Lung function after cold-water dives with a standard scuba regulator or full-face-mask during wintertime

Florian Uhlig, Claus-Martin Muth, Kay Tetzlaff, Andreas Koch, Richard Leberle, Michael Georgieff and Bernd E Winkler

Abstract

(Uhlig F, Muth CM, Tetzlaff K, Koch A, Leberle R, Georgieff M, Winkler BE. Lung function after cold-water dives with a standard scuba -regulator or full-face-mask during wintertime. *Diving and Hyperbaric Medicine*. 2014 June;44(2):70-73.)

Introduction: Full-face-masks (FFM) prevent the diver's face from cold and can support nasal breathing underwater. The aim of the study was to evaluate the effect of the use of FFMs on lung function and wellbeing.

Methods: Twenty-one, healthy, non-asthmatic divers performed two cold-water dives (4°C, 25 min, 10 metres' depth) – one with a FFM and the other with a standard scuba regulator (SSR). Spirometry was performed before and after each dive and well-being and cold sensation were assessed after the dives.

Results: Significant decreases in forced vital capacity (FVC), forced expiratory volume in one second (FEV_1) and mid-expiratory flow at 75% of FVC (MEF_{75}) occurred after both FFM and SSR dives. Changes in FVC and FEV_1 did not differ significantly between FFM and SSR dives. However, the mid-expiratory flows measured at 50% and 25% of FVC (MEF_{50} and MEF_{25}) were significantly lower 10 minutes after the FFM dive compared to 10 minutes after the SSR dive. The well-being and cold sensation of the divers were significantly improved with FFM dives compared to SSR dives.

Conclusions: Cold-water dives during wintertime can be associated with airway narrowing. During cold-water dives, the use of a FFM appears to reduce the cold sensation and enhance the well-being of the divers. However, a FFM does not appear to prevent airway narrowing in healthy, non-asthmatic subjects.

Key words

Cold, scuba diving, lung function, physiology, diving reflex, thermal problems (hypothermia and hyperthermia)

Introduction

Even though the majority of recreational diving is performed in warm water, a considerable number of scuba divers also conduct cold-water dives. Diving during wintertime and in cold water is associated with a heat loss from the body and the face. While the face of commercial divers is usually protected from cold stress by diving helmets or full-face-masks (FFM), standard scuba regulators (SSR) and diving masks are frequently used by recreational divers.

Apart from covering and protecting the entire face from cold water, a FFM offers the possibility of nasal breathing. Consequently, the ventilated air can be humidified and warmed in the nose and nasal pharynx before reaching the lungs. Nasal breathing as well as the use of face-masks has been reported to reduce the likelihood of airway narrowing in non-diving subjects with exercise-induced asthma.[1] Enforced mouth breathing can decrease the lung function in susceptible subjects.[2] A FFM provides some thermal insulation of the face and might, therefore, reduce both heat loss and reflexes induced by facial cooling.[3,4] Since the inhalation of cold, dry breathing air has been reported to foster airway narrowing, it may increase the risk of pulmonary barotrauma during the ascent.[5] The use of a FFM might, therefore, reduce the effects of cold-water dives on the respiratory system.

The aim of the present study was to evaluate changes in lung function after a cold-water dive during wintertime and the impact of the breathing system, i.e., use of a SSR or a FFM.

Methods

SUBJECTS

The study was approved by the Committee on Human Ethics of the University of Ulm, Germany (approval no. 290/10). Twenty-six subjects provided written, informed consent before participating. All subjects were certified adult professional rescue divers or diving instructors. Five divers were excluded from statistical analysis. One did not attempt the first dive because of feeling unwell. In another diver, the FFM regulator froze during his FFM dive and resulted in a free-flow (downstream) failure. Three divers were sick on the second weekend. Accordingly, 21 male divers completed both dives. The individual diving experience was 438, range 118–1,160 logged dives. All were non-smokers and none suffered from bronchial asthma or other chronic obstructive pulmonary disease. All divers successfully passed a medical fitness-to-dive examination prior to the study.

EXPERIMENTAL PROTOCOL

Height and body weight were measured and spirometry performed 45 and 15 minutes pre dive. The divers performed two dives in random order in a cross-over design: 11 divers performed the FFM dive first and the SSR second, and 10 divers in the reverse order. An interval of seven days between dives and the same time of day for diving performance were chosen in order to control for possible variations in circadian lung function. Prior to each dive a period of relative rest for 24 h and no diving for 72 h was required.

