Short-term effect of reduction in forced vital capacity after diving exposure

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Abstract

To discuss whether there is relationship between short-term and long-time attenuation effects of ventilation caused by diving activity. The ventilation observed before and after hyperbaric exposure for 20*min* by case-control experiments. Participants of the experimental group (EG) stayed for 20*min* under 12-m underwater and the control group (CG) stayed in hyperbaric chamber under pressure of 2.2*ATA*. Immediate effects of pulmonary ventilation detected by the Spirometer and compared by paired *T* test to reveal the different caused by environmental pressure. The Vital Capacity (*VC*) rises while the Minute Ventilation (*MV*), Maximal Voluntary Ventilation (*MVV*) decreases after the exposure for 20*min* in both groups. The Forced Vital Capacity (*FVC*) is detected decreased significantly in EG (t=1.21, P =0.25) while it slightly increased in CG (t=-0.42, P =0.68).The ratio of Forced Expiratory Volume in one second to *VC* ($FEV_{1.0}/VC$ %) increase in EG (t=-0.73, P=0.48) while decrease in CG (t=0.42, P=0.17). The Ratio of $FEV_{1.0}$ to FVC ($FEV_{1.0}$ %) values increase obviously in EG (t=-1.48, P =0.16) and a bit in CG (t=-0.23, P =0.82). High pressure is the common factor in both groups that leads the changes in the same trend in *VC*, *MV* and *MVV*. Extra factors as immersion effect, loading of diving equipment and low temperature underwater, would encounter EG participants. Instant reduced effects of *FVC* under diving exposure in the study are quite consistent with the long-term cumulative effect of professional divers in previous research, which illustrated even small depth of short-range diving exercise have definite influences on ventilation.

Keywords: *Forced Vital Capacity; hyperbaric exposure; SCUBA Diving*

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Introduction

SCUBA diving is a popular sport though confront with some medical risk factors (Eichhorn & Leyk, 2015). It requires inhalation of compressed air through the breathing tube and the pressure of the breath is exacerbated by strikingly inhomogeneous inhalation patterns (Muradyan et al., 2010), which makes the lung organ become one of the most vulnerable organs. Inhalation of high density gas leads to breathing work increase. Oxygen partial pressure and the oxygen toxicity effect to respiratory membrane and inflammation induced by micro bubbles in pulmonary circulation during decompression process (Konarski, Klos, Nitsch-Osuch, Korzeniewski, & Prokop, 2013;Pougnet et al., 2014;Richard et al., 2013a).The effects of functional hyperinflation or bronchial obstruction lead to obstructive ventilation impairment. Furthermore, sports produce capillary leakage underwater and immersion in water increase stress on pulmonary capillaries and result in hemodynamic pulmonary edema (Bove, 2016;Moon et al., 2016).When diving, hypothermia, hyperoxia, hydrostatic pressure increase and strenuous exercise all induced pulmonary circulation change rapidly promotes the occurrence of pulmonary edema (Coulange et al., 2010),further affected the lung ventilation function.

The *FVC* is significantly reduced according to previous physical examination of professional divers (Watt, 1985).Exposure to diving affects small airways and may lead to changes in lung function(Richard et al., 2013b;Skogstad, Thorsen, & Haldorsen, 2000).Prevalence indicated that 6~15% of professional divers have a tendency to of airflow obstruction as the diving experience grows(Konarski et al., 2013;Weaver, Churchill, Hegewald, Jensen, & Crapo, 2009). Airways narrowing might be due to diving-induced loss of lung elastic tissue and causes the reduction of $FEV_{1.0}$. In the meantime diving exposure affects the vital capacity and the forced expiratory flow rate (Davey, Cotes, & Reed, 1984).

Although the cumulative effect of lung function in professional divers has been observed before (Richard et al., 2013a;Skogstad, Thorsen, Haldorsen, & Kjuus, 2002), but the relationship of possible influence factors not been clearly explained. This study observed changes of ventilation function in diving experiment and hyperbaric chamber pressure exposure. In this paper, the relationship between the immediate effect and the cumulative effect of pulmonary function was discussed by comparing before and after the same pressure exposure.

