Respiratory Medicine 137 (2018) 129–133

Contents lists available at ScienceDirect

Respiratory Medicine

journal homepage: www.elsevier.com/locate/rmed

Systemic and airway oxidative stress in competitive swimmers

Sabina Škrgat*, Robert Marčun, Izidor Kern, Mira Šilar, Julij Šelb, Matjaž Fležar, Peter Korošec

University Hospital of Respiratory and Allergic Diseases, Golnik, Slovenia

ARTICLE INFO

Keywords:
Competitive swimmers
Training
Bronchial hyperresponsiveness
Oxidative stress
Inflammation

ABSTRACT

Background: The environment in swimming pools, which contain chlorine, might interact with the airway epithelium, resulting in oxidative stress and/or inflammation during high intensity training periods.

Methods: We evaluated pulmonary functional (metacholine challenge test, FEV1 and VC), cellular (eosinophils and neutrophils), inflammatory (FeNo, IL-5, IL-6, IL-8 and TNF-α), oxidative (8-isoprostanes) and angiogenesis factors (VEGF) in induced sputum and peripheral blood of 41 healthy non-asthmatic elite swimmers (median 16 years) during the period of high intensity training before a national championship. The second paired sampling was performed seven months later after training had been stopped for one month.

Results: There was a ten-fold increase (median 82–924 pg/ml; $P < 0.001$) in 8-isoprostanes in induced sputum and five-fold increase (median 82–924 pg/ml; $P < 0.001$) in sera during training in comparison to the period of rest. However, there was no difference in FEV1 (113 vs 116%), VC (119 vs 118%), FeNo (median 34 vs 38 ppb), eosinophils (2.7 vs 2.9% in sputum; 180 vs 165 cells/μl in blood), neutrophils, different cytokines or VEGF in induced sputum or sera. The only exception was TNF-α, which was moderately increased in sera (median 23 vs 40 pg/ml; $P = 0.02$) during the peak training period. Almost half (18 of 41) of swimmers showed bronchial hyperresponsiveness during the peak training period (PC20 cutoff was 4 mg/ml). There was no correlation between hyperresponsiveness and the markers of oxidative stress or inflammation.

Conclusions: High intensity training in healthy, non-asthmatic competitive swimmers results in marked oxidative stress at the airway and systemic levels, but does not lead to airway inflammation. However, we could not confirm that oxidative stress is associated with bronchial hyperresponsiveness (AHR), which is often observed during the peak exercise training period.

1. Introduction

The mechanisms of airway disorders associated with competitive swimming are not fully understood. The high level of ventilation during exercise is believed to affect the airway mucosa through two mechanisms: dehydration and mechanical stress [1,2]. Chemical treatment with chlorine is used to disinfect water in indoor swimming pools, and the gaseous chlorine by-products above the water level, such as trichloramines or trihalometans, may be especially important. However, there are conflicting data concerning the impact of the chlorinated pool environment on the airways of competitive swimmers [3–5]. The chlorine hypothesis suggests that the interaction between chlorine and the airway epithelium results in oxidative stress and airway inflammation. When inhalation of chlorine by-products repeatedly occurs, such as in elite swimmers, it may result in an impairment of antioxidant activity and/or the pro-inflammatory response, contributing to increased airway responsiveness or asthma [6,7].

In previous studies of induced sputum in swimmers, there were no significant differences in neutrophil counts between swimmers and mild asthmatic subjects and controls. Eosinophils were increased in both swimmers and asthmatic subjects compared with controls [4]. Furthermore, no significant differences in inflammatory cell counts were observed between swimmers with a PC20 FEV1 of less than 4 mg/mL and those with a PC20 FEV1 of more than 4 mg/mL [5]. In addition, adolescent swimmers had increased IL-6 and TNF-αlevels after exercise [8]. Regarding the cytokine response to exercise, swimmers, but not the controls, showed a decrease in the amount of some cytokines, including IL-6 and TNF-α [9].