The subjects used the mask they were most experienced with, either the Interspiro MK II (Interspiro AB, Täby, Sweden) or the Dräger Panorama Nova Dive (Dräger Safety AG, Luebeck, Germany). The corresponding standard scuba regulators were used for the SSR dives. During diving in a cold lake in wintertime (25 min at a depth of approximately 10 metres), the divers were equipped with a dive computer (Scubapro Uwatec AG, Henggart, Switzerland) for the measurement of ambient water temperature and diving depth. During the FFM dives, the divers were instructed to breathe through the nose exclusively. Ascent and descent times were specified with 1 min for each. The divers were secured with a signalling line. In the case of FFM dives, a special phone line was used for verbal communication. The divers ascended 24 minutes after descent.

After surfacing, spirometry was performed 10, 20 and 30 minutes post dive. While being transferred to the measurement room, the divers continued to breathe via the FFM or SSR. The divers quantified their well-being during the dive according to a visual analogue scale, 0–10 (0 – very uncomfortable, 10 – very comfortable). The divers' sensation of cold was quantified in the same way (0 – not cold at all, 10 – extremely cold) after each dive.

SPIROMETRY

Spirometry was performed whilst standing, wearing a nose clip. The spirometer (Jaeger Master Scope Pneumotachograph, Viasys Healthcare GmbH, Wuerzburg Germany) was volume-calibrated before each spirometry and the following parameters were measured: forced vital capacity (FVC), forced expiratory volume in 1 s (FEV_1) and mid-expiratory flow at 75%, 50% and 25% of FVC (MEF_{75}, MEF_{50} and MEF_{25}). For each measurement, the best of three consecutive trials differing in FVC and FEV_1 by no more than 5% was selected for analysis. Baseline lung function was computed as the mean of the 45-min and 15-min pre-dive measurements and post-dive lung function was defined as the mean value measured 10, 20 and 30 min post dive.

STATISTICS

Microsoft Excel™ 2007 (Microsoft Inc, Redmond, Washington, USA) and SPSS 19 (IBM Inc., Armonk, NY, USA) were used for statistical analysis. All variables were tested for normal distribution using a Kolmogorov-Smirnov test. The pre-dive values of each spirometric parameter were assessed with an ANOVA. Pre- and post-dive lung function within each group and the absolute and relative changes between both groups were compared by paired Student's *t*-tests. A paired Student's *t*-test was also performed to compare the spirometric changes in subjects using the Interspiro MK II mask to those using the Dräger mask. The FEV_1 and FVC, heart rate, diving depth and ambient water temperature were analyzed by a two-factorial (breathing system and time of measurement) ANOVA for repeated measures and a Bonferroni adjusted post-hoc analysis was performed. For mid-expiratory flows, a three-factorial ANOVA was performed (breathing system, time of measurement and MEF-type 75/50/25).

A relative decrease of at least 10% in FEV_1 was considered to be a clinically relevant degree of airways narrowing according to the ATS guidelines for exercise challenge testing.[6] Based on this criterion, both FFM and SSR dives were separated into two groups (bronchoconstriction after dive and no bronchoconstriction after dive). Differences between the bronchoconstriction and no-bronchoconstriction groups concerning dive specifics and anthropometric data were assessed by independent-samples Student's *t*-tests.

The wellbeing and cold-sensation between the SSR and FFM groups were compared by Wilcoxon signed rank tests. The interaction of bronchoconstriction and wellbeing or cold sensation was tested by a Mann-Whitney U test. Data are presented as mean ± standard deviation (range). Statistical significance was assumed with *P*-values ≤ 0.05.

Results

The mean age of the 21 subjects was 37.2 ± 9.7 (range 20–55) years, height 177 ± 7 (range 158–188) cm and weight 84.4 ± 14.4 (range 55–112) kg. The body mass index (BMI) was 26.6 ± 3.4 (range 20.8–32.4) $kg \cdot m^{-2}$ and body surface area 2.0 ± 0.2 (range 1.5–2.4) m^2.