Methods

Participants

Healthy volunteers are enrolled as participants in the experiment, whose maximum diving depth are no less than 20*m* underwater and the maximum duration of staying at the same depth for no less than 5*min*.Participants who have acute respiratory diseases or suffered from diving diseases could affect the normal conditions of diving should be ruled out. Informed consent forms were issued and signed to ensure all participants were familiar with the details of the research procedure and their options are non-mandatory. The written consent of our study had obtained the approval from the local Ethics Committee of the university.

Methods

Measuring instrument

Lung function measuring device (MINATO AS -505) was used as spirometer in the study to obtain the ventilation indicators. With the 0-14 $L{\cdot}s^{-1}$ in the flow range, ±3% or ±0.01 $L{\cdot}s^{-1}$ of measuring range in accuracy, 10*L* in maximum capacity, ±3% or 50*mL* in capacity accuracy, the spirometer is repeatable, responsive and reliable for ventilation measurement (Tepper et al., 2012).

Measuring procedure

Measuring starts after nasal splint pinched then breathing in and out through the mouthpiece for 30seconds and wait at least four breathing cycles for the baseline of the tidal breathing to plateau. A valuable values reference to at least 2 or 3 times of repeated measurements. Adequate rest is needed between each repeat. The error between the best and the suboptimal values should be under than 0.15*L*. Information about the participants' *gender*, *age*, *height*, *weight* was collected. The parameters of static lung capacity *VC* is consist of *TV*, *IRV*, *ERV* (equation 1). *TV* and *IRV* add up to be *IC* (equation 2). Timed vital capacity of parameters includes *FVC*, $FEV_{1.0}$ (equation 3), $FEV_{1.0}$ %(equation 4), *PEF*, $FEF_{25\text{-}75}$, MEF_{50} and MEF_{25}. The indicators of eupnea and forced respiration of every minute respectively were *MV* (equation 5) and *MVV*, which predict the percentage of the ventilation reserves (equation 6).

$$VC(\mathrm{L}) = TV(\mathrm{L}) + IRV(\mathrm{L}) + ERV(\mathrm{L}) \quad (1)$$

$$IC(\mathrm{L}) = TV(\mathrm{L}) + IRV(\mathrm{L}) \quad (2)$$

$$FEV_{1.0}\% = \frac{FEV_{1.0}(\mathrm{L})}{FVC(\mathrm{L})} \times 100\% \quad (3)$$

$$FEV_{1.0}\%t = \frac{FEV_{1.0}(\mathrm{L})}{VC(\mathrm{L})} \times 100\% \quad (4)$$

$$MV(\mathrm{L}) = TV(\mathrm{L}) \times RR(\mathrm{bpm}) \quad (5)$$

$$VR\% = \frac{MVV(\mathrm{L}) - MV(\mathrm{L})}{MVV(\mathrm{L})} \times 100\% \quad (6)$$

Experiments Settings

Diving experimental environment pressure settings are referenced to the safety standards of decompression procedures through controlling diving depth and time of hyperbaric exposure, compression and decompression speed (Moore et al., 2009). The participants were classified into the SCUBA diving group (the experimental group, EG) and the hyperbaric chamber group (the control group, CG) according to the match of their indicators of the *Age*, *Gender*, *BMI* and *FVC*. Participants in the EG wore tight wet diving suits and carried scuba tank of 12*L*. Each of them made a dive to 12m-depth under water from the surface at $6m{\cdot}min^{-1}$ and stops at 12*m* for 20*min*

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and then ascends to the surface at the same speed. The parameters values of ventilations (*VC*, *FVC*, *MV* and *MVV*) are assessed by the instructor right after surfacing. The actual ventilation per minute underwater can be calculated as the following procedure according to *Boyle-Mariotte law* (equation 7).

