EFFECT OF RECREATIONAL SCUBA DIVING ON CARDIORESPIRATORY FITNESS IN MALAYSIAN NOVICE DIVERS

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Abstract

Objective: The aim of this study was to investigate scuba diving induced exercise response in novice divers as required in open water scuba diving certification.

Methods: Maximal cardiopulmonary exercise test (CPET) was performed in 30 novice divers before and within 24 hours after a standard scuba diving open water certification diving protocol of four open water dives.

Results: A significant increase in maximal oxygen consumption (VO_{2max}) in $mL\cdot kg^{-1}\cdot min^{-1}$ after scuba diving training [25.84 (6.0) vs. 27.04 (7.0)] ($p<0.05$) suggestive of an increase in exercise performance. Ventilatory drive (VE/VCO_2) also showed a significant increase 27.95 (2.7) vs. 30.07 (5.3). Ventilatory anaerobic threshold (VAT), blood pressure and lung function parameters showed no significant differences with open water scuba diving certification training.

Conclusion: In novice divers, repeated training exposure during open water scuba diving certification results in increased cardiorespiratory fitness. Although further corroborating studies are needed, this would suggest that recreational scuba diving may be an option for exercise promotion in the future.

Keywords: Recreational Diving, Scuba Diving, Diving Medicine, Oxygen Consumption, Exercise

Introduction

Exposure to an underwater environment offsets unique adjustment to human physiology in response to inert gas supersaturation, altered gas characteristics and cardiovascular effects on pulmonary function (1). The extent of consequences to these adjustments differs with diving depth, time underwater, frequency of exposure and chronology of effect. The self-contained underwater breathing apparatus (scuba) is a form of breathing support for divers. In recreational diving, this involves inhaling air at ambient pressure through a pressure regulator connected to a cylinder containing compressed air which provides flow that matches the ventilatory rate of the diver. Expired air is released into surrounding water. Other types of diving such as commercial and military diving might involve different breathing systems i.e. closed-circuit rebreather (1).

Several studies have shown reduction in pulmonary function parameters after a single scuba dive (2-4) while others have suggested long-term adverse effects such as the development of small airway disease and accelerated loss of lung function associated with commercial diving (5, 6). Study found no pulmonary function difference when comparing between recreational divers and non-divers (7).

However, pulmonary function in isolation does not reflect global physiological function. In this study, cardiopulmonary exercise testing (CPET) was used to measure integrative exercise responses involving the pulmonary, cardiovascular, hematopoietic, neuropsychological and skeletal muscular systems which were not adequately reflected through isolated measurement of individual organ system function (8). The gold standard for measuring cardiorespiratory fitness (CRF) is by using CPET and obtaining the value of maximal oxygen consumption (VO_{2max}) (9).CRF is widely recognised as an important marker of health with low levels associated with not only cardiovascular disease but also with all-cause mortality (10, 11). CRF is also a strong and independent predictor of mortality (12). Increment in VO_{2max} corresponds with a reduction in all-cause and cardiovascular mortality (13).

Various types of diving showed different effects specifically on VO_{2max}. Studies done on commercial divers showed deep diving to depths exceeding 300msw to be associated with significant reduction in VO_{2max} (14, 15). In military divers, an increase in VO_{2max} post-diving training was previously demonstrated (16). It is estimated that there is an upward trend in recreational diving with 6 million people certified as recreational divers worldwide and 500,000 more in training each year (17). Limited studies are available on effects of recreational diving on $VO_{2max.}$ A 2017 study of professional recreational divers showed a preservation of VO_{2max} after scuba diving (4). Given the volume of newly certified recreational divers annually, the primary aim of this study was to investigate changes in VO_{2max} following open water scuba diving certification in novice recreational divers. This study additionally aims to analyse changes in other CPET parameters i.e. ventilatory anaerobic threshold (VAT), ventilatory drive (VE/VCO_2) and pulmonary function post-dive certification.

Materials and Methods

This quasi-experimental study was done in accordance with the Declaration of Helsinki and has obtained the approval of local ethics committees (University Malaya Research Ethics, MREC ID NO:201896-6662 and Universiti Teknologi MARA Research Ethics, Ref No. REC/348/19). Study enrolment was from April to September 2019.

