Journal articles

Influence of the diving wetsuit on standard spirometry

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Abstract

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Introduction: A well-fitting wetsuit exerts a pressure on the body that may influence spirometry. This pressure is expected to reduce the forced vital capacity (FVC) due to hampered inspiration. Since the shape of the spirometric flow curve should not be changed by the pressure effects of the wetsuits, FVC, the forced expiratory volume during the first second of expiration (FEV_1), the peak expiratory flow (PEF) and the flow between 25 and 75% of FVC (FEF_{25-75}) should change to the same degree. This study investigates the influence of a wetsuit on spirometric variables using age, suit thickness and suit type as the parameters.

Methods: Spirometry (dry) was performed in 28 volunteers (12 women), aged 27–69 years.

Results: The wetsuit (3.8 mm, range 2–7 mm) resulted in a change in FVC of -4.0% ($P = 2{\cdot}E{-}08 < 0.001$), in FEV_1 of -3.6% ($P = 3{\cdot}E{-}05 < 0.001$) and in PEF of -2.4% ($P = 0.03$); the FEF_{25-75} may also diminish. The FEV_1/FVC ratio did not change. The decreases can be regarded as a quasi-ageing effect of about 3.5 years. No influence of age, suit thickness and suit type was found.

Conclusion: The wetsuit appears to impair ventilatory mechanics. Both the medical examiner and the diver should be aware that a too-thick or too-tight suit might be a potential pulmonary risk factor in diving.

Key words

Lung function; pulmonary function; age; risk factors

Introduction

A variety of factors may affect respiratory mechanics when diving. In addition to factors related to the underwater environment (gas density, hydrostatic forces on the body, etc.), the artificial breathing source and other equipment,[1] an effect of a diving wetsuit may be expected. The wetsuit, particularly when tight, increases central vascular volume,[2] and is thought to be a factor in swimming-induced pulmonary oedema in triathletes due to the assumed increased cardiac pre-load of immersion.[3,4] In addition to blood redistribution, hydrostatic pressure differences over the body result in considerable shifts in fluid and electrolyte balance.[5] Similarly, the compression effect of a wetsuit may also change fluid and electrolyte homeostasis. A wetsuit of 5 mm produces an interface pressure between the suit and skin of about 0.034 bar (= 34 cm water).[5] This value is independent of immersion and diving depth, since the elastic recoil tension of the suit is not depth-dependant.[5] All these factors are likely to affect pulmonary mechanics.

The force exerted by the suit will diminish the forced inspired volume (FIV) and, consequently, the forced vital capacity (FVC). This restrictive effect is the assumed underlying mechanism of the suit effect. It is reported that chest wall strapping can decrease spirometric volumes and capacities by 15–50%.[6]

The standard spirogram (here, only expiration is considered) is defined as the (dV/dt)/V diagram. When the (dV/dt)/V curve is changed by a constant (along the vertical axis) due to some condition, such as fatigue, the flow changes with the same factor and the curve retains its shape. As a result, FVC, the forced expiratory volume during the first second of expiration (FEV_1), the flow between 25 and 75% of FVC (FEF_{25-75}) and the peak expiratory flow (PEF) will change by the same factor and, consequently, the FEV_1/FVC ratio will remain the same. We assume that this shape invariance also applies to the wetsuit.

The pressure effect of a tight and/or very thick wetsuit (e.g., 16 mm thick) will seriously affect spirometric volume and flow characteristics and, during diving, also the (sub) maximal RMVs (respiratory minute volumes), whereas a 2 mm neoprene T-shirt will result in a much smaller effect. In general, with increasing age, the ability to cope with physical stress (e.g., thermal stress, dehydration) diminishes. This implies that when a constant load is increased by a small amount, this increase is harder for older persons to cope with than younger persons. An indication of this in older subjects has been described in a pulmonary exercise study.[7] Therefore, increasing age may increase the wetsuit effect.

In view of these data and assumptions, the present study investigates the effect of the wetsuit on spirometric values in recreational divers by testing the following hypotheses:

1. FVC decreases when wearing a wetsuit (‘in-suit’).
2. FVC, FEV_1, FEF_{25-75} and PEF decrease with the same factor when in-suit.
3. FEV_1/FVC does not change.

4. All effects increase with suit thickness.
5. With increasing age, the spirometric differences between in-suit and not wearing a wetsuit ('out-of-suit') become larger.

Methods

This study included 28 (12 women) fit-to-dive recreational divers who volunteered to participate. For this non-invasive study, ethical approval was not required by the Medical Ethical Committee of the University of Amsterdam (Project W15_278, Decision #15.0329). The study was part of a course in diving medicine on the island of Bonaire (Dutch Caribbean) that focused on pulmonary examination of divers. All participants provided informed consent.