$$P_1(\text{kPa})V_1(\text{L}) = P_2(\text{kPa})V_2(\text{L}) \;\text{ or }\; P(\text{kPa})V(\text{L}) = k \quad (7)$$

$$\because \; \text{T}_{underwater}(min) = T_{down}(min) + T_{stay}(min) + T_{up}(min)$$

$$V_2(L) = \frac{\text{V}_1(L) \times P_1(kPa)}{\text{P}_2(kPa)} = \frac{\text{V}_1(L) \times \Delta\text{P}(kPa)}{\text{P}_2(kPa)}$$

$$\text{MV}_{underwater} = \text{TV} \times \text{RR} = V_2(L) \div T_{underwater}(min)$$

$$\therefore \; \text{MV}_{underwater} = \frac{\text{V}_1(L) \times \Delta\text{P}(kPa) \,/\, \text{P}_2(kPa)}{T_{down}(min) + T_{stay}(min) + T_{up}(min)}$$

The participants of CG exposed in a pressure of 2.2*ATA* simulating 12*m* deep diving environment in a hyperbaric chamber (GY2200). The technician operate on panel to control pressure inside the cabin from 1*ATA* to 2.2*ATA* within 2*min* and maintain the constant pressure at 2.2*ATA* for 20min through differential pressure regulating valve, then decompress in the same rate to 1*ATA*. The values of *VC*, *FVC*, *MV* and *MVV* of divers were immediately measured by spirometer as soon as they step out of the chamber.

Data Processing and Statistics

Data statistics are processed by statistics software SPSS22.0. Comparisons analyzed by paired sample *t* tests to distinguish the differences in measured values and the percentage of measured-values to predicted-values in EG and CG before and after the hyperbaric exposure. The test level is statistically significant at $P < 0.05$.

Results

Study participants

There were 34 participants with an average *age* of 21.79±1.01*y*, *weight* of 63.68±7.28*Kg*, *height* of 172.15±6.05*cm* and *BMI* of 21.45±1.90. Based on the ***Baldwin*** Regression prediction formula the prediction of the average ventilation parameter values are concluded, which include *VC* (4.26±0.35*L*),*FVC*(4.09±0.39*L*),*FEV*(3.96±0.41*L*), $FEV_{1.0}$ / *FVC* %(77.01%±1.33%), *PEF* (11.17±1.21$L{\cdot}s^{-1}$),$FEF_{25\text{-}75}$ (5.33±0.37 $L{\cdot}s^{-1}$), MEF_{50} (6.00±0.62 $L{\cdot}s^{-1}$), MEF_{25}(3.49±0.18 $L{\cdot}s^{-1}$), *MVV*(130.30±13.44 *L*).

There are 14 of them (12males and 2females) in EG and 20 participants (19males and 1female) in CG. Analyzed the values of the *Age*, *Weight*, *Height*, *BMI* and their respiratory function parameters of both groups through independent sample *t*-test and the results show that the differences of physiological parameters mentioned above are not significant, which is $P > 0.05$,

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the physiological basis parameters of the two groups were similar, which suggested that the two control samples have homogeneity and can be compared.

Change of Minute Ventilation underwater in EG

The mean values of *MV* of the whole EG was 30.09±14.27*L* before exposure ,and down to 24.01±5.04*L* underwater and rise up to 27.98±12.99*L* after emerging（Figure. 1）. The lung capacity was not immediately recovered after environmental pressure was restored though it was only 20 *min* underwater.

Changes on measured values of the pulmonary ventilation in two groups' pre- and post-hyperbaric exposure

Paired sample *t* tests compare the measured values of ventilation parameters between the EG (Table. I) and the CG (Table. II) pre- & post- hyperbaric exposure. By comparison, there are same change trends and opposite trends are found in two groups.