Oxidative stress is defined as the presence of active oxygen species in excess of the available antioxidant buffering capacity. Major reactive oxygen species belong to free radicals, and reactive oxygen species may damage proteins, lipids, DNA and carbohydrates by changing their structure and function [10,11]. They are involved in non-enzymatic processes that involve the peroxidation of membrane phospholipids, resulting in the generation of isoprostanes. Isoprostanes are thus major oxidative stress markers that are generated from polyunsaturated fatty

* Corresponding author. University Hospital of Respiratory and Allergic Diseases, Golnik 36, 4204 Golnik, Slovenia.
E-mail address: sabina.skrgat@klinika-golnik.si (S. Škrgat).

https://doi.org/10.1016/j.rmed.2018.03.005
Received 30 December 2017; Accepted 2 March 2018
Available online 03 March 2018
0954-6111/

acids, mainly from arachidonic acid. Isoprostanes are stable compounds that are present in urine, plasma, cerebrovascular fluid and exhaled breath condensate. They are unaffected by the lipid content and diet [12]. Oxidative stress is known to be associated with many acute and chronic diseases, such as cancer and cardiovascular, neurodegenerative and lung diseases. There are several reports highlighting oxidative stress as a part of the pathogenesis of asthma [13–15]. Balanza and colleagues found elevated concentrations of isoprostane levels in exhaled breath condensate in children with moderate persistent asthma compared to healthy controls [13].

The aim of our study was to monitor pulmonary function, airway hyperresponsiveness (AHR), FeNO and respiratory symptoms in healthy non-asthmatic elite swimmers during the period of high intensity training before a national championship and then during the period of rest after training had stopped for one month.

We therefore aimed to characterise systemic and airway (induced sputum) oxidative stress and inflammation in competitive swimmers during two different swimming periods: the period of high intensity training just before a national championship and after training had stopped for one month. At both time points, we evaluated systemic and airway (induced sputum) inflammation (eosinophils, neutrophils, IL-5, IL-6, IL-8 and TNF cytokines), oxidative stress (8-isoprostane), chemokines (MCP1) and angiogenesis factors (VEGF).

To understand the environmental impact on these processes, we compared swimmers in two different swimming pools with different exposures to chlorine and its by-products.

2. Methods

2.1. Study subjects

We included 41 healthy competitive swimmers. The exclusion criteria included a previous diagnosis of asthma or any other chronic disease. All subjects were prospectively followed for 8 months: first during high intensity training before the beginning of the national championship in February 2015 and then after training had stopped for one month in September 2015. At the first time point in February, we performed pulmonary function tests, metacholin testing, induced sputum and peripheral blood sampling. At the second time point in September, we repeated all of the testing and sampling, except metacholin testing. Swimmers were trained in two different pools with different levels of ventilation: 23 swimmers were trained in pool 1 and 18 swimmers were trained in pool 2.

2.2. Spirometry, metacholin and FeNO

Spirometry was carried out according to American Thoracic Society Criteria [16] on a spirometer (Vyntus CPX, CareFusion Germany 234 GmbH). Airway responsiveness to metacholine was measured during the high intensity training period by using the tidal breathing method according to the standards recommended by the American Thoracic Society [16]. The PD20 FEV1 (provocation dose of inhaled metacholine causing a 20% fall in FEV1) was obtained by linear interpolation on the log concentration response curve. A cutoff of a maximum of 2 mg of metacholine was used to determine the PD20.

FeNO was measured with the online chemiluminescence FeNO analyser CLD 88 Series (ECOMEDICS, Duernten, Switzerland) according to published guidelines from the European Respiratory Society (ERS) and American Thoracic Society (ATS) [17].

2.3. Induced sputum

Sputum was induced as previously described in detail [18]. Briefly, subjects inhaled 4,5% hypertonic saline, nebulized via an ultrasonic nebulizer (PARI MASTER Type 84.0100, PARI GmbH, Starnberg, Germany), during three 5-min periods, and at least 2 ml of sputum was collected into a sterile container. The sputum was immediately processed and homogenized with 0,1% dithiothreitol (Sputolysin, Calbiochem, San Diego, CA, USA), and cell-free supernatants was frozen at −80 °C until subsequent analysis. The total number of nonsquamous cells (TNNC) per ml of sputum sample was assessed using a hemocytometer. Cytospins were stained according to the May-Grünwald-Giemsa and Papanicolaou methods. Differential cell counts were performed by one observer counting 200 nonepithelial cells. The quality of the induced sputum was assessed according to the recommendations of Pizzichini E et al. [19], and only samples with a score of 7 or more were used for further analysis.

