last ten years (Busquets, 1996; Matsumoto, 1999). Many investigators have found that although the specificity of exercise challenge tests (normal subjects with negative test/total normal subjects tested) is generally of the order of ≥80-90%, the sensitivity of the exercise challenges in detecting asthma (asthmatics with positive test/total asthmatics tested) is generally only of the order of 40-70% (Backer, 1991; Pattemore PK, 1990). Furthermore, the positive predictive value of challenges (asthmatics with positive test/total subjects with a positive test), is in the order of 10-50% (Backer, 1991). This low sensitivity and poor positive predictive value leaves a question mark as to the optimal cut-off point for the diagnosis of asthma and EIB. In many studies the cut-off has been made on a purely arbitrary basis. As described earlier, other bronchial provocation tests with Mannitol and Methacholine have recently been suggested as alternatives to diagnose EIB.

3. Environmental factors

The temperature and humidity of inspired air is also critical in the development of EIB (Paul, 1993; Henriksen, 1981). Cold or dry inhaled air cause higher bronchial sensitivity and cause a higher incidence of EIB (McFadden, 1988). The warming of inspired air and dehydration or water loss in the airways contribute to the development of EIB (Langdeau, 2001). These factors need to be controlled for when making the diagnosis of EIB.

4. Use of medication

Medication needs to be withdrawn for a period before the exercise challenge test to diagnose EIB (Carlsen, 2000). It has been recommended that, inhaled short-term acting B2-agonists and disodium cromoglycate be withheld for 8 hours prior to testing; inhaled steroids for the last 12 hours, inhaled salmeterol for the last 36 hours and oral anti-histamine and theophyllin for the last 72 hours before any test (Carlsen, 2000). However, there is concern that by terminating medication, it is possible that an acute asthma attack may be precipitated during the exercise challenge. However, in other studies (Carlsen, 2000; Henrikson, 1981; Schnall, 1982; Reggiani, 1988) no acute asthma attacks were reported when medication was withheld before an exercise challenge test.

5. Chlorine exposure and EIB in swimmers

It has recently been hypothesised that chronic exposure to chlorine compounds might sensitise the airways and cause exercise induce bronchospasm (EIB) in swimmers (Aggazzoti, 1998; Carbonelle, 2002; Bernard, 2003). The effect of chlorine in the water and chlorine by-products in the air above the water on bronchial responsiveness, has been investigated (Bernard, 2003; Carbonelle, 2002; Nemery, 2002; Helenius, 2000; Aggazzotti, 1990, 1995; Thicket, 2002; Langdeau, 2001). It has been found that during exposure to chlorine in swimming pools, there is short-term deterioration in lung function (Carbonelle, 2002), which correlated with an increase in permeability of the lung epithelium (Bernard, 2003; Carbonelle, 2002). Therefore, swimming in chlorinated pools may represent a hazard that can cause pulmonary damage, and could even be responsible for the recently observed increase in the prevalence of asthma in the Western society (Carbonelle, 2002). This implies that swimming in chlorinated pools may not be the most appropriate exercise prescription for asthmatics.

The main by-products of swimming pool water chlorination are trihalomethanes (THM) (of which chloroform ($CHCl_3$) is the most important) and chloramines (of which trichloramines (NCl_3) is the most important). These by-products are released in swimming pool water when disinfection is performed with sodium hypochloride or, more recently, with sodium dichloroisocyanurate (Aggazzoti, 1998; Bernard, 2003). Surveys in a number of countries have reported the presence of THM in swimming pools as by-products of treatment with chlorine (Aggazzotti, 1990, 1995; Fantuzzi, 2001, Levesque, 2000; Olivo, 1989). Chloroform, which is a volatile substance released at the surface of the water, can enter the body through dermal contact, inhalation or ingestion. Other THM documented are bromochloromethane ($CHBr_2Cl$), bromodichloromethane ($CHBrCl_2$) and bromoform ($CHBr_3$) (Aggazzoti, 1998). The exposure of the swimmer to THM can be evaluated in blood, urine and alveolar air compartments separately (Aggazzotti, 1990, 1993). It is well known that swimmers are exposed to these products of chlorine (THM) in the breathing zone above the water level in amounts that exceed recommendations by the World Health Organization

(Drobnic, 1995). This exposure may provoke or sensitise the airways for EIB. In a study conducted in Spain, the concentration of chlorine in swimming pools was lower than the threshold limited value (TLV) but the total chlorine inhaled by swimmers during a training session can be enough and even more than the TLV. These concentrations are high enough to be a possible factor that causes EIB (Drobnic, 1996).

The other important by-product of water chlorination, Trichloramines (NCl3), is formed when chlorine and chlorinated water reacts with urine, sweat or other organic matter from swimmers. Trichloramine, a gassy, easily inhalable irritant is the main end product in a complex reaction between chlorinated water and human organic matter (Bernard, 2003; Carbonelle, 2002). Recent studies have investigated the effect of NCl3 on the permeability of lung epithelium. To assess this, pneumoproteins (three lung specific proteins) were measured in the serum of swimmers that were exposed to NCl3 (Bernard, 2003). An increase in the serum concentration of the pneumoproteins, reflecting lung epithelium damage, correlated with decreased lung function, as measured by a decrease in FEV1 (Bernard, 2003; Carbonelle, 2002).

The implication of this is that the deteriorating effect of by-products of water chlorination on lung function can be measured in the serum of swimmers and it can be compared to their lung functions. This can also be measured over time. This will be an important parameter to test the acute and chronic effects on lung function after exposure to water chlorination.

Thus despite the protective benefits of swimming in the development of EIB, there are more possible reasons for the higher prevalence of EIB in swimmers. These require further investigation.

CONCLUSION

Although swimming is a prescribed exercise activity for asthmatics and young children, there is some evidence that the exposure to chlorine and by-products of water chlorination may have a negative effect on respiratory health in swimmers. The by-products of chlorination are trihalomethanes and chloramines. These products cause an increase in lung epithelium permeability and this correlates with a decreased lung function, as measured by a decrease in FEV1. This mechanism may explain the observation why there is increased airways sensitivity in swimmers.

However, further investigation is required to determine if there is a specific threshold of chlorine concentration where the negative effect on respiratory health and lung function can be measured. Investigation also needs to relate the presence of chlorination by-products with the degree of deterioration of lung function. Furthermore, the long-term effects of chlorine exposure need to be investigated in swimmers.

The specific chlorine concentration in swimming pool water when athletes perform an exercise challenge test to diagnose EIB can result in a diagnostic problem for EIB in swimmers. Swimmers can potentially be misdiagnosed with EIB and started on treatment if the chlorine concentration in the swimming pool water has not been controlled for. Standardized testing may need to be in place to control for the role of different chlorine concentrations on the diagnosis of EIB in swimmers.