Subjects

Participants were recruited from commercial dive centres within a 10 km radius of the University of Malaya Medical Centre, Kuala Lumpur, Malaysia. Inclusion criteria for this study were; 1) participants were newly registered for open water scuba diving certification, 2) aged between 18 – 60 years old with no previous scuba diving exposure, 3) comprehended English and Malay Language and 4) consented to the study. Written consent was obtained from all participants. Those with known underlying medical illnesses i.e. hypertension, diabetes mellitus, dyslipidaemia, cardiac disease, peripheral arterial disease or pulmonary disease were excluded from the study. We also excluded subjects who were pregnant, hydrophobic, claustrophobic, active smokers, had other absolute contraindications to scuba diving as listed in World Recreational Scuba Training Council as well as individuals classified as high risk for exercise according to American College Sports Medicine (ACSM) Pre-participation Risk Stratification (18).

Pre-dive assessment

Pre-dive assessment was done prior to exposure to scuba diving. Demographic data (age, sex, race) and medical data (medical problems, medications, smoking history and alcohol consumption history) were documented. The subjects then underwent exercise risk assessment according to the ACSM Pre-participation Risk Stratification, and completed the Recreational Scuba Training Council (RSTC) Diver's Medical Questionnaire and Statement for diving medical clearance and the International Physical Activity Questionnaire (IPAQ) long form. Anthropometric assessment of height was measured using a stadiometer (SECA model 703, SECA, Hangzhou, China). Weight and body composition were measured using Body Impedance Analysis (InBody 270, Biospace co., Seoul, Korea). Blood pressure and resting heart rate were assessed using an automated device (Omron HEM-705CP, Omro Healthcare Company, Japan). Each participant then underwent a pulmonary function test and cardiopulmonary exercise testing (CPET). Investigations were done in the morning, after at least eight hours of rest in a quiet room with temperature maintained at 24°Celcius. Body composition analysis was done on subjects in a fasted condition (at least 8 hours) who were advised to take a light meal. Each subject then performed a lung function test and maximal exercise test with a one-minute incremental step protocol of 20 Watts on cycle ergometry using a breath-by-breath system (Quark, COSMED, Roma, Italy) calibrated prior to each test. Test was performed with breath-by-breath ventilation and gas monitoring and was ended by participants at self-reported maximal effort. VO_{2max} in this study was defined by a plateau in oxygen uptake despite increased workload. Anaerobic threshold was determined using V-slope analysis on VCO_2 vs. O_2 equal scale plot and VE/VCO_2 relationship slope was measured from one minute after the beginning of loaded exercise to respiratory compensation point (19). Classification of cardiorespiratory fitness levels were grouped using VO_{2max} values according to ACSM Classification (8).

Open water dive certification

All subjects underwent four no-decompression dives using air in open water as part of their open water scuba diving certification. Dives were done on two consecutive days, with two shore dives on Day One and two boat dives on Day Two. Dive protocols were standardised to included descent to 10-18 meters of sea water (msw) at an average temperature of 29°Celsius with an average bottom stay of 35 minutes for each dive followed by ascent. All dives were done off the shores of the Malaysian East Coast.

Post-dive assessment

Post-dive assessment was repeated within 24 hours of surfacing from the last open water dive. Assessment included a post-dive CPET as well as body composition, blood pressure, resting heart rate, pulmonary function test and IPAQ.

Statistical analysis

Data was reported as mean (SD) and statistical tests were run on IBM SPSS software version 20 (SPSS Inc., Chicago, USA). The data distribution was analysed with a Shapiro-Wilk test and found to be of normal distribution. Differences were considered significant at $p<0.05$ and changes before and after dives were assessed by paired *t*-test.

Results

Of the 34 novice divers enrolled in this study, only 30 participants completed the protocol: a response rate of 88.23%. Of the four who did not complete the protocol, one was excluded after a medical condition was detected and three did not obtain dive certification during the study duration. Participants' details are shown in Table 1.