2.4. Cytokines, MCP1 and VEGF

The detection of pro-inflammatory cytokines and VEGF was performed as reported previously [18]. Briefly, IL-5, IL-6, IL-8, TNF, MCP1 and VEGF (subtypes 165 and 121), were measured with cytometric bead arrays (BD Biosciences, San Diego, CA, USA) containing microparticles dyed to different fluorescence intensities. The captured beads were incubated with standards (purified from human plasma) or test samples (serum or induced sputum supernatant), followed by a wash and incubation with phycoerythrin-conjugated detection antibodies to form sandwich complexes. Flow cytometric analysis was performed using a FACSCalibur flow cytometer (BD Biosciences). Data were acquired and analysed using cytometric bead array software.

2.5. 8-Isoprostanes

8-isoprostane in serum or induced sputum supernatant was measured with a competitive enzyme immunoassay for the quantification of 8-isoprostane (8-isoprostane EIA KIT, Cayman Chemical Company, MI, USA) according to the manufacturer's instructions. Immediately after the collection of the sample, we added 0.005% butylated hydroxytoluene stabilizer. The detection limit of this immunoassay is in the pg/ml range.

2.6. Chlorine and trihalometans

We determined the free chlorine and total chlorine in swimming pools by using a colorimetric method with *N*,*N*-diethyl-1,4-phenylenediamine (according EN ISO 7393:2000 standard). Trihalometans were determined with Electron Capture Detectors and HP-5 columns according to SIST EN ISO 10301:1998 standard (Agilent, Santa Clara, CA, USA) in the air 5 cm above the water level.

3. Results

3.1. Study subjects

There were 23 (56.1%) females and 18 (43.9%) males. The median age was 16 years (IQR 4 years). All subjects were healthy, without any previous or current diagnosis of asthma, and they were not taking any inhaled or systemic therapies. Twenty-seven of the 41 swimmers had a history of mild and occasional respiratory symptoms during the high training period.

3.2. Pulmonary function

There was no difference in FEV1 (median 116% in high training vs. 113% in rest; P = 0.248) or VC (median 118% in high training vs. 119% in rest) (Table 1). However, almost half (18 of 41) of the swimmers showed bronchial hyperresponsiveness during the peak training period (PD20 cutoff was 4 mg/mL, median 0.59 mg/mL). There was no difference in FeNO measurements (median 39 ppb in high training vs 34 ppb in rest).

Table 1
Pulmonary function test results. Data are presented as the median with interquartile ranges (IQR).

	High Intensity (median)	High Intensity (IQR)	Rest (median)	Rest (IQR)	p-value
VC (%)	118	16	119	17.5	0.452
FEV 1 (%)	116	16	113	15	0.248
NO (ppb)	39	24.5	34	29.5	0.706

3.3. Eosinophils and neutrophils

There was a higher total cell number in induced sputum during the high intensity period in comparison to the rest period (median 2880 vs.1170 cells/ml) (Table 2). However, we could not find any difference in the percentages of eosinophils (median 2.9% vs 2.7%) and neutrophils (median 48% vs 48.5%) in the induced sputum between the training and rest period. There was only a slight difference in the absolute number of eosinophils in peripheral blood at high intensity vs rest (training median 165 cells/μl vs rest median 180 cells/μl). There was no significant difference in the induced sputum concentrations of eosinophils ($p = 0.898$) and neutrophils ($p = 0.323$) between swimmers with negative and positive AHR.

3.4. Oxidative stress

There was a ten-fold increase (median 82–924 pg/ml) in the 8-isoprostane concentrations in induced sputum and five-fold increase (median 82–924 pg/ml) in sera during the training period in comparison to the rest period (Fig. 1A–B; Table 3). There was no difference in the 8-isoprostane measurements between swimmers with and without AHR.

3.5. Cytokines

There were no differences in cytokines (IL-5, IL-6, IL-8) or VEGF (vascular endothelial growth factor) in induced sputum or sera between the training and rest period (Table 4). We found only a moderate increase in TNF in the sera during the peak training period (median 27.9 vs 17.9 pg/ml; $P = 0.02$), but this difference was not evident in the induced sputum. There was also a difference in the concentrations of the chemokine MCP1 in serum (median 115.4 in high intensity vs. 147.2 pg/ml in rest; $P < 0.001$) and induced sputum (median 3.07 in high intensity vs. 1.37 pg/ml in rest; $P = 0.002$).