The average depth reached during the dives was 9.7 ± 0.5 (range 8.9–10.5) metres in FFM dives and 9.7 ± 0.4 (range 8.9–10.5) metres in SSR dives. The mean ambient water temperature was 3.7 ± 0.5 (range 3.2–5.2) ^{O}C (air temperature 3.8 ± 2.5, range 0–7.5 ^{O}C) for the FFM dives, and 3.8 ± 0.7 (range 2.8–5.6) ^{O}C (air temperature 3.7 ± 2.6, range 0.2–8.2 ^{O}C) for the SSR dives.

Table 1 presents the pre- and post-dive values for pulmonary function parameters. There were no significant differences in the pre-dive values for any spirometric parameter. Both groups showed significant decreases in FVC, FEV_1 and MEF_{75} post-dive compared to pre-dive. Pre- and post-dive MEF_{50} and MEF_{25} were not significantly different. The pair-wise comparison of absolute and relative changes in lung function values did not reveal any significant differences between FFM and SSR dives. Furthermore, the spirometric changes in subjects using the Interspiro mask did not differ significantly from those using the Dräger mask.

The two-factorial ANOVA demonstrated significant time effects for post-dive FVC and FEV_1. The post-hoc analysis demonstrated a significant difference between 10 and 20 minutes post dive for FEV_1 but not for FVC and did not show a difference between FFM and SSR. The three-factorial ANOVA for post-dive mid-expiratory flows revealed significant effects for all three MEF values (MEF_{75}, MEF_{50} and MEF_{25}) and a significant interaction between MEF type and time, but no effect for time and type of breathing

Table 1

Pre- and post-dive spirometric values, mean (SD), and relative changes and significance levels for forced vital capacity (FVC), forced expiratory volume in one second (FEV_1) and mid-expiratory flows at 75, 50 and 25% of FVC (MEF_{75}, MEF_{50}, MEF_{25}) after dives breathing from either a full-face-mask or a standard scuba regulator; *P*-values are derived from paired-samples *t*-tests (pre-dive vs. post-dive)

	Pre-dive		Post-dive		Relative change (%)		*P*-value
Full-face-mask							
FVC (L)	6.08	(1.00)	5.85	(1.04)	-4.1	(3.4)	<0.01
FEV_1 (L)	4.77	(0.96)	4.56	(0.99)	-4.5	(4.0)	<0.01
MEF_{75} ($L \cdot s^{-1}$)	8.98	(2.43)	8.54	(2.60)	-5.1	(10.6)	0.017
MEF_{50} ($L \cdot s^{-1}$)	5.10	(1.78)	4.91	(1.91)	-4.4	(10.4)	0.144
MEF_{25} ($L \cdot s^{-1}$)	1.86	(0.88)	1.77	(0.77)	-3.0	(12.1)	0.121
Standard scuba regulator							
FVC (L)	6.08	(0.99)	5.83	(0.99)	-4.2	(3.2)	<0.01
FEV_1 (L)	4.79	(0.99)	4.61	(0.99)	-3.8	(2.9)	<0.01
MEF_{75} ($L \cdot s^{-1}$)	9.13	(2.41)	8.52	(2.43)	-6.9	(6.5)	<0.01
MEF_{50} ($L \cdot s^{-1}$)	5.30	(2.06)	5.12	(2.06)	-3.8	(7.6)	0.059
MEF_{25} ($L \cdot s^{-1}$)	1.91	(0.88)	1.88	(0.88)	-1.1	(9.4)	0.559

regulator. The post-hoc analysis did not show general differences between the breathing regulators but a significant difference between FFM and SSR in the MEF_{50} and MEF_{25} measured 10 minutes after the dive. Mean MEF_{50} and MEF_{25} were 4.91 and 1.77 $L \cdot s^{-1}$ 10 minutes after the FFM vs. 5.12 and 1.88 $L \cdot s^{-1}$ after the SSR dive.

Subjects with post-dive bronchoconstriction did not significantly differ from those without with respect to any demographic parameters. Wellbeing scores were significantly higher during and after FFM dives. Cold sensation was significantly more pronounced after SSR dives (6.4 ± 1.9, range 3–9 and 5.1 ± 2.0 range 2–9 respectively; $P = 0.03$) than after FFM dives. (7.3 ± 1.6, range 4–10 and 5.1 ± 1.5 range 3–8 respectively; $P < 0.01$). There was no significant relation between bronchoconstriction and wellbeing after the dives (FFM dives $P = 0.79$; SSR dives $P = 0.95$) or bronchoconstriction and cold-sensation (FFM dives $P = 0.27$; SSR dives $P = 0.61$).