The *TV* and *IRV* are increased, while the *ERV* is decreased after high pressure exposure. So, the *IC* and *VC* also increase after high voltage exposure. The decline in *ERV* does not offset the rise in *TV* and *IRV*. These changes were even more evidently in the CG, which only under the mere 2.2*ATA* pressure (Figure. 2-A). $FEV_{1.0}$ showed an increase in both groups, indicating that the Forced Expiratory Volume in the first second of the high-pressure exposure both increased in two groups. Although the *FVC* decline in the EG and increased in the CG, the proportion of $FEV_{1.0}$ to *FVC* ($FEV_{1.0}$%) in both groups still increased, indicated that the rise in the $FEV_{1.0}$ might exceed the *FVC* in the CG. Both $FEV_{1.0}$%t declined due to the increase of *VC* in both groups (Figure. 2-B & 2-C).The expiratory gas flow rate (*PFE*、$FEF_{25\text{-}75}$、MEF_{75}、MEF_{50}、MEF_{25}) were all shown to increase in EG. But the *PFE*、$FEF_{25\text{-}75}$、MEF_{75}、MEF_{50} decreased while only MEF_{25} increased in CG(Figure. 2-D).The *MV*, *RR* and *MVV* were reduced after high pressure exposure. Due to $T = 60s / RR$, the duration of every breathing is prolonged after high pressure exposure (Figure. 2-E, 2-F & 2-G).

Discussion

The physiological factors affecting static lung volume are many, including age(Sharma & Goodwin, 2006), gender(Carey et al., 2007), height(Hsia, Hyde, & Weibel, 2016),weight(Jones & Nzekwu, 2006),BMI(Zavorsky et al., 2007), race(Kamal, Kesavachandran, Bihari, Sathian, & Srivastava, 2015;Whittaker, Sutton, & Beardsmore, 2005),posture (Nielsen, Holte, & Kehlet, 2003), physical activity levels(Zemková & Hamar, 2014) and altitude, *etc*. Predictions can be made for normal lung capacity based on these physiological factors. The functional prediction equation is applicable to almost everyone who ages' from 3 to 95(Quanjer et al., 2012). But the

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limits of the normal range of lung volume and capacity in different geographical, age, gender, and ethnic groups are still blurred. A high accuracy predicting equation is not 100% identical to the measured values. The lower and upper limit of the acceptable range is between 80% and 120% of the predicted value (Hansen ,2011;Mannino & Diaz-Guzman ,2012;Miller, Quanjer, Swanney, Ruppel, & Enright ,2011).

Short-term aftereffects in ventilation after pure hyperbaric exposure of 2.2ATA

In this experiment, the participants were observed to be bradypnea in aftereffect of pressure exposure. The value of *MV* is also being observed being at a lower level than in the normal circumstances. In general, when the *MV* reduced to hypoxia condition, the regulation of the respiration increases the *RR*. But in this experiment, the increase of the *RR* was not accelerated, which indicated the reduction of *MV* might be not caused by the lack of oxygen, but the shrink of gas volume under high pressure environment.

The value of *TV* increases in aftereffect of pressure exposure as the environment pressure drops according to *Boyle Mariotte law*. The gas in the airway produce different pressure profiles, bringing to lung volume dilatation and *TV* spread (Andersson B, Lundin S, Lindgren S, Stenqvist O, & Odenstedt Hergès H, 2011). *IRV* increases because the gas inhaled is in lower density. But *ERV* decreased due to different density of gases mixed.

FVC increases after hyperbaric exposure. $FEV_{1.0}$ comes from the upper alveolar where the gas density is lower, so as the expiratory resistance is lesser. Thus, exhaled gas volume is correspondingly larger. So, the $FEV_{1.0}$ rise and the $FEV_{1.0}$ % increase at the same time in the study. $FEV_{1.0}$ / *VC* % declined unlike normal circumstances, illustrated that the *VC* grow much more than the *FVC*. *FVC* has limited increased probably associated with the fatigue of respiratory muscles underwater diving. The results of random movements of unlike density of the expiratory gases always tend to be homogeneous mixing. So the volume of expired gas in per unit time undergoing the process of pressure variation is less than in stable atmospheric environment. That is to say the expiratory flow is reduced, which are the *PEF*, FEF_{25-75}, MEF_{75}, MEF_{50} decline. After 75% of gas of *FVC* being exhaled, the expiratory movement mainly squeezes the residual gas in the bottom of alveoli. And with the evacuation of airway, the reserved gas refilling makes the gas density decreases and leads to the increases of MEF_{25}.