It is clear that further studies are needed to test the hypothesis that parameters of lung functions will be altered when swimmers are exposed to chlorinated swimming pools compared with non-chlorinated swimming pools.

Chapter 3

Increased chlorine concentration in swimming pool water is associated with exercised induced bronchospasm

3.1 Introduction

Asthma is the commonest chronic disease in children and the dominant pathophysiological process underlying asthma is airway inflammation resulting in a transient narrowing of airways (Motala, 2000). The inflammatory process is often triggered by viral infections, environmental factors and allergens. Asthma is a clinical diagnosis and the severity of asthma determines the intervention in asthma treatment (Allergy Society of South Africa, 2000, Bethesda, 1995; NHLBI, 1997; Motala, 2000).

Activities and sports that involve high intensity exercise in a cold and dry environment can provoke an attack of asthma in susceptible persons. This is known as exercise-induced asthma or exercise-induced bronchoconstriction (EIB). The definition of EIB is the transient narrowing of airways following vigorous exercise that usually is 6 minutes duration or more (Anderson, 1997). The symptoms of EIB are shortness of breath, cough, wheeze and chest pain. However, EIB is also recorded in individuals without symptoms, and there is no predictable association between symptoms and the presence or absence of EIB (Kenneth, 2000; Rundell, 2000; Rundell, 2001).

The stimulus whereby exercise provokes airways to narrow is the loss of water by evaporation from the airways. This loss of water occurs as a result of the need to humidify the inspired air to body conditions. It is important to note that when the inspired air is fully humidified at body temperature, EIB is completely prevented or inhibited. EIB also occurs in hot (>37 °C), dry conditions and it is therefore thought that the osmotic effects of water loss are more significant than the thermal effects. Thus, the intracellular events following cell shrinkage because of water loss are thought to be critical for mediators to be released resulting in the subsequent narrowing of airways (Anderson, 1997, 2000).

There is also a strong relationship between EIB and asthma. Before the widespread use of inhaled corticosteroids the prevalence of EIB in asthmatics was reported to be up to 80%, and this was similar in adults and children. EIB can also occur in patients without a history of asthma (Sinclair, 1995).

The diagnosis of EIB can be confirmed with spirometry or bronchial provocation tests. Spirometry refers to the measurement of FEV1, forced vital capacity (FVC) and the ratio between these two volumes (FEV1/FVC %). FEV1 and FVC are all measured during a forced expiratory manoeuvre (Quanjer, 1993). It is well established that a 10% or 15% fall in forced expiratory flow in one second (FEV1) after an exercise challenge confirms the diagnosis of EIB (Busquets, 1996; Haby, 1994; Matsumoto, 1999). Subjects can perform exercise on a treadmill or a cycle ergometer in a laboratory under standardised conditions (Anderson, 1997). Alternatively, provocation tests with Mannitol or Metacholine are less expensive, easily portable and a very objective test to evaluate evidence for the use of beta 2-agonists in swimmers with previously diagnosed EIB (Anderson, 2002).

The exercise protocol and specific measurements using spirometry are important in the diagnosis of EIB. The commonly used protocol is to exercise the subject on a treadmill or cycle ergometer at 90%-95% of predicted maximum heart rate for the age range sustained for 4-6 minutes (Haby, 1995; Sterk, 1993). Six minutes of strenuous swimming in the swimming pool has also been used as an exercise challenge test. Bronchial hyper-reactivity is affected by temperature, humidity, specific type, intensity and duration of exercise performed and also by the interval since last attack of EIB (Mc Fadden, 1988; D'Urzo, 1995). During the exercise protocol these factors need to be controlled for. The temperature and humidity of inspired air are also critical in the development of EIB (Paul, 1993; Hendrickson, 1981).

The relationship between swimming and asthma is of particular interest. Swimming is a well-known exercise prescription for asthmatics because it is less asthmogenic than other exercise. The reasons for this are that swimming is an exercise that is conducted in an environment where humid warm air rather than dry cold air is inhaled. However, in recent years, a high rate of bronchial responsiveness to methacholine and a higher prevalence of EIB in swimmers have been reported (Drobnic, 1992). The reason for this reported high prevalence of EIB amongst swimmers is not known. The clinician is therefore faced with the problem of whether to encourage or discourage swimming as a suitable exercise for athletes with EIB.

It has recently been hypothesized that chronic exposure to chlorine compounds might sensitize the airways and cause EIB in elite swimmers (Wick, 1990; Potts, 1994, 1996). Trihalomethanes (THM) are the main by-product of water chlorination when disinfection is performed with sodium hypochloride or, more recently, with sodium dichloroisocyanurate (Aggazzoti, 1998). A number of surveys have reported the presence of THM in swimming pools as by-products of treatment with chlorine and its derivates, of which chloroform (CHCl3) is the most common (Aggazzotti, 1990, 1995; Fantuzzi, 2001, Levesque, 2000; Olivo, 1989). Chloroform (CHCl3), which is a volatile substance released at the surface of the water, can also be inhaled by swimmers. These THM can enter the body by three routes while swimming in chlorinated pools: inhalation, dermal absorption and ingestion. The exposure of the swimmer to THM can be measured in blood, urine and alveolar air compartments (Aggazzotti, 1990, 1993). It has been shown that swimmers are exposed to these products of chlorine (THM) in the breathing zone above the water level in amounts exceeding recommendation by the World Health Organization (Drobnic, 1995). It is therefore possible that the products in the breathing zone above the water level, when inhaled by the swimmer, may provoke or sensitize the airways for EIB.

Thus, despite the benefits of swimming for asthmatics, factors such as chlorine by-products in the air above the water level may increase the risk for the development of EIB in swimmers. The effects of different chlorine concentrations in swimming pool water on airway responsiveness in swimmers with and without a history of EIB are not known.

3.2 Aim of the Study

The aim of the study was to assess whether chlorine exposure during swimming sensitizes the airways of well-trained swimmers with and without a history of EIB. To our knowledge this is the first study comparing the bronchial airways reaction in well trained swimmers with and without symptoms of EIB after swimming in swimming pools with different chlorination systems and chlorine concentrations.

3.3 Methodology

Type of study

Randomized controlled clinical trial

Subjects

The study commenced in November 2002 after ethics approval has been obtained from the Ethics and Research Committee of the University of Cape Town. Swimming clubs in the Western Cape, South Africa, were used to recruit potential subjects. Subjects were well-trained swimmers who were actively competing for the club or at a higher level (provincial or national) for at least 12 months. Exclusion criteria were severe chronic asthma according to severity classification (Allergy Society of South Africa Working Group, 2000), smoking and an upper respiratory tract infection in the preceding 2 weeks before testing.