3.6. Swimming pool environments

During the intensive training period, the concentration of free chlorine in water was 0.5–0.6 mg/L (normative 0.3–0.6 mg/L) and the concentration of total chlorine was 0.1–0.2 mg/L (normative 0.3 mg/L in both swimming pools). The concentration of trihalometans in the water was 0.005–0.007 mg/L (normative 0.050 mg/L), and at 5 cm above the water surface, the concentration was 9.8 mg/m^3 in swimming pool 1 and 20.1 mg/m^3 in swimming pool 2. Overall, there were 18 swimmers in pool 1 and 23 in pool 2. However, despite training in environments with different concentrations of trihalometans, we did not find any differences in pulmonary function tests or the measurements of 8-isoprostanes, eosinophils, neutrophils, cytokines or VEGF during the high intensity period and rest.

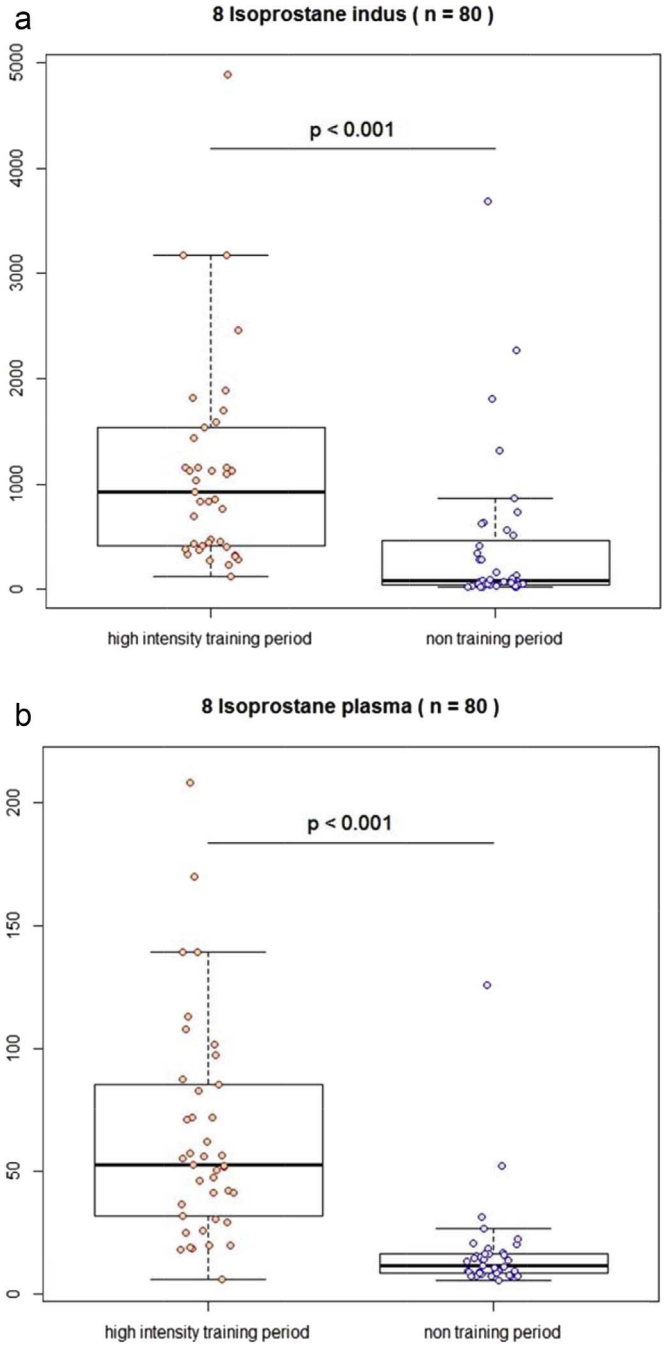

Fig. 1. A–B. 8-Isoprostane concentration in A induced sputum and B serum during high the intensity training period compared to the non-training period. The bars indicate the median value with interquartile ranges for each group.

Table 2
Cell counts in the induced sputum in the high intensity training period and in the rest period. Data are presented as the median with interquartile ranges (IQR).