Concerning diving depth and ambient water temperature, two-factorial ANOVA did not show any effects for the time of measurement or for the breathing system used. Thus, comparable diving profiles and conditions can be assumed for both breathing systems.

Discussion

The present study revealed significant decreases in lung function after cold-water dives during winter time. The mean changes in expiratory flows and volumes were small and most likely not clinically relevant. Nevertheless, individual subjects demonstrated more pronounced respiratory effects and met the diagnostic criteria of the American Thoracic Society for exercise-induced bronchoconstriction.[6] The literature is inconsistent concerning lung function changes after scuba diving. On the one hand, previous studies have reported that breathing and diving at shallow depths does not have an impact on static and dynamic lung function parameters after a single scuba dive.[7–8] On the other hand, scuba diving has been reported to be associated with a decrease in spirometric values directly after diving and as a long-term effect.[7,9–12] Breathing cold, dry breathing gas might trigger bronchoconstriction.[5,13–14] One study reported significant changes in FEV_1 during winter dives but not during summer dives.[15]

When using a FFM, the divers were instructed to breathe through the nose. Hence, the air entering the lung is likely to be warmer and more humid when using a FFM than when breathing via the mouth during SSR dives. This assumption is in line with previous studies in non-diving subjects with exercise-induced asthma in whom it was reported that nasal breathing and the use of face masks reduces airway narrowing and the likelihood of asthma attacks.[1] In contrast, enforced mouth breathing – as performed during SSR dives, can decrease lung function in susceptible subjects.[2]

Surprisingly, the use of a FFM resulted in a similar, possibly slightly more pronounced (MEF_{50} and MEF_{25} 10 minutes after the dive) airways narrowing than diving with a conventional SSR. It is possible that factors other than the humidity and temperature of the inspiratory gas during scuba diving may be responsible for the changes in expiratory flows and volumes measured after dives, for instance, intrapulmonary fluid redistribution due to immersion, inspiratory resistance from the regulators and the increased dead space of a FFM. However, most previous studies investigating the respiratory effects of cold, dry air were performed in susceptible subjects with exercise-induced asthma. In contrast to the non-smoking and non-asthmatic healthy subjects that participated in the present study, subjects susceptible to the cold and dryness stimuli might have benefitted from the use of a FFM. We tried to include a group of asthmatic scuba divers at an early stage of the study design but the conduct of these experiments was considered potentially dangerous to susceptible subjects because of a possible increased risk of pulmonary barotrauma. Based on the current findings in healthy subjects, divers with pre-existing exercised-induced bronchoconstriction might indeed be at an increased risk for airway narrowing and injury in cold-water dives. The use of a FFM does not appear to reduce the adverse respiratory effects of cold-water diving observed in this study.

Hyperoxia has also been reported to foster bronchoconstriction.[16] However, the diving profiles were comparable and hyperoxia is unlikely to play a relevant role. Furthermore, ambient cold is also believed to contribute to airway narrowing but the ambient conditions of depth and water temperature were comparable during both dives. Hence, the thermal effects cannot sufficiently explain the decrease in expiratory flows and volumes after FFM dives in this study. The cold sensation of the divers was significantly lower and individual wellbeing was higher during FFM dives but did not reduce the spirometric responses.

Conclusions

Cold-water (3–5°C) scuba diving resulted in a decrease in expiratory flows and volumes that may be clinically relevant in individual subjects. The use of a FFM reduced the cold sensation and enhanced the wellbeing of the divers. However, FFM diving did not appear to prevent the airway narrowing observed after these cold-water dives. The use of a FFM is unlikely to reduce the risk of bronchoconstriction-associated pulmonary barotrauma in healthy subjects. Subjects with susceptible airways might potentially benefit from the use of a FFM because airway irritation by cold, dry air might play a more pronounced role in these subjects. However, asthmatic divers were not included in the present study for ethical considerations. Further studies are required to investigate the respiratory effects of cold-water diving, especially in subjects who might be more at risk for airway narrowing and, therefore, pulmonary barotrauma.

References

1 Anderson SD, Kippelen P. Assessment and prevention of exercise-induced bronchoconstriction. *Br J Sports Med*. 2012;46:391-6.

2 Hallani M, Wheatley JR, Amis TC. Enforced mouth breathing decreases lung function in mild asthmatics. *Respirology*. 2008;13:553-8.