Short-term aftereffects in ventilation after diving exposure of 12m underwater

The *VC* increase and the *MVV* and *MV* reduced in both groups. But the *FVC* in EG decline is different from the CG. Except *FVC*, parameters of *PEF*, FEF_{25-75}, MEF_{75} and MEF_{50} also appear to speed up after hyperbaric exposure in contrast to the CG. Velocity is inversely proportional to the pressure according to the ***Bernoulli's*** equation (Falahatpisheh et al., 2016). Exhaled air

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velocity (PEF, FEF_{25-75}, MEF_{75} and MEF_{50}) accelerate after hyperbaric exposure is owing to pressure.

In addition to the gas pressure and density, the inner diameter of the bronchus and absolute temperature of the gas also affects the expiratory flow. Submersion increased pressure on respiratory work and energy cost of breathing (Held & Pendergast, 2013), while diving immersion effect easily causes more fatigued in the breathing muscles. A closed-fitting diving suit exerting pressure on chest affects the ventilation of the lungs while diving and diving suits of too thick or tight can hinder the ventilation of the lungs (Schellart & Sterk, 2016). In addition, pressure between thoracic and alveolar alters the respiratory function. A breathing gas cylinder could add the hydrostatic pressure to the thoracic cage (Pendergast & Lundgren, 2009), then the respiratory system load aggravates the change of the lung volume at the end of expiration. When the end of the expiratory lung volume increase makes the length of respiratory muscles exceed over more than the optimum initial length and lessen the contraction force. Thus respiratory muscles couldn't make or sustain sufficient strain to cope with the increasing breathing work, which driving FVC to decrease.

The reliance of pulmonary circulation on gravity decreasing triggered the redistribution of cycle during immersion(Rohdin et al., 2003).The increased in pulmonary circulation, pulmonary capillary hyperemia, pulmonary artery pressure and vascular volume leads to pulmonary interstitial edema and breathing membrane elasticity decreased because of its 'thickening, ultimately the residual capacity increase and VC dwindle(Lundgren, 1984) .Therefore, $FEV_{1.0}$ / VC % increases. Peripheral circulation vessels shrink in low temperature underwater, increase circulation redistribution and pulmonary blood volume, exacerbation pulmonary interstitial edema and eventually cause airway stenosis (Uhlig F et al., 2014). So that expiratory flow rate increases during the expiratory phase, and PEF, FEF_{25-75}, MEF_{75}, MEF_{50} and MEF_{25} increase. To sum up, the aftereffect of pure pressure exposure of 2.2ATA in lung ventilation parameters of VC, MV and MVV are increasing. While as a result of 12m diving exposure, underwater immersion effect and low temperature of the diving environment caused pulmonary interstitial edema and small airway stenosis, makes the FVC decline, speeded the expiratory flow rate. In addition to environmental pressure, the non-pressure factors of the environment also affect the ventilation changes in the lungs.

Conclusion

Instant effects of diving exposure in the study are consistent with the long-term cumulative effect of professional divers in previous research, which is FVC reduced. The results illustrate even the small depth of short-range diving exercise have definite influences on pulmonary ventilation, which mainly comes from the environmental factor but not the pressure increases. The research suggested that sufficient rest and proper compression exercise is in need in relief interval during

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the occupational training or working, in order to avoid the superimposed effects of every single diving exposure immediate effect which acceleration attenuation of lung function.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

This work was supported by the [Science Research Project of Lingnan Normal University] under Grant [ZL1508]; [Research Program of Science and Technology of Zhanjiang] under Grant [2015B01115].

Acknowledgements

Special thanks are for Zhanjiang Diving School that provides experimental area and the main experimental equipment. And also like to thank the diving instructors from Zhanjiang Diving School who had offered me a lot of help and in the experiment.