	High Intensity (median)	High Intensity (IQR)	Rest (median)	Rest (IQR)	p-value
Total cell number/ml of sputum	2880	6210	1170	3127.5	0.026
Eosinophils sputum (%)	2.85	2.55	2.7	2.55	0.071
Neutrophils sputum (%)	48	45.75	48.5	54.25	0.112
Eosinophils (absolute) in blood (cells/μl)	0.165	0.183	0.18	0.16	0.024

Table 3
Concentration of isoprostanes in serum and induced sputum in the high intensity training period and in the rest period. Data are presented as the median with interquartile ranges (IQR).

	High Intensity (median)	High Intensity (IQR)	Rest (median)	Rest (IQR)	p-value
Isoprostane Serum (pg/ml)	52.5	53.5	11.6	7.85	< 0.001
Isoprostane Supernatant (pg/ml)	923.8	1123.7	81.815	422.874	< 0.001

Table 4
Concentrations of cytokines, MCP1 and VEGF in the high intensity training period and in the non-training period. Data are presented as the median with interquartile ranges (IQR).

Cytokine	High Intensity (median)	High Intensity (IQR)	Rest (median)	Rest (IQR)	p-value
IL-5 Supernatant	1.31	4.03	1.35	0.827	0.438
IL-6 Serum	8.92	5.83	8.89	4.05	0.485
IL-6 Supernatant	42.77	604.66	202.525	380.88	0.446
IL-8 Serum	16.87	8.92	16.88	10.775	0.219
IL-8 Supernatant	773.27	3826.29	625.045	1404.773	0.153
TNF Serum	27.996	32.112	17.916	21.925	0.023
TNF Supernatant	1.969	2.473	1.872	0.755	0.72
VEGF Serum	63.15	68.55	59.36	43.035	0.236
VEGF Supernatant	24.4	41.25	18.795	33.3	0.35
MCP1 Serum	115.4	139.18	147.26	183.72	< 0.001
MCP1 Supernatant	3.07	17.18	1.37	0.7	0.002

All measured values are in pg/ml.

4. Discussion

In the present study we showed that high intensity training in healthy, non-asthmatic competitive swimmers results in marked oxidative stress at the airway level. Chlorine and its by-products are strong oxidants, which may irritate the airways and are considered increasingly responsible for the occurrence of respiratory disorders in swimmers. There is a recent report on isoprostanes in swimmers [20], where researchers found increased levels of 8-isoprostane in exhaled breath condensate 10 min after the training session, highlighting the impact of exercise-induced hyperpnoea on oxidative stress. We corroborated those data and showed marked airway and systemic oxidative stress during the high training period, indicating that the problem of airway oxidative stress is not only an » acute « airway problem, linked to hyperpnoea. The impact of air quality on oxidative stress in the lung has been studied during the Beijing Olympics in young healthy non-athlete subjects [21]. Findings from this study suggest that air pollution adversely affected the airway, measured through 8-isoprostanes in exhaled air condensate.

We have shown marked oxidative stress at the systemic level in swimmers during the high intensity training period. There are also other reports of systemic oxidative stress and induction of muscle damage markers by high intensity interval training in competitive swimmers [22]. On the other hand, it seems that low intensity long duration exercise protocols are not associated with oxidative stress [23].

According to our results, exercise-induced oxidative stress in competitive swimmers was not followed by airway or systemic inflammation. Previously, studies on bronchial biopsies of competing swimmers have shown inflammatory and remodelling changes, similar to patients with mild asthma [5], suggesting that swim training in chlorinated pools affects the structure of the airway in elite swimmers. Researchers found increased eosinophils in swimmers and asthmatics, but no significant differences in neutrophil counts. According to the results of our study, a high training indoor pool environment does not result in significant changes at the level of airway inflammation, FeNO, eosinophils, neutrophils or different cytokines. The explanation for these differences might due to different methodologies (biopsy vs induced sputum) and the age of swimmers. The median age of our swimmers was 5 years less, and we can speculate that the occurrence of eosinophilia may be dependent on many years of intensive training, and therefore it is too early to find eosinophilia in our younger group of swimmers. Our results are more comparable to the results of previous studies on induced sputum [4], which found minimal or no airway inflammation in elite swimmers, except for those with AHR, who had a significant increase in airway eosinophil count.