3 Koskela H, Tukiainen H. Facial cooling, but not nasal breathing of cold air, induces bronchoconstriction: a study in asthmatic and healthy subjects. *Eur Resp J*. 1995;8:2088-93.

4 Zeitoun M, Wilk B, Matsuzaka A, Knopfli BH, Wilson BA, Bar-Or O. Facial cooling enhances exercise-induced bronchoconstriction in asthmatic children. *Med Sci Sports Exercise*. 2004;36:767-71.

5 Koskela HO. Cold air-provoked respiratory symptoms: the mechanisms and management. *Int J Circumpolar Health*. 2007;66:91-100.

6 Crapo RO, Casaburi R, Coates AL, Enright PL, Hankinson JL, Irvin CG, et al. Guidelines for methacholine and exercise challenge testing-1999. *Am J Resp Crit Care Med*. 2000;161:309-29.

7 Koehle MS, Hodges AN, Lynn BM, Rachich MF, McKenzie DC. Diffusing capacity and spirometry following a 60-minute dive to 4.5 meters. *Undersea Hyperb Med*. 2006;33:109-18.

8 Tetzlaff K, Friege L, Koch A, Heine L, Neubauer B, Struck N, et al. Effects of ambient cold and depth on lung function in humans after a single scuba dive. *Eur J Appl Physiol*. 2001;85:125-9.

9 Tetzlaff K, Staschen CM, Struck N, Mutzbauer TS. Respiratory effects of a single dive to 50 meters in sport divers with asymptomatic respiratory atopy. *Int J Sports Med*. 2001;22:85-9.

10 Wilson A. Prevalence and characteristics of lung function changes in recreational scuba divers. *Primary Care Respiratory Journal*. 2011;20:59-63.

11 Winkler BE, Tetzlaff K, Muth CM, Hebestreit H. Pulmonary function in children after open water SCUBA dives. *Int J Sports Med*. 2010;31:724-30.

12 Lemaitre F, Tourny-Chollet C, Hamidouche V, Lemouton MC. Pulmonary function in children after a single scuba dive. *Int J Sports Med*. 2006;27:870-4.

13 Neubauer B, Struck N, Mutzbauer TS, Schotte U, Langfeldt N, Tetzlaff K. Leukotriene-B4 concentrations in exhaled breath condensate and lung function after thirty minutes of breathing technically dried compressed air. *Int Marit Health*. 2002;53:93-101.

14 Tetzlaff K, Staschen CM, Koch A, Heine L, Kampen J, Neubauer B. Respiratory pattern after wet and dry chamber dives to 0.6 MPa ambient pressure in healthy males. *Resp Physiol*. 1999;118:219-26.

15 Paun-Schueepp R, Schueepp J, Baenziger O. Changes in lung function and oxygen saturation after cold fresh water scuba dives in healthy recreational divers. Abstract. *Proceedings of 34th Annual Meeting of the European Underwater and Baromedical Society*. September, 2008. Graz, Austria; 2008. p. 140-1. ISBN: 978-3-200-01314 8.

16 Caspersen C, Stensrud T, Thorsen E. Bronchial nitric oxide flux and alveolar nitric oxide concentration after exposure to hyperoxia. *Aviat Space Environ Med*. 2011;82:946-50.

Acknowledgements

We thank all divers for their voluntary participation, the Bavarian Red Cross Wasserwacht Mering for their support with staff and the location, Franka Böttger, Christopher Beck and all other assistants, Viasys Healthcare for providing the Jaeger Master Scope spirometer and Uwatec for providing Galileo Sol diving computers.

Conflicts of interest: nil

Submitted: 28 August 2013
Accepted: 26 March 2014

Florian Uhlig[1,2], Claus-Martin Muth[1], Kay Tetzlaff[3], Andreas Koch[4], Richard Leberle[5], Michael Georgieff[1], Bernd E Winkler[1,6]
[1] Department of Anesthesiology, University of Ulm, Germany
[2] Friedrich Schiller University, Jena, Germany
[3] Department of Sports Medicine, University of Tuebingen, Germany
[4] German Naval Medical Institute, Kiel-Kronshagen, Germany
[5] Department of Anesthesiology, University of Regensburg
[6] Department of Anesthesiology and Intensive Care Medicine, University Hospital, Leipzig, Germany

Corresponding author:
Florian Uhlig
E-mail: *<florian_uhlig@freenet.de>*