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Appendices

Abbreviation

Terminology	Abbreviation
Tidal Volume	TV
Inspiratory Reserve Volume	IRV
Expiratory Reserve Volume	ERV
Residual Volume	RV
Inspiratory Capacity	IC
Vital Capacity	VC
Function Residual Capacity	FRC
Total Lung Capacity	TLC
Minute Ventilation	MV
Maximal Voluntary Ventilation	MVV
Forced Vital Capacity	FVC
Forced Expiratory Volume in one second	$FEV_{1.0}$
Ratio of FEV1 to FVC	$FEV_{1.0}$/FVC ($FEV_{1.0}$%)
Ratio of FEV1 to VC	$FEV_{1.0}$/VC ($FEV_{1.0}$%t)
Forced Expiratory Flow	$FEF_{25\sim75}$%
Peak Expiratory Flow	PEF
Forced Expiratory Flow after 25% of the FVC has been exhaled	FEF_{25}%
Forced Expiratory Flow after 50% of the FVC has been exhaled	FEF_{50}%
Forced Expiratory Flow after 75% of the FVC has been exhaled	FEF_{75}%
Ventilation Reserve%	VR%
Respiratory Rate	RR

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Tables

Table I. Measured Values of the Pulmonary Ventilation in EG pre- and post- Hyperbaric Exposure

		$\bar{x}$	N	s		t	P
1	VC(*pre-*)	3.61	14	0.56	0.15	-1.26	0.23
	VC(*post-*)	3.67	14	0.48	0.13		
2	TV(*pre-*)	1.50	14	0.72	0.19	-0.67	0.52
	TV(*post-*)	1.57	14	0.71	0.19		
3	IRV(*pre-*)	0.99	14	0.45	0.12	-0.81	0.43
	IRV(*post-*)	1.05	14	0.47	0.13		
4	ERV(*pre-*)	1.12	14	0.36	0.10	0.76	0.46
	ERV(*post-*)	1.05	14	0.35	0.09		
5	IC(*pre-*)	2.49	14	0.59	0.16	-1.17	0.26
	IC(*post-*)	2.62	14	0.49	0.13		
6	FVC(*pre-*)	3.64	14	0.57	0.15	1.21	0.25
	FVC(*post-*)	3.55	14	0.54	0.14		
7	$FEV_{1.0}$(*pre-*)	2.68	14	0.94	0.25	-0.73	0.48
	$FEV_{1.0}$(*post-*)	2.84	14	0.59	0.16		
8	$FEV_{1.0}$%(*pre-*)	72.99%	14	21.25%	5.68%	-1.48	0.16
	$FEV_{1.0}$%(*post-*)	80.94%	14	15.63%	4.18%		
9	FEV1.0/VC%(*pre-*)	73.68%	14	22.32%	5.97%	-0.73	0.48
	FEV1.0/VC% (*post-*)	77.73%	14	14.66%	3.92%		
10	PEF(*pre-*)	3.97	14	2.01	0.54	-0.72	0.49
	PEF(*post-*)	4.28	14	1.86	0.50		
11	$FEF_{25\text{-}75}$(*pre-*)	2.92	14	1.54	0.41	-0.69	0.50
	$FEF_{25\text{-}75}$(*post-*)	3.17	14	1.31	0.35		
12	MEF_{75}(*pre-*)	3.68	14	1.98	0.53	-0.87	0.40
	MEF_{75}(*post-*)	4.05	14	1.86	0.50		
13	MEF_{50}(*pre-*)	3.14	14	1.70	0.45	-0.36	0.72
	MEF_{50}(*post-*)	3.26	14	1.23	0.33		
14	MEF_{25}(*pre-*)	2.01	14	0.99	0.26	-0.68	0.51
	MEF_{25}(*post-*)	2.14	14	0.88	0.24		
15	MVV(*pre-*)	60.05	14	22.90	6.12	0.23	0.82
	MVV(*post-*)	58.96	14	14.34	3.83		
16	MV(*pre-*)	30.09	14	14.27	3.81	1.71	0.11
	MV(*post-*)	27.98	14	12.99	3.47		
17	RR(*pre-*)	21.50	14	8.21	2.20	1.32	0.21
	RR(*post-*)	19.39	14	8.07	2.16		
18	VR%(*pre-*)	49.20%	14	18.27%	4.88%	-0.85	0.41
	VR%(*post-*)	52.23%	14	19.14%	5.12%		

pre-：pre-hyperbaric exposure；*post-*：post-hyperbaric exposure；

*$P<0.05$, Difference was statistically significant；**$P<0.01$, Difference was significant statistical significance