The spirometric measurements (NDD Easy on-PC spirometer, NDD Medical Technologies, Andover, MA, USA) were performed at a temperature of ca. 26°C and humidity of ca. 85%. Half of the participants performed the sequence 'in-suit' followed by 'out-of-suit' (i.e., in thin and loose clothing) and half in the reverse order to avoid a possible learning effect. In each condition the participants had to perform three accepted (according to the spirometer evaluation algorithm) attempts. The values of these attempts were averaged and the difference between the two conditions was calculated. The period between in-suit and out-of-suit measurements was about 7 min. The neoprene wetsuits were intended for tropical waters; either complete or a 'shorty', but without hood, gloves or boots.

Reproducibility of the spirograms obtained with the two conditions was compared by calculating the (largest - smallest)/largest of the values of the three attempts in both conditions and statistically analysing their difference (the higher the outcome, the poorer is the reproducibility). This was done for FVC and FEV$_1$ but not for FEF$_{25-75}$ and PEF, since the two latter parameters behave much more erratically owing to 'ripples' in the spirogram; this is seen particularly in older people.

The Kolmogorov-Smirnov (KS) test was used to test normality. Analyses were performed with paired Student's *t*-test, and with Pearson's and Spearman's correlation coefficient (r). Testing was double-sided and a *P*-value ≤ 0.05 was considered statistically significant.

Results

Table 1 summarizes the demographic characteristics and data on the FVC, FEV$_1$, FEV$_1$/FVC, FEF$_{25-75}$ and PEF of the participants. Age, height, BMI and the spirometric variables were normally distributed (KS test); suit thickness was not (mean 3.8 mm, median 3 mm, 25, 50 and 75 percentiles 3.0, 3.0 and 4.9 mm respectively). The FVC reproducibility according to (largest – smallest)/largest in-suit (5.1%) was less than with out-of-suit (3.6%); $P = 0.05$; for FEV$_1$ values of 4.9% and 3.0%, respectively, were found ($P = 0.02$).

Table 1

Demographic and reference spirometric quantities of the 28 participants (mean ± SD); suit thickness (median (range)); * see Results for details

	Mean	SD
Age (years)	49.0	± 13.5
Height (cm)	178.6	± 7.8
BMI (kg·m^{-2})	25.5	± 4.2
FVC (L)	4.8	± 0.9
FEV$_1$ (L·s^{-1})	3.6	± 0.7
FEV$_1$/FVC (%)	80	± 10
FEF$_{25-75}$ (L·s^{-1})	2.9	± 1.1
PEF (L·s^{-1})	9.3	± 1.6
	Median	Range
Suit thickness (mm)*	3	(2–7)

Table 2

Change in spirometric values when wearing a wetsuit: expressed as 100 (in-suit minus out-of-suit)/out-of-suit (%)

	Mean	SD	95% CI	*P*-value
ΔFVC	-4.0	± 2.7	-5.0, -3.0	2.E–08
ΔFEV$_1$	-3.6	± 3.8	-4.9, -2.0	3.E–05
ΔFEV$_1$/FVC	0.2	± 2.5	-0.73, -1.22	0.69
ΔFEF$_{25-75}$	-2.6	± 9.5	-6.2, -1.1	0.15
ΔPEF	-2.4	± 5.6	-4.5, -0.24	0.03

Table 2 shows the differences between in-suit minus out-of-suit of the spirometric variables. All are normally distributed (KS test). FVC and FEV$_1$ showed a significant decrease ($P < 0.001$ in both cases) and ΔPEF was also significantly smaller (less reduction, but not significantly different from the former two). The decrease in ΔFEF$_{25-75}$ was not significant. However, after removing one extreme outlier (+33%), ΔFEF$_{25-75}$ was -3.9% ($P = 0.005$). FEV$_1$/FVC did not change.

ΔFEV$_1$ is correlated with ΔFVC, with FEF$_{25-75}$ and (of course) with FEV$_1$/FVC (all r's > 0.67; $P < 0.0005$). No other significant correlations were found between the spirometric Δ-quantities, between age and the spirometric Δ-quantities (Pearson's correlations), between suit thickness and any other quantity (Spearman's correlations) or between the type of wetsuit used (complete or shorty) and any other quantity (Spearman's correlations). No effects of gender were found.

Discussion

This study shows that wearing a wetsuit (median thickness 3 mm) reduces FVC by 4.0%, implying that hypothesis 1 is correct. Reductions were found in FEV$_1$, FEF$_{25-75}$ and PEF. However, none of these reductions were significantly different from each other, or from the reduction in FVC (Table 2). Thus, hypothesis 2 is probably correct and, as FEV_1/FVC did not change, hypothesis 3 correct. Hypothesis 4, the increasing effect with increasing suit thickness, could not be confirmed, as also holds for the expected increase of the suit effect with increasing age (hypothesis 5).