In our group, almost half of swimmers have AHR to metacholin. How ewer, there was no correlation between hyperresponsiveness and the markers of oxidative stress or inflammation. Screening in competitive swimmers has demonstrated that up to 76% have symptomatic or asymptomatic airway hyperresponsiveness (AHR) and/or exercise-induced bronchoconstriction (EIB) [24]. In accordance with the criteria used by the International Olympic Committee-Medical Commission's (IOC-MC) Independent Asthma Panel [25], approximately 60% of young competitive swimmers had AHR to at least one bronchial provocation test [26,27]. In some athletes, provocation tests with direct stimuli, such as methacholine, may be negative, while EIB can be confirmed by indirect tests such as eucapnic voluntary hyperpnoea (EVH) [27].

A number of studies report a high prevalence of AHR in winter sports [28–31]. Bjermer et al. [32] reported that the airways of elite skiers clearly react in a heterogeneous manner in the training season, being more responsive to metacholine than to indirect provocation. They also reported that AHR to metacholine was more prevalent in those not reporting asthma-like symptoms. Furthermore, asthmatic airway inflammation was not a prerequisite for AHR to metacholine. We now highlight a similar point in competitive swimmers, where we did not find a correlation between airway inflammation and AHR to metacholin. The limitation of our study is that we did not repeat the metacholin testing in the rest period to document possible decreasing AHR. Previous study suggest that training may contribute to the development of AHR in elite swimmers, but this seems reversible in many athletes after training cessation for at least 2 weeks [33].

In conclusion, high intensity training in healthy, non-asthmatic elite swimmers results in marked oxidative stress at the airway and systemic levels, but does not lead to airway inflammation. Further studies are needed to confirm the clinical relevance of oxidative stress in swimmers and the possible risk in cold-air athletes.

Conflicts of interest

I declare no conflict of interest.

Acknowledgements

We thank Prof. Ratko Djukanović, NIHR Respiratory Biomedical Research Unit, Clinical and Experimental Sciences, Faculty of Medicine, University of Southampton, Southampton, UK, for comments and revision of the manuscript.

References

[1] S.D. Anderson, K. Holzer, Exercise-induced asthma: is it the right diagnosis in elite athletes? J. Allergy Clin. Immunol. 106 (3) (2000 Sep) 419–428.
[2] D.J. Tschumperlin, J.M. Drazen, Chronic effects of mechanical force on airways, Annu. Rev. Physiol. 68 (1) (2006 Jan) 563–583.
[3] L. Font-Ribera, C.M. Villanueva, M.J. Nieuwenhuijsen, J.-P. Zock, M. Kogevinas, J. Henderson, Swimming pool attendance, asthma, allergies, and lung function in the Avon Longitudinal Study of Parents and Children cohort, Am. J. Respir. Crit. Care Med. 183 (5) (2011 Mar) 582–588.