In approaching the clubs and swimmers a hand out with information on the study was given to all possible participants (Appendix 1).

Forty one subjects were identified and completed a questionnaire (Appendix 2) which included demographic and personal details e.g. age, height, weight, sex, competition level, swimming hours per week, previous history of illnesses and specific respiratory diseases (asthma, EIB or asthma like symptoms). Based on the results of the questionnaire, subjects were divided into the EIB subgroup (n=21) and the CON subgroup (n=20).

For the purposes of this study the main criteria to include subjects into the EIB subgroup was a positive answer to the question whether swimmers are on medical treatment for asthma or EIB or if subjects have any symptoms of asthma according to the chronic asthma severity classification.

Baseline testing of subjects

Subjects in both subgroups performed baseline spirometry at rest to determine a Forced Expiratory Volume in the 1st second (FEV1) for each subject. The frequency of clinical symptoms (day or night cough, recurrent or persistent wheezing, exercise-induce cough and/or wheeze) during daytime and nighttime and the FEV1 were used to assess the severity of asthma in the EIB group. The main purpose for grading the severity of asthma was to exclude the severe asthmatics from the study. None of the subjects were excluded because of severe asthma.

The subjects were fully informed of the testing procedure and possible complications, and once fully informed, they were requested to sign a consent form (Appendix 3).

Testing protocol during the exercise challenge

The study was conducted as a randomized controlled study with the interventions being the exposure of swimmers to swimming pool water at no chlorine and two different chlorine concentrations. In addition all swimmers completed a non-swimming exercise challenge at the same intensity next to the pool as a control.

The following procedures were standard in all test conditions.

- Subjects were randomly exposed to different test conditions.
- The time of day and air temperature at the testing venue was recorded. (Penny, 1983; Bar-Or, 1992; Drobnic, 1996).
- All the subjects were tested between 6h00 and 10h00 in the morning.
- Inhaled short-term acting β_2-agonists and disodium cromoglycate were withheld for 8 hours prior to testing; inhaled steroids were withheld for the last 12 hours, inhaled salmeterol was withheld for the last 36 hours and anti-histamine and theophyllin were withheld for the last 72 hours before tests (Carlsen, 2000).
- Subjects were not allowed to perform any physical exercise in the twelve hours before testing.
- Subjects had to be free from any respiratory infection 2 weeks preceding the testing.
- FEV1 was measured during spirometry lung function tests during a forced expiratory manoeuvre. The expiratory manoeuvre was supervised by a trained clinician. The swimmer was asked to sit down, relax and exhale to maximum effort. Swimmers then inhaled with maximum effort, tightly closed the mouthpiece of the spirometry with the lips and then performed a maximum exhalation through the mouthpiece of the spirometer. Once the reading in the spirometer was registered, the FEV1 was recorded on the data collection sheet (Appendix 4).

Measurement of swimming pool chlorine concentrations

At all testing venues the swimming pool water was sampled and tested for the chlorine concentration. Water samples were obtained from the pools half an hour before the swimmers started the exercise challenge in the swimming pool. A water sample was collected at different ends of the pool. The sample was tested on standard equipment (as described below) by the swimming pool technicians at the different venues. The chlorine level in that sample was recorded on the data collection sheet.

(i) Pool 1 (No chlorine - NoChl)

At this swimming pool, a copper ionizing system was in place to disinfect the water. No chlorine was added to the pool water. Therefore the chlorine concentration was zero. A zero concentration of chlorine was confirmed using a standard HTH chlorine testing kit (Arch Chemicals (PTY) LTD, Sandton, Gauteng, South Africa). At the time of testing, the chlorine concentration in the swimming pool was recorded as zero.

(ii) Pool 2 (Chlorine at 0.5ppm – Chl[0.5])

This city council outdoor swimming pool was available for public use. At this swimming pool the water was disinfected with chlorine that is produced by a gas chlorinator and pumped into the water. The chlorine concentration was tested by a Comparator (manufactured by HACH, Ames, State of IOWA, USA). A chlorine concentration of 0.5 ppm is the standard level for all public chlorinated outdoor swimming pools in the Western Cape, South Africa. At the time of testing, the chlorine concentration in the swimming pool was recorded as 0.5 ppm.

(iii) Pool 3 (Chlorine at 1.0 ppm – Chl[1.0])

This city council outdoor swimming pool was available for public use. At this swimming pool the water was also disinfected with chlorine that is produced by a gas chlorinator and pumped into the water. The chlorine concentration was tested by a TDS meter (HI98302 Dist2, by Hanna Instruments, USA). For the purpose of the study, the concentration of chlorine in the pool was increased the night before the test to a concentration of 1.0 ppm. Because the public also uses the pool, only a few selected days were available for testing the swimmers.

A handheld spirometer (Microloop Spirometry, Cobalt Medical Technology, N1 City Goodwood, Cape Town, South Africa) was calibrated according to testing protocols before and during the testing period (Appendix 5). All tests were conducted by a pulmonary technician trained in spirometry testing according the guidelines of the American Thoracic Society of Standardization of Spirometry (1994 Update). Bronchodilators and a medical doctor were available at testing venues. During testing, the achieved heart rate was monitored manually by counting the radial pulse beats for 30 seconds or by using a Polar Heart Rate Monitor (IHF products, Johannesburg). The maximum heart rate achieved during the exercise challenge was recorded. Subjects were asked to exercise or swim at least 8 minutes at 80 to 90 percent of the maximum heart rate (determined as 220 minus age).

The time intervals for testing were pre-exercise, immediately after exercise, and at 5 minutes, 10 minutes, 15 minutes and 30 minutes post-exercise (Matsumoto, 1999). These time intervals were chosen because it has been shown that the bronchoconstriction is progressive, reaching a peak 5 - 15 min after exercise has stopped (Mc Fadden, 1980; D'Urzo, 1995; Voy, 1986; Randolph, 1997). The time to the maximum percentage fall in FEV1 (min) was also recorded. The percentage reduction in FEV_1 was recorded and cut-off points of ≥10% and ≥15% reduction were recorded and considered as positive test for EIB.

All the data were recorded on a data sheet for each patient (Appendix 4). The information was then transferred into Microsoft Excel (Microsoft Office XP Standard for Students and teachers, Version 2002, Microsoft Corporation, USA) to perform the data analysis and statistics. Percentage fall in FEV1 after the exercise test were calculated by: (pre-exercise FEV1 minus the minimum post–exercise FEV1) divided by the pre-exercise FEV1 multiplied by 100% (Carlsen, 1999).