Generally, a stressor (mental or physical) results in a lower reproducibility of the correct performance of a task as compared to performing the task in the reference condition (no stressor). In the present study, in which wearing a wetsuit represents a stressor, the triple sets of FVC and FEV_1 are less reproducible in-suit than out-of-suit. This was confirmed by evaluations of the spirograms using the spirometric software.

In addition to the expected and experimentally confirmed decrease in FVC due to the reduced FIV caused by the wetsuit, FEV_1 and PEF also diminished, but seemingly to a lesser extent than FVC. This may be due to the elasticity of the wetsuit facilitating flow. This counteracts the decrease of the flow characteristics in accordance with the shape invariance of the spirogram when FVC decreases. Finally, this would result in a larger PEF/FVC ratio in-suit than out-of-suit. However, Δ(PEF/FVC) was only 1.6% larger in-suit, being non-significant ($P = 0.15$). With chest wall strapping, which is much more restrictive than wearing a wetsuit, the PEF also decreases.[6] However, in contrast to our study, the use of rigid straps blocks inspiration half way through the inspiratory phase. This implies that lung mechanics data acquired with such strapping cannot be realistically compared with data acquired when wearing a wetsuit.[6]

The double sets of spirograms show a tendency for the in-suit spirograms to be more concave, suggesting constriction of the small airways as also occurs with ageing.

Data from the literature shows that FVC and FEV_1 decrease by about 1.25% per year (linearly from 40 years onwards).[8,9] Therefore, the 4.0% decrease in FVC (median suit thickness 3 mm) can be regarded as a quasi-ageing effect of about 3.5 years. Similarly, 2.5-year quasi-ageing is found for FEV_1. Whilst diving, the suit effect is superimposed on the limitations of lung function due to the higher density of the breathing gas and physiological submersion effects such as pulmonary blood pooling, an effect of about 200 ml when submerged (in addition about 4% reduction of FVC or a quasi-ageing of ca. 3.5 years).[10]

It is unknown whether the effect of the wetsuit is in linear relation with suit thickness. However, a 16-mm thick suit (as may be used in very cold waters) is assumed to give a much higher reduction and, consequently, a quasi-ageing effect of possibly > 10 years. Also a too-tight suit will impair pulmonary function even more and, moreover, will strongly reduce blood flow in the respiratory and other musculature. This is a potential risk factor in diving situations demanding high levels of exercise. This item should be addressed during diving education and medical examination, since it has a direct impact on diving safety.

DISPUTABLE AND STRONG POINTS

With the use of a complete wetsuit we expected some pulmonary pooling since the pressure at the extremities would be larger (Pascal's law), similar to compression pants of a combat flyer. With the use of a 'shorty' the reverse will happen. However, in both cases the main effect is the pressure effect of the suit on the thorax and abdomen. The present study was underpowered to find a significant difference between a complete wetsuit and a 'shorty', and the same applies to an effect of wetsuit thickness. With both types of wetsuit, the many different brands of suits, as well as differences in the age of the suits and the tightness of the fitting, the effect of suit thickness is corrupted. The lack of a significant effect of age might also be attributed to the small number of participants.

A learning effect can be excluded since half of the group started with spirometry in-suit and the other half with out-of-suit (e.g., ΔFVC; $P = 0.27$). Moreover, most volunteers were aware of the pitfalls of spirometry and many (as a medical examiner) had practiced spirometry themselves.

The present sample had a relatively high age. However, the recreational diving community is ageing and older divers are especially at risk. The suit effect contributes to this risk. In fact, it was surprising that, despite the small sample, wetsuits of varying thickness, participants with a large age range, and no data on the fitting precision of the wetsuits, such a clear effect on FVC and FEV_1 was shown. Methodologically, the use of new wetsuits made of the same fabric would have been more optimal. However, to measure the effect of suit thickness precisely, the suits would need to be covered by many strain gauges with subsequent modelling of the pressure effects. This was beyond the scope and aims of this small study.

Conclusions

The wetsuit appears to impair ventilatory mechanics, particularly FVC and FEV_1. The effects of the wetsuit can be considered as a quasi-ageing effect of about 3.5 years for divers wearing a thin wetsuit. It is speculated that too thick and too tight suits are a pulmonary risk factor. Even with a thin wetsuit, it could contribute to problems during diving for persons with less than optimal lung function. More research is needed to establish the effects of wetsuit type and thickness on spirometric variables, the possible effect of age on in-suit spirometry, and to elucidate in more detail the effects on respiratory mechanics.

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