[4] V. Bougault, J. Turmel, J. St-Laurent, M. Bertrand, L.P. Boulet, Asthma, airway inflammation and epithelial damage in swimmers and cold-air athletes, Eur. Respir. J. 33 (4) (2009) 740–746.
[5] V. Bougault, L. Loubaki, P. Joubert, J. Turmel, C. Couture, M. Laviolette, et al., Airway remodeling and inflammation in competitive swimmers training in indoor chlorinated swimming pools, J. Allergy Clin. Immunol. 129 (2) (2012 Feb) 351–358.e1.
[6] V. Bougault, M. Morissette, N. Murray, J. Milot, L. Boulet, Oxidative stress in swimmers' airways, Eur. Respir. J. 36 (Suppl 54) (2010) 5582.
[7] V. Bougault, J. Turmel, L.-P. Boulet, Bronchial challenges and respiratory symptoms in elite swimmers and winter sport athletes: airway hyperresponsivenes in asthma: its measurement and clinical significanca, Chest 138 (2) (2010 Aug) 31S–37S.
[8] L.D. Wilson, F.P. Zaldivar, C.D. Schwindt, D.M. Cooper, The pro- and anti-inflammatory cytokine response to exercise in adolescent swimmers, Pediatr. Asthma Allergy Immunol. 22 (3) (2009) 95–100.
[9] J.M. Morgado, L. Rama, I. Silva, M. de Jesus Inácio, A. Henriques, P. Laranjeira, et al., Cytokine production by monocytes, neutrophils, and dendritic cells is hampered by long-term intensive training in elite swimmers, Eur. J. Appl. Physiol. [Internet] 112 (2) (2012 Feb 17) 471–482 [cited 2017 May 26] Available from: http://link.springer.com/10.1007/s00421-011-1966-4.
[10] T. Yoshikawa, Y. Naito, What is oxidative stress? Japan Med. Assoc. J. 45 (7) (2002) 271–276.
[11] H. Sies, Oxidative stress: oxidants and antioxidants, Exp. Physiol. 82 (2) (1997 Mar) 291–295.
[12] D. Praticò, J.A. Lawson, J. Rokach, G.A. FitzGerald, The isoprostanes in biology and medicine, Trends Endocrinol. Metabol. 12 (6) (2001 Aug) 243–247.
[13] S. Caballero Balanzá, A. Martorell Aragonés, J.C. Cerdá Mir, J. Belda Ramírez, J.B. Ramírez, R. Navarro Iváñez, et al., Leukotriene B4 and 8-isoprostane in exhaled breath condensate of children with episodic and persistent asthma, J Investig. Allergol. Clin. Immunol. 20 (3) (2010) 237–243.
[14] R. Dworski, Oxidant stress in asthma, Thorax. BMJ Publishing Group 55 (Suppl 2) (2000 Oct) S51–S53.
[15] E. Baraldi, L. Ghiro, V. Piovan, S. Carraro, G. Ciabattoni, P.J. Barnes, et al., Increased exhaled 8-isoprostane in childhood asthma, Chest 124 (1) (2003 Jul) 25–31.
[16] R.O. Crapo, R. Casaburi, A.L. Coates, P.L. Enright, J.L. Hankinson, C.G. Irvin, et al., Guidelines for methacholine and exercise challenge testing 1999. This official statement of American Thoracic society was adopted by ATS Board of Directors, July 1999, Am. J. Respir. Crit. Care Med. 161 (1) (2000 Jan) 309–329.
[17] Recommendations for standardized procedures for the online and offline measurement of exhaled lower respiratory nitric oxide and nasal nitric oxide in adults and Children—1999, Am. J. Respir. Crit. Care Med. [Internet] 160 (6) (1999 Dec) 2104–2117 [cited 2017 May 9] Available from: http://www.atsjournals.org/doi/abs/10.1164/ajrccm.160.6.ats8-99.
[18] S.S. Kristan, M.M. Malovrh, M. Silar, I. Kern, M. Flezar, M. Kosnik, et al., Airway angiogenesis in patients with rhinitis and controlled asthma, Clin. Exp. Allergy 39 (3) (2009) 354–360.
[19] E. Pizzichini, M.M. Pizzichini, A. Efthimiadis, F.E. Hargreave, J. Dolovich, Measurement of inflammatory indices in induced sputum: effects of selection of sputum to minimize salivary contamination, Eur. Respir. J. 9 (6) (1996 Jun) 1174–1180.
[20] M.C. Morissette, N. Murray, J. Turmel, J. Milot, L.-P. Boulet, V. Bougault, Increased exhaled breath condensate 8-isoprostane after a swimming session in competitive swimmers, Eur. J. Sport Sci. 16 (5) (2016 Jul) 569–576.
[21] W. Huang, G. Wang, S.E. Lu, H. Kipen, Y. Wang, M. Hu, et al., Inflammatory and oxidative stress responses of healthy young adults to changes in air quality during the Beijing Olympics, Am. J. Respir. Crit. Care Med. [Internet] 186 (11) (2012) 1150–1159. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22936356.
[22] R. Deminice, C.S. Trindade, G.C. Degiovanni, M.R. Garlip, G.V. Portari, M. Teixeira, et al., Oxidative stress biomarkers response to high intensity interval training and relation to performance in competitive swimmers, J. Sports Med. Phys. Fit. 50 (3) (2010) 356–362.
[23] A. Kabasakalis, A. Kyparos, G. Tsalis, D. Loupos, A. Pavlidou, D. Kouretas, Blood oxidative stress markers after ultramarathon swimming, J. Strength Cond. Res. [Internet] 25 (3) (2011) 805–811. Available from: http://content.wkhealth.com/linkback/openurl?sid=WKPTLP:landingpage&an=00124278-201103000-00030.
[24] V. Bougault, J. Turmel, B. Levesque, L.P. Boulet, The respiratory health of swimmers, Sports Med. (2009) 295–312.
[25] K.D. Fitch, M. Sue-Chu, S.D. Anderson, L.-P. Boulet, R.J. Hancox, D.C. McKenzie, et al., Asthma and the elite athlete: summary of the international olympic Committee's consensus conference, lausanne, Switzerland, january 22-24, 2008, J. Allergy Clin. Immunol. [Internet] 122 (2) (2008 Aug) 254–260.e7. [cited 2017 May 29] Available from: http://www.ncbi.nlm.nih.gov/pubmed/18678340.
[26] V. Bougault, J. Turmel, L.-P. Boulet, Bronchial challenges and respiratory symptoms in elite swimmers and winter sport athletes: airway hyperresponsiveness in asthma: its measurement and clinical significance, Chest [Internet] 138 (2 Suppl) (2010 Aug) 31S–37S [cited 2017 May 29] Available from: http://linkinghub.elsevier.com/retrieve/pii/S0012369210603959.
[27] A. Castricum, K. Holzer, P. Brukner, L. Irving, The role of the bronchial provocation challenge tests in the diagnosis of exercise-induced bronchoconstriction in elite swimmers, Br. J. Sports Med. [Internet] 44 (10) (2010 Aug 1) 736–740 [cited 2017 May 29] Available from: http://bjsm.bmj.com/cgi/doi/10.1136/bjsm.2008.051169.
[28] K. Larsson, P. Ohlsén, L. Larsson, P. Malmberg, P.O. Rydström, H. Ulriksen, High prevalence of asthma in cross country skiers, BMJ 307 (6915) (1993 Nov) 1326–1329.
[29] M. Kaelin, O. Brändli, Exertional asthma in Swiss top-ranking athletes, Schweiz. Med. Wochenschr. 123 (5) (1993 Feb) 174–182.
[30] N.T. Rupp, D.S. Brudno, M.F. Guill, The value of screening for risk of exercise-induced asthma in high school athletes, Ann. Allergy 70 (4) (1993 Apr) 339–342.
[31] M. Sue-Chu, L. Larsson, L. Bjermer, Prevalence of asthma in young cross-country skiers in central Scandinavia: differences between Norway and Sweden, Respir. Med. 90 (2) (1996 Feb) 99–105.
[32] M. Sue-Chu, J.D. Brannan, S.D. Anderson, N. Chew, L. Bjermer, Airway hyperresponsiveness to methacholine, adenosine 5-monophosphate, mannitol, eucapnic voluntary hyperpnoea and field exercise challenge in elite cross-country skiers, Br. J. Sports Med. 44 (11) (2010 Sep) 827–832.
[33] V. Bougault, J. Turmel, L.P. Boulet, Airway hyperresponsiveness in elite swimmers: is it a transient phenomenon? J. Allergy Clin. Immunol. 127 (4) (2011) 892–898.