The Running/Cycling (non-swimming) exercise challenge

Subjects underwent a running or cycling challenge test next to one of the swimming pools as a control. Standard procedures as described above were followed during the non-swimming exercise challenge. All swimmers who were able to perform the exercise challenge at Pool 1 completed the exercise challenge test next to the swimming pool on a cycle ergometer. The other swimmers completed the running test next to the Pool 3. Of the thirty-seven subjects who completed the exercise test outside the pool, twenty subjects ran next to the pool and seventeen cycled next to the pool. The subjects were requested to run or cycle at an increasing speed for the first 2 minutes until a target heart rate of 85 % of the predicted maximum heart rate has been achieved. The predicted maximum heart rate has been calculated as 220 minus the age of the subject. The challenge consisted of 6-8 minutes of running or cycling at the required heart rate (Voy, 1986; D Urzo, 1995; Mahler, 1993; Matsumoto, 1999; Carlsen, 1999). The lung function tests were recorded at the same time intervals as after the swimming challenge. The same lung function parameters were recorded during and after the non-swimming challenge as after the swimming exercise challenge.

Swimming Exercise Challenge

Twenty-nine of the forty-one subjects completed a swimming exercise challenge test at Pool 1 (NoChl) in line with the testing protocol as described.

Swimmers also completed a swimming exercise challenge test at a chlorinated swimming pool with two different chlorine concentrations according the testing procedure described above. Seventeen subjects completed the swimming exercise challenge test at chlorine concentrations of 0.5 parts per million Chl[0.5] =17. Thirty subjects completed their swimming exercise challenge test at chlorine levels of 1.0 parts per million Chl[1.0] =30. Not all subjects could complete all tests at the different testing venues, because some subjects were unable to attend specific testing venues on the specific testing days. Eighteen subjects complete the exercise challenge in both Pool1 (NoChl) and Pool3 (Chl[1.0]).

Baseline testing at rest

Subjects were rested in the same environment as during the exercise challenge testing in line with the testing protocol as described. All forty-one subjects completed lung function tests before and after resting for 20 minutes next to the swimming pool.

Statistical analysis of data

Data were transferred into Microsoft Excel (Microsoft Office XP Standard for Students and teachers, Version 2002, Microsoft Corporation, USA) to perform the data analysis and statistics. Demographic data are given as mean values ± standard deviation (SD). Other results are reported as mean values unless otherwise stated. Statistical analysis was conducted by a trained statistician at the University of Stellenbosch. The incidence of EIB in subgroups was compared using the Chi-square test and a p-value of <0.05 was considered as significant.

3.4 Results

The physical characteristics and training history of the subjects in the EIB and the CON subgroups is depicted in Table 1. There was no difference in the two subgroups with respect to age, weight, height and hours of training a week.

The symptoms and medication use in the EIB subgroup (n=20) is summarized in Table 2. The EIB subgroup consisted of subjects who reported daytime or nighttime symptoms of asthma or EIB during exercise or any subject under medical treatment for asthma. Seventeen (85%) of the EIB subgroup used no medication, whereas one (5%) subject used one medication, one subject (5%) used two medications, and one subject (5%) used three medications. The severity of daytime symptoms in the EIB subgroups was as follows: 15% experienced no daytime symptoms, 60% experienced daytime symptoms < 2 times per week, 15% experienced daytime symptoms between 2 and 4 times per week, and 10% experienced daytime symptoms > 4 times per week. The severity of night time symptoms in the EIB subgroup was as follows: 55% experienced no night time symptoms, 35% experienced night time symptoms < 2 times per month, 10% experienced night time symptoms between 2 and 4 times per month, and no subjects experienced night time symptoms > 4 times per month.

The incidence of positive results for EIB at the different testing conditions and at different cut-off points of 10% and 15% is compared in Table 4 (i) and Table 4 (ii). First a fall of 10% or more in the FEV1% was considered positive for the diagnosis of EIB. The EIB and CON subgroups were also compared at the different testing conditions. The incidence of EIB when subjects were exposed to the Chl[1.0] swimming pool was 63%. This was significantly higher (p=<0.01) than the incidence of EIB in the Chl[0.5] (11%) and NoChl (17%) swimming pools. Between the EIB and CON subgroups there was no difference in the incidence of EIB in the different testing conditions. When a 15% fall in FEV1% was used as the cut-off for the diagnosis of EIB, there was also a higher incidence of EIB in the Chl[1.0] swimming pool (27%) compared with the other testing conditions (Chl[0.5] =5%, NoChl=7%).

The maximum fall in FEV1% occurred within 0 to 10 minutes after the exercise challenge (Figure 2, Table 5). Testing in the Chl[1.0] pool showed the greatest fall in FEV1% (10.4%). In the Chl[0.5], NoChl and Non-Swim Exercise subgroups the maximum fall in FEV1% were less then 5.2%.

Analysis of the results of the subjects that were tested in both the no chlorine and the high chlorine pools (n=18), were similar (Table 6). Although the p-value (0.07) is not significant, there was a tendency for more swimmers to be tested negative in the NoChl (15, 83%) and positive in the Chl[1.0] pool (10, 56%) vs. swimmers tested positive in the NoChl pool (3, 17%) and negative in the Chl[1.0] pool (8, 44%).

Discussion

The main finding of this study is that there is an increase in the incidence of EIB after swimming in Chl[1.0] pool (chlorine=1.0 part per million). Swimming in the Chl[0.5] pool (chlorine=0.5 parts per million) or in the NoChl pool did not increase the risk for developing EIB post exercise compared with exercise performed at the same intensity and duration outside the swimming pool. This study shows the short-term effects of chlorine exposure on lung function of swimmers, and supports the hypothesis that chlorine exposure is an important factor that increases the risk of developing EIB in swimmers. Previous studies documenting short-term deterioration in lung function and increase in lung permeability after chlorine exposure correlate with our findings. However, in our study we show that concentrations of chlorine above 0.5 parts per million are associated with an increase in the incidence of EIB. At a chlorine concentration of 0.5 ppm or less the incidence of EIB is no different than when exercising next to the swimming pool.

A further interesting finding of our study was that there was no difference in the response to high chlorine concentrations in the EIB subgroup compared with the CON subgroup. It has previously been shown that there is no predictable association between symptoms and the presence or absence of EIB (Rundell, 2002; Rundell, 2003). However, further studies are required to investigate the effect of chlorine on lung functions of swimmers with and without a history of EIB.

The last finding of the study was that the maximum fall in FEV1% was within 10 minutes after the exercise challenge. This is similar to the findings of others who reported that the peak time of bronchospasm is within 10 minutes after an exercise bout and can last up to 30 minutes (Mc Fadden, 1988; D'Urzo, 1995; Voy, 1986; Randolph, 1997; Anderson, 1997; Mahler, 1993).