Table II. Measured Values of the Pulmonary Ventilation in CG pre- and post- Hyperbaric Exposure

		$\bar{x}$	N	s	t	P
1	VC(*pre-*)	3.56	20	0.48	-2.92	0.009**

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	VC(*post-*)	3.69	20	0.51		
2	TV(*pre-*)	1.41	20	0.56	-0.66	0.52
	TV(*post-*)	1.47	20	0.68		
3	IRV(*pre-*)	0.89	20	0.33	-3.48	0.003**
	IRV(*post-*)	1.16	20	0.47		
4	ERV(*pre-*)	1.25	20	0.38	3.34	0.003**
	ERV(*post-*)	1.07	20	0.37		
5	IC(*pre-*)	2.30	20	0.38	-5.68	0.000**
	IC(*post-*)	2.62	20	0.50		
6	FVC(*pre-*)	3.68	20	0.46	-0.42	0.68
	FVC(*post-*)	3.70	20	0.56		
7	$FEV_{1.0}$(*pre-*)	3.09	20	0.53	-0.24	0.82
	$FEV_{1.0}$(*post-*)	3.11	20	0.52		
8	$FEV_{1.0}$%(*pre-*)	84.21%	20	12.22%	-0.23	0.82
	$FEV_{1.0}$%(*post-*)	84.66%	20	10.81%		
9	FEV1.0/VC%(*pre-*)	87.65%	20	12.29%	1.42	0.17
	FEV1.0/VC% (*post-*)	84.68%	20	10.02%		
10	PEF(*pre-*)	4.72	20	1.37	1.67	0.11
	PEF(*post-*)	4.31	20	1.18		
11	FEF_{25-75}(*pre-*)	3.46	20	0.94	0.50	0.62
	FEF_{25-75}(*post-*)	3.37	20	0.97		
12	MEF_{75}(*pre-*)	4.49	20	1.37	1.53	0.14
	MEF_{75}(*post-*)	4.12	20	1.23		
13	MEF_{50}(*pre-*)	3.74	20	1.01	0.71	0.49
	MEF_{50}(*post-*)	3.60	20	1.00		
14	MEF_{25}(*pre-*)	2.43	20	0.62	-0.36	0.72
	MEF_{25}(*post-*)	2.48	20	0.78		
15	MVV(*pre-*)	56.56	20	17.47	0.59	0.56
	MVV(*post-*)	55.20	20	15.62		
16	MV(*pre-*)	27.27	20	10.52	0.98	0.34
	MV(*post-*)	26.15	20	9.89		
17	RR(*pre-*)	20.43	20	7.57	0.07	0.94
	RR(*post-*)	20.29	20	10.13		
18	VR%(*pre-*)	50.98%	20	14.55%	-0.76	0.46
	VR%(*post-*)	52.51%	20	12.52%		

pre-：pre-hyperbaric exposure；*post-*：post-hyperbaric exposure；

*P<0.05, Difference was statistically significant；**P<0.01, Difference was significant statistical significance

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Figures

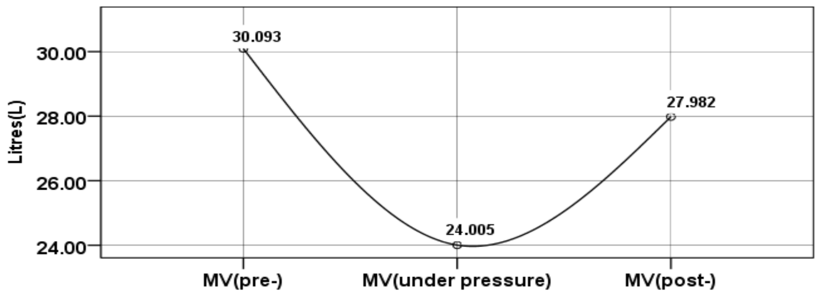

Figure 1. The variation of ventilation in different experimental stages

pre-: pre-hyperbaric exposure; underwater: underwater hyperbaric exposure;

post-: post-hyperbaric exposure; MV: Minute ventilation (L)