Update

Respiratory Medicine

Volume 142, Issue , September 2018, Page 102

DOI: https://doi.org/10.1016/j.rmed.2018.03.026

Respiratory Medicine 142 (2018) 102

Contents lists available at ScienceDirect

Respiratory Medicine

journal homepage: www.elsevier.com/locate/rmed

Corrigendum to "Systemic and airway oxidative stress in competitive swimmers" [Respiratory Medicine 137 (2018) 129–133]

Sabina Škrgat*, Peter Korošec, Izidor Kern, Mira Šilar, Julij Šelb, Matjaž Fležar, Robert Marčun

University Hospital of Respiratory and Allergic Diseases, Golnik 36, 4204, Slovenia

The authors regret < that an error occurred in the order of listed authors. The correct order of author is as follows:

Sabina Škrgat, Peter Korošec, Izidor Kern, Mira Šilar, Julij Šelb, Matjaž Fležar, Robert Marčun > .

The authors would like to apologise for any inconvenience caused.

DOI of original article: http://dx.doi.org/10.1016/j.rmed.2018.03.005

* Corresponding author.
E-mail address: sabina.skrgat@klinika-golnik.si (S. Škrgat).

https://doi.org/10.1016/j.rmed.2018.03.026

Available online 03 April 2018
0954-6111/