There are limitations to our study. Chlorine exposure was only confirmed with chlorine concentrations of the water and no blood or alveolar samples were taken from the subjects. No samples were taken of the air above the pool water to confirm the exposure to chlorine above the level of the swimming pool water. All the subjects were also not exposed to all four exercise challenges because of the availability of the subjects on specific days of testing. The testing was done during the summer in South Africa where air is more dry and hot. In other studies, tests were also conducted in cold air and at lower temperatures. Lastly, inhalant allergens can have an additive effect on inducing asthma. The study did perform skin tests to allergens and thus could not exclude the role of these allergens in inducing asthma.

Despite the limitations of the study, the objective to assess whether chlorine exposure during swimming provokes EIB in well-trained swimmers with and without a history of EIB was achieved. The factors that influence the lung function tests and thus the diagnosis of EIB were well controlled for.

In summary, this study confirms that the chlorine concentration in swimming pools above a threshold of 0.5 parts per million provokes bronchospasm without the subjects necessarily experiencing any symptoms. Bronchospasm or EIB occurs to a lesser degree at lower concentrations of chlorine and the incidence under these conditions is similar to exercise challenge at the same duration and intensity while performing non-swimming exercise next to the swimming pool.

A few questions can be raised based on these findings.

1. Do plasma protein levels (pneumoproteins) indicating damage to lung permeability compare to lung function parameters when swimmers were exposed to different chlorine concentrations?
2. Will smaller increases in chlorine concentration above 0.5 parts per million show a definite level where there is deterioration in lung function tests and lung permeability?
3. In the cause of EIB, which plays a bigger role: the increase in lung permeability because of chlorine exposure or the osmotic effect on airways during exercise?
4. Does chlorination with different chlorine substances in indoor and outdoor swimming pools have the same effect on respiratory health?

Although these results and previous studies confirm the negative effects of chlorine on respiratory health, more research needs to be done. The following practical recommendations can assist in further research on this topic.

1. The exact concentration of chlorine in water needs to be compared to the blood levels of chlorine and the concentration of chlorine in the air above the water.
2. Smaller increases of chlorine concentrations can be compared to lung functions parameters at specific concentrations.

3. The serum level of pneumoproteins needs to be analyzed and compared with chlorine levels, lung permeability damage and spirometry results.
4. The effect of chronic exposure on respiratory health requires investigation as our results confirm only short-term deterioration in respiratory health.
5. More subjects must participate in further studies and the swimmers needs to be tested in cold and dry environments.
6. When performing diagnostic exercise challenge tests to diagnose EIB, standardized protocols have to be in place to prevent the misdiagnoses of EIB.

Table 1 Physical characteristics (age; weight; height) and training hours of the control group compared to the EIB group. Values are mean (SD).

	Age(yrs)	Male/ Female	Weight (kg)	Height (cm)	Training (Hrs/ wk)
All subjects (n=41)	15 (13)	20:21	58 (19)	159 (17)	12 (5)
EIB subgroup (n=20)	13 (14)	08:12	54 (20)	158 (19)	11 (4)
CON subgroup (n=21)	15 (14)	12:09	62 (17)	160 (15)	15 (5)

There were no significant differences between the EIB and CON subgroups.

Table 2 Nighttime symptoms, daytime symptoms and use of medication in the EIB subgroup (n=20)

Night time symptoms	**n (%)**
> 4 times a month	0 (0%)
2-4 times a month	2 (10%)
< 1 time a month	7 (35%)
No symptoms	11 (55%)
Total subjects with night symptoms	***9***

Day time symptoms	**n (%)**
> 4 times a month	2 (10%)
2-4 times a month	3 (15%)
< 2 time a month	12 (60%)
No symptoms	3 (15%)
Total subjects with day symptoms	***17***

Use of medication	**n (%)**
Subjects on no medication	17 (85%)
Subjects on one medication	1 (5%)
Subjects on > one medication	2 (10%)
Total subjects on medications	***3 (15%)***

Table 3 Physical characteristics of the subjects who were tested during non-swimming exercise and swimming in the no chlorine, 0.5 ppm and 1.0 ppm chlorine conditions and the air temperature during the testing conditions.

	Median Age (years) (SD)	EIB subgroup	CON subgroup	Male: Female	Median Weight (kg) (SD)	Median Height (cm) (SD)	Median Hours/wk (SD)	Median Air temp °C (SD)
Non-swimming exercise n=37	15 (14)	16 (43%)	21 (57%)	18:19	60 (18)	160 (15)	12 (5)	24 (2)
NoChl n=29	**17 (15)**	**12 (41%)**	**17 (59%)**	**13:16**	**58 (17)**	**159 (15)**	**12 (5)**	**22 (1)**
Chl[0.5] n=17	29 (16)	7 (41%)	10 (59%)	07:10	62 (11)	165 (14)	8 (5)	22 (0)
Chl[1.0] n=30	**12 (4)**	**15 (50%)**	**15 (50%)**	**18:12**	**55 (18)**	**155 (15)**	**15 (3)**	**24 (1)**

There was no difference in the physical characteristics between the subgroups that were tested in the different testing conditions.

Table 4 (i) Incidence of EIB (FEV1% fall of 10% or more) when subjects were tested during non-swimming exercise and swimming in the no chlorine, 0.5 ppm and 1.0 ppm chlorine conditions. Values are number of subjects (%).

	Subjects with negative results			Subjects with positive results		
	EIB subgroup	CON subgroup	Subjects tested negative	Symptomatic group	Control group	Subjects tested positive (>10%)
Non-swimming exercise n=37	14	19	33 (89%)	2	2	4 (11%)
NoChl n=29	**10**	**14**	**24 (83%)**	**2**	**3**	**5 (17%)**
Chl[0.5] n=17	7	9	16 (94%)	0	1	1 (6%)
Chl[1.0] n=30	**5**	**6**	**11 (37%)**	**10**	**9**	**19 (63%)**

Table 4 (ii) Incidence of EIB (FEV1% fall of 15% or more) when subjects were tested during non-swimming exercise and swimming in the no chlorine, 0.5 ppm and 1.0 ppm chlorine conditions. Values are number of subjects (%).