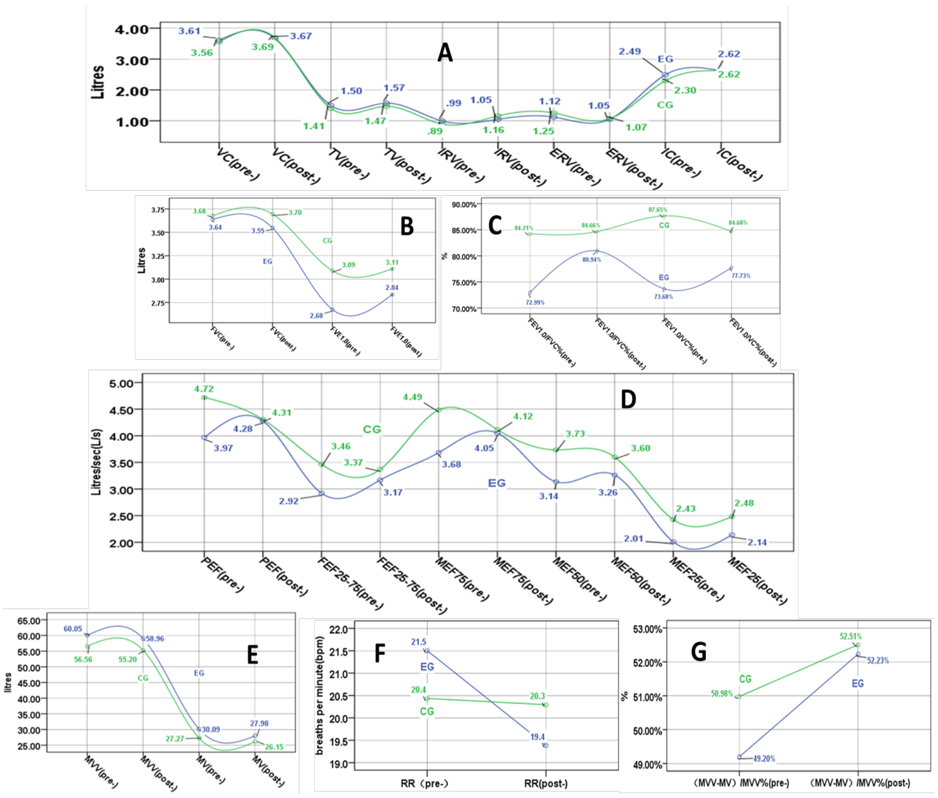

Figure 2. Comparison of Average in Measured Values of Ventilation Parameters in Both Groups Pre- and Post-Hyperbaric Exposure

EG: Experimental Group; CG: Control Group;

pre-: pre-hyperbaric exposure; post-: post-hyperbaric exposure;

【A】VC: Vital Capacity(L); TV: Tidal Volume(L); IRV: Inspiratory Reserve Volume(L); ERV: Expiratory Reserve Volume(L); IC: Inspiratory Capacity(L);

【B】FVC: Forced Vital Capacity(L); $FEV_{1.0}$: Forced Expiratory Volume in one second(L);

【C】$FEV_{1.0}$%: a ratio of FEV_1 to FVC; $FEV_{1.0}$/VC%: ratio of FEV_1 to VC;

【D】PEF: Peak Expiratory Flow(L/s); FEF_{25-75}: Forced Expiratory Flow(L/s); MEF_{75}: forced expiratory flow after 25% of the FVC has been exhaled(L/s); MEF_{50}: forced expiratory flow after 50% of the FVC has been exhaled(L/s); MEF_{25}: forced expiratory flow after 75% of the FVC has been exhaled(L/s);

【E】MVV: Maximal Voluntary Ventilation(L); MV: Minute Ventilation(L);

【F】RR: Respiratory Rate(bpm);

【G】VR%: Ventilation Reserve%=(MVV-MV)/MVV%