	Subjects with negative results			Subjects with positive results		
	EIB subgroup	CON subgroup	Subjects tested negative	EIB subgroup	CON subgroup	Subjects tested positive (>15 %)
Non-swimming Exercise n=37	15	20	**35 (95%)**	1	**1**	**2 (5%)**
NoChl n=29	11	16	**27 (93%)**	1	**1**	**2 (7%)**
Chl[0.5] n=17	7	10	**17 (100%)**	0	**0**	**0**
Chl[1.0] n=30	11	11	**22 (73%)**	4	**4**	**8 (27%)**

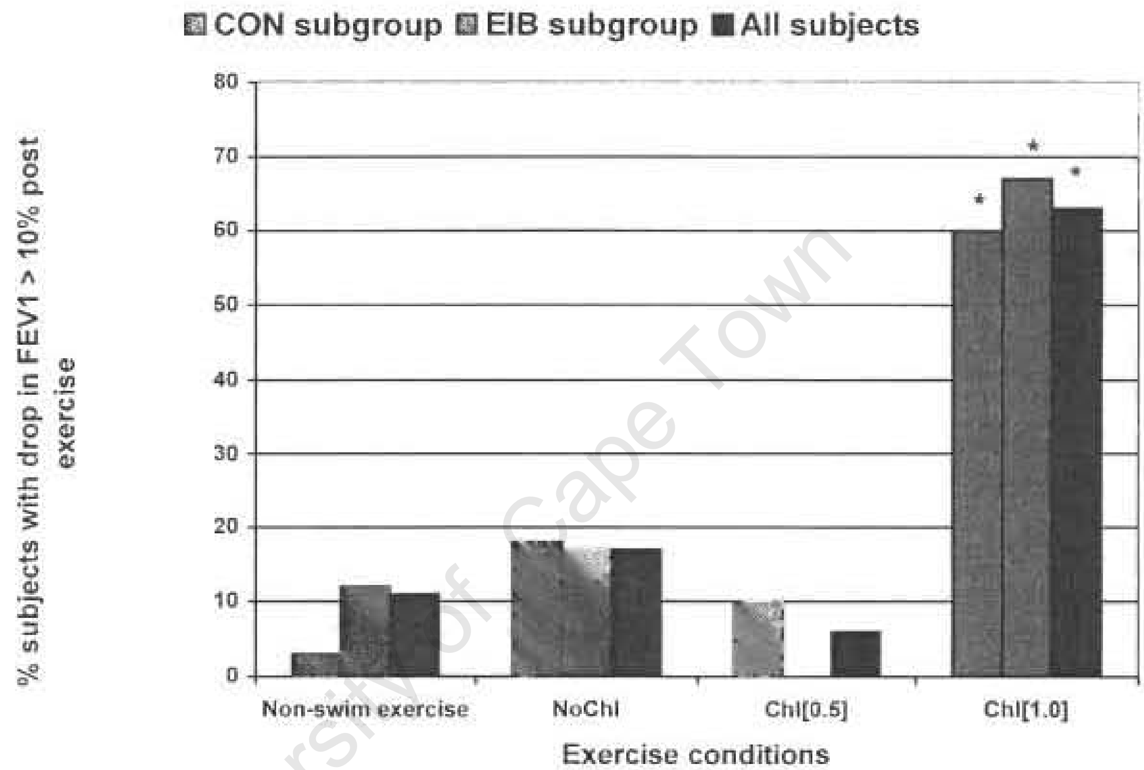
Table 5 **The %change in FEV1 following non-swim exercise and swimming in the no chlorine, 0.5 ppm and 1.0 ppm chlorine conditions in all the subjects. Values are mean (SD) %.**

	Immediate (SD)	5 min (SD)	10 min (SD)	15 min (SD)	30 min (SD)
Non-swim exercise	0.00 (7.16)%	-1.03 (5.72)%	-1.45 (6.83)%	-0.42 (4.50)%	0.00 (5.26)%
NoCHI	0.74 (7.25)%	-1.95 (6.09)%	1.21 (5.50)%	2.02 (5.94)%	-0.43 (5.28)%
Chl[0.5]	-0.72 (5.71)%	-0.27 (3.73)%	-0.47 (4.47)%	2.2 (4.44)%	2.36 (5.23)%
Chl[1.0]	-4.23 (7.75)%	-5.51 (7.33)%	-4.96 (8.74)%	-1.33 (8.05)%	0.00 (11.36)%

Table 6 Physical characteristics (weight, height), training hours and incidence of EIB of the control and EIB group who were tested in both the no chlorine and 1.0 ppm chlorine conditions. Values are mean (SD).

	Median Weight (kg)	Median Height (cm)	Median Training Hours	NoChl		Chl[1.0]	
				Negative	Positive	Negative	Positive
EIB subgroup (n=7)	47 (9)	149 (9)	15 (3)	6 (86%)	**1 (14%)**	**3 (43%)**	**4 (57%)**
CON subgroup (n=11)	58 (11)	155 (11)	15 (3)	9 (82%)	**2 (18%)**	**5 (45%)**	**6 (55%)**
TOTAL (N=18)				**15 (83%)**	**3 (17%)**	**8 (44%)**	**10 (56%)**

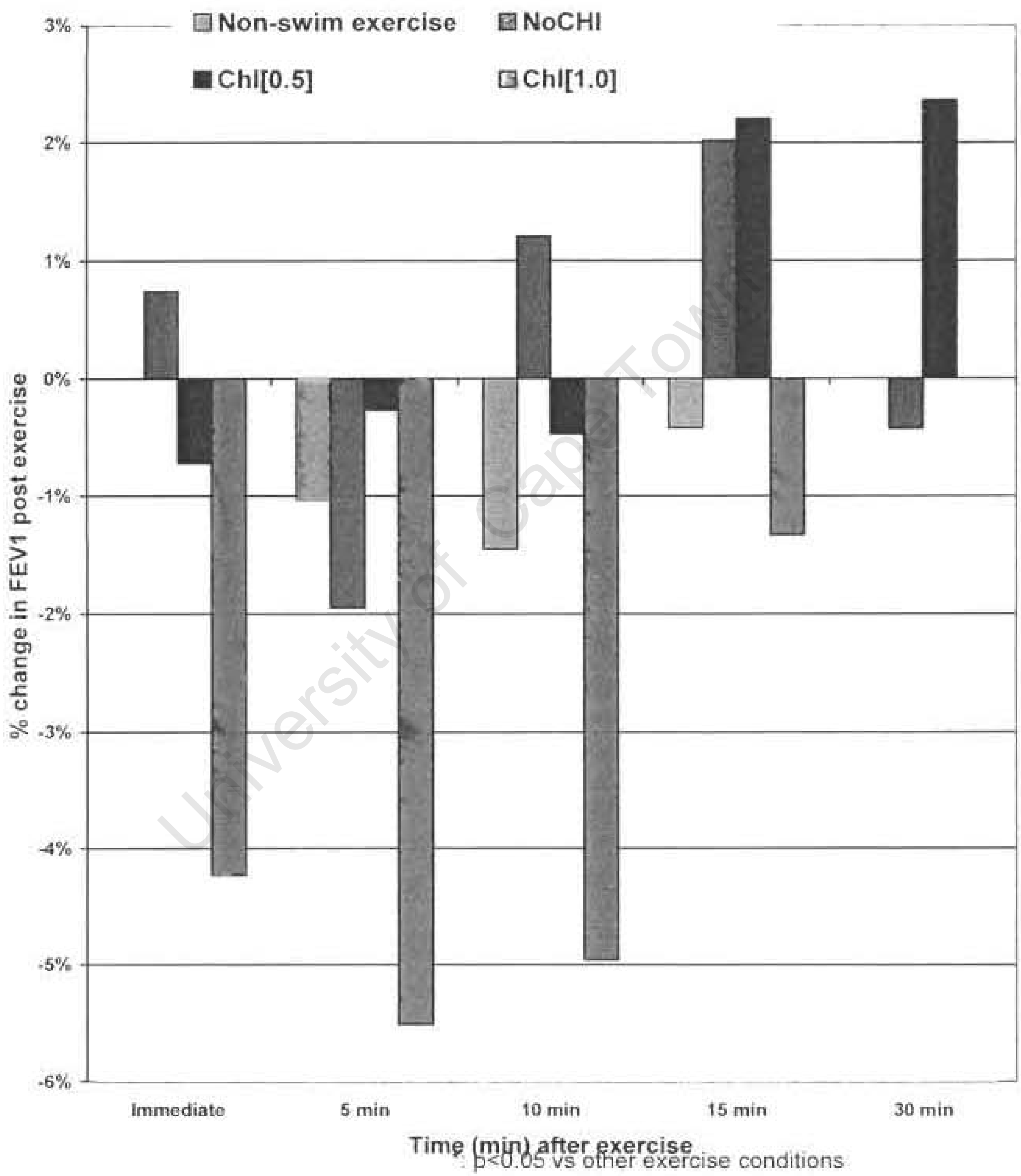
Figure 1: The incidence (% subjects) of Exercise-Induced Bronchospasm (EIB) (FEV1% fall of 10% or more) in all subjects, and the EIB and Control subgroups during non-swimming exercise and swimming in the no chlorine, 0.5 ppm and 1.0 ppm chlorine conditions



*: p<0.05 vs other exercise conditions

No significant differences between EIB and Control groups at any swimming condition

Figure 2: The mean % change in FEV1 following non-swim exercise and swimming in the no chlorine, 0.5 ppm and 1.0 ppm chlorine conditions in all the subjects



Chapter 4

Summary and conclusion

Research in the last two years investigated the question whether exposure to chorine and the by-products of swimming pool chlorination can provoke EIB. The effect of the products of chlorination on respiratory health and the higher incidence of asthma in the western population cause much concern. One possible explanation for the observation that swimmers have a higher incidence of EIB may be related to chlorination of swimming pools. Chlorination is still the main disinfective process in swimming pools all over the world. There are only a few studies that have investigated the effects of chlorination on respiratory health. The reason why exercise provokes EIB is the osmotic effects of water loss from the airways, while during the swimming the chlorine exposure during inhalation of air above the water and chlorine by-products in the water cause a higher risk of provoking EIB in athletes during swimming. This study confirms that chlorine exposure at concentrations of >0.5 ppm cause a higher incidence of EIB in swimmers irrespective of their past history of EIB or asthma.

Research on the question of pool water chlorination and respiratory health is only in the beginning phase. Although there is early evidence of the negative effects of chlorination on respiratory health, further studies are needed. The diagnostic procedure for EIB in swimmers needs to be standardized.

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APPENDIXES

Appendix 1: SUBJECT INFORMATION SHEET

RESEARCHER: ARTHUR J WILLIAMS

SPORT INSTITUTE OF SOUTH AFRICA (NEWLANDS)
MRC/UCT Research Unit for Exercise Science and Sports Medicine In the Faculty of Health Sciences
University of Cape Town

<u>What is this study about?</u>
The study investigate the question whether chlorine in swimming pools cause bronchospasm (exercise induce bronchoconstriction - EIB) of which the symptoms are wheezing, shortness of breath, coughing or chest pain within 30 minutes after exercise or poor performance.

<u>Who are we?</u>
We are a team of doctors, scientists and biokineticist from the Science Institute of South Africa in Newlands who investigate this question.

<u>Where will this study be undertaken?</u>
Sport Science Institute, Newlands, Western Cape, South Africa.

<u>What do we need?</u>
We need 40 well-trained swimmers (who actively participate in club competitions or on higher levels the last 12 months) who can be sufferers of EIB (taking medication for it) and who are not smoking or suffering from a respiratory infection.

<u>What investigations will be done?</u>
Each swimmer will be asked to fill in a questionnaire and perform a baseline lung function test. The lung function test is a non-invasive test under supervision of a biokineticist who will instruct you as the swimmer on how to do the test. The test takes only a minute or two and will be done before and after each exercise that you as the swimmer will undertake. The test will be repeated every 5 minutes after the exercise up to 30 minutes after the exercise.

<u>What type of exercise will the swimmers need to do?</u>
The swimmers will undergo 3 different type of exercise. The first test is a progressive exercise challenge run for more or less 10 minutes at the Sport Science Institute of South Africa, Newlands (SCISA) on an indoor track. The 2nd test will be a swimming exercise challenge test of the same exercise intensity for almost 10 minutes in a salt water chlorinated indoor pool at the SCISA. The 3rd test will be a swimming test in an indoor traditional chlorinated swimming indoor pool in Cape Town. Transport to these venues will be supplied if needed and the

tests will be done on separate days and each will take almost an hour. Swimmers under the age of 18 will be requested to complete a permission form from their parents. All the tests will be perform under supervision of a biokineticist and in the presence of the research team who will have a doctor present at all time.

Will the information be available to the swimmers and what benefits will there be?
Yes. The information will have detail on each swimmer's lung capacity in each of these circumstances after exposure to exercise and chlorine in different indoor pools. The diagnosis of EIB can be made in swimmers even if you don't have any symptoms. Reasons for poor performance, coughing, wheezing and shortness of breath can be identified and treated if needed. Each swimmer can thus be correctly treated after these tests.

Possible risks for you as the swimmer
Swimmers on medication for asthma need to stop the medication for up 36 hours before each test. The control over your asthma can deteriorate and you will be supplied with an information sheet that will inform you what you need to do if you develop any symptoms of an acute asthma and whom you can contact. Treatment for asthma by a qualified doctor will be available at all testing venues.

FOR QUERIES CONTACT THE FOLLOWING NUMBER: DR A WILLIAMS 082-453-4724

Appendix 2: PERSONAL QUESTIONNAIRE

Name		Surname	
Date of birth		Male /Female	
Address			
Name and tel. of doctor			
Telephone	Home:	Work:	Cell:
Weight (kg)		Height (cm)	
Hours swimming/ week		Level	1- Club only 2- Province

Do you use any medication for asthma (Y/N)? If yes, what medication are you using?

....

Treatment? *Give name, dosage and frequency of therapy.*

Grading of severity of asthma

How often do the experience the following symptoms: shortness of breath, wheezing, coughing and coughing after exercise?

During daytime (in a week)	*<2 times week*	*2-4 week*	*>4 times week*	*Continuous*
During night time (in a month)	*<1 time a month*	*2-3 times*	*>4 times a month*	*Frequent*
Baseline PEF	*>80%*	*>80%*	*60-80%*	*<60%*

Appendix 3: Informed consent form

Does the exposure to chlorine in swimming pools cause an asthma attack (symptoms of coughing, wheezing, short of breath, chest pain or fatigue) in well-trained swimmers?

I ______________________________________ have been fully informed of the nature of this research project and hereby give my consent to act as a subject for the reset.

I am fully aware of the procedures involved:

- The answering of a questionnaire
- A standardized treatment plan which include medication and the availability of a medical doctor for any symptoms or attack of asthma before, during or after the exercise program
- Performing lung function testing which is non-invasive and for up to 30 minutes after the exercise under the supervision of a trained Biokinetist and a Medical Doctor.
- Performing a swimming exercise test in a chlorinated and salt chlorinated swimming pool whereby I have to swim in a specific indoor swimming pool for a certain duration of time and at a certain exercise intensity level
- Performing a exercise running challenge test (running on an indoor running tract at the Sport Science Institute for a certain duration of time and at a certain exercise intensity level)

I am aware of the potential risks and complications such as:

- If I am an asthmatic on medical treatment I have to stop my asthma medication which can elicit asthmatic symptoms such as shortness of breath, cough, wheeze and chest pain
- These symptoms can start before, during or after the exercise testing
- Running and swimming can cause minor injuries and allergies.

I am also aware of the possible benefits such as:

- **The diagnosis of exercise-induce asthma that can be made during the testing even if I have no symptoms of asthma**
- **The degree of my asthma can be determine and be treated**
- **The factors that provoke an asthma attack during swimming will be determine (exercise, swimming or the chlorine exposure in swimming pools)**

I have been informed that medical treatment for asthma will be available at all testing venues.

I am aware that I may withdraw my consent and participation in the research project at any time.

I understand that the data collected may be used for scientific purposes and publication in a confidential manner.

I understand the implications of my informed consent and any questions I may have had have been answered to my satisfaction.

Name:____________________ Signed:____________________ Date:
Parent/Guardian:____________ Signed:____________________ Date:
Researcher: _______________ Signed:____________________ Date:
Witness:___________________ Signed:____________________ Date:

Appendix 4: PATIENT DATA COLLECTION SHEET

NAME OF PATIENT	Record Nr			
	Resting	Running	No chlorine	Low/high Chl
Date				
Location nr				
Technician				
Air Temp				
Humidity				
Chlorine				
Time of day				
Baseline FEV				
Post exercise FEV1				
% Fall in FEV1				
5 MIN POST EXERCISE				
10 MIN POST EXERCISE				
% Fall FEV1				
15 MIN POST EXERCISE				
% Fall FEV1				
30 MIN POST EXERCISE				
%Fall FEV1				
MAX %FALL IN FEV1				

APPENDIX 5: LUNGFUNCTION CALIBRATION REPORT

Cobalt medical technology cc

P.O.Box 12779, N1 city, Goodwood, 7463
Rep. Of South Africa

Tel: (021) 910-0555
Fax: (021) 910-0782

LUNGFUNCTION SERVICE REPORT

Client: Dr A Williams

Address: P.O.Box 2 Pniel 7681

Tel: 8851880 **Fax:**

Technician: REX **Date:** 15/1/2003

Type of Machine: Micro Loop II

Serial Number: 1264

	Action taken	Comment:
1.	Check power lead and fuses	OK
2.	Check power supply and charging rate	9V 500mA charging fine
3.	Check battery	Faulty replaced battery pack
4.	Checked and cleaned transducer/turbine	OK no damage
5.	Check spindle	spindle OK , no obstruction
6.	Check optical sensor	transmitter and receiver OK
7.	Check calibration	OK, see printout , calibration within the

		required specification
8.	Check keypad /switch	OK no damage
9.	Check printer unit	
	a. Stylus temperature	N/A
	b. Thermal printer head	N/A
	c. Optical eye sensor	N/A
10.	Check stand alone printer	
	name:	N/A
	serial No:	
	a. Check power supply	
	b. Check ink cartridge	
	c. Check paper feed	
	d. Check converter cable	
11.	Check dongle	N/A
12.	General clean of machine	general clean ,no damaged to unit

Comment: working fine

Replaced battery pack

Next Service Due:15/1/2004

Assuring you of our best attention and technical back-up service at all times.

Thanking you

Rex Elferink
Technical Manager

Cobalt medical technology cc

P.O.Box 12779, N1 city, Goodwood, 7463
Rep. Of South Africa

Tel: (021) 910-0555
Fax: (021) 910-0782

LUNGFUNCTION SERVICE REPORT

Client: Dr A Williams

Address: P.O.Box 2 Pniel 7681

Tel: 8851880 **Fax:**

Technician: REX **Date:** 26/4/2002

Type of Machine: Micro Loop II

Serial Number: 1264

	Action taken	Comment:
1.	Check power lead and fuses	OK
2.	Check power supply and charging rate	9V 500mA charging fine
3.	Check battery	battery pack ok
4.	Checked and cleaned transducer/turbine	OK no damage
5.	Check spindle	spindle OK , no obstruction
6.	Check optical sensor	transmitter and receiver OK
7.	Check calibration	OK, calibration within the required

		specification
8.	Check keypad /switch	OK no damage
9.	Check printer unit	
	a. Stylus temperature	N/A
	b. Thermal printer head	N/A
	c. Optical eye sensor	N/A
10.	Check stand alone printer	
	name:	N/A
	serial No:	
	a. Check power supply	
	b. Check ink cartridge	
	c. Check paper feed	
	d. Check converter cable	
11.	Check dongle	N/A
12.	General clean of machine	general clean ,no damaged to unit

Comment: working fine

Next Service Due:26/4/2003

Assuring you of our best attention and technical back-up service at all times.

Thanking you

Rex Elferink
Technical Manager