Table 1: Demographic and anthropometric parameters of the divers

Characteristics	Total		Mean (S.D.)
	n	%	
Age (years)			
20-30	25	83.33	25.57 (6.37)
30-40	5	16.67	
Gender			
Male	12	40	
Female	18	60	
BMI (kg/m²)			
18-25	11	36.67	
25-30	10	33.33	25.80 (5.32)
>30	9	30.00	
Race			
Chinese	15	50	
Malay	14	46.67	
Others (Bidayuh)	1	3.33	
IPAQ (MET-min/week)			
Low	1	3.3	
Moderate	10	33.3	6333.4 (7075.2)
Vigorous	19	63.3	
Cardio-respiratory Fitness* (kg/ml/min)			
Very Poor	26	86.67	25.84 (6.00)
Poor	4	13.33	

*CRF classification done according to ACSM 10th Edition (2018)

A paired *t*-test with an α of 0.05 was used to compare parameters of exercise performance after four open water dives. There were no significant changes in hemodynamic (blood pressure, resting heart rate) and lung function parameters (functional vital capacity, forced expiratory volume, mid-expiratory volume) at rest. However, during repeat CPET, VO_{2max} and VE/VCO_2 slope after diving were significantly higher than before diving, with t (29) = 2.19 and p = 0.037 and t (29) = 2.21 and p = 0.035, respectively (Table 2). There was no significant difference in repeat VAT. There was also no significant difference in reported physical activity levels before and after scuba diving training.

Table 2: Acute effects of scuba diving training

Parameter	Before dive Mean (S.D)	After dive Mean (S.D)	Mean difference (95% CI)	*t*-value, (df)	p-value
Systolic BP (mmHg)	119.67 (11.70)	119.37 (11.19)	0.30 (3.96,4.56)	0.14 (29)	0.887
Diastolic BP (mmHg)	69.53 (9.91)	69.77 (9.93)	0.23 (4.17, 3.70)	0.12 (29)	0.904
Heart rate (beats/ min)	73.83 (8.17)	74.60 (13.22)	0.77 (6.25, 4.72)	0.29 (29)	0.777
Functional vital capacity (FVC) (ml)	3.47 (0.76)	3.39 (0.71)	0.08 (0.04, 0.20)	1.37 (29)	0.179
Forced Expiratory Volume/1 sec (FEV_1) (ml)	2.99 (0.58)	2.94 (0.53)	0.05 (0.04, 0.15)	1.13 (29)	0.267
Mid-expiratory volume (MEF_{50}) (ml)	4.17 (1.04)	4.14 (0.87)	0.027 (0.15,0.20)	0.31 (29)	0.762
$IPAQ_{total}$ (MET.min/ week)	4642.69 (3478.41)	4745.57 (3329.90)	551.18 (1235.85, 1030.07)	0.19 (29)	0.853
Maximal oxygen uptake (VO_{2max}) (ml/kg/ min)	25.84 (6.00)	27.04 (7.02)	1.20 (2.32, 0.08)	2.19 (29)	0.037*
Anaerobic threshold (ml/kg/ min)	19.58 (5.27)	18.72 (4.43)	0.86 (0.64, 2.36)	1.18 (29)	0.249
VE/VCO_2	27.95 (2.71)	30.07 (5.27)	2.12 (4.09, 0.16)	2.21 (29)	0.035*

*p<0.05 taken as significant

Discussion

This study demonstrates an improvement in CRF among novice recreational divers after open water scuba diving certification. While ventilatory drive was increased, lung function parameters at rest showed no significant difference after 24 hours. Blood pressure, resting heart rate and VAT were also preserved post-dive.

Among the study participants, 36.7% had normal BMI according to WHO classifications with the remaining 33.3% and 30.0% in the overweight and obese categories, respectively. The BMI percentages in our study were comparable with previous studies that looked at experienced recreational divers which had 37.3% to 53.2% of divers having normal BMI, 34.1% to 42.1% of divers being overweight and 12.5% to 20.6% of the divers being obese (20, 21).

Our participants had a mean IPAQ- total in the high physical activity group of 4642.69 MET·min·week^{-1}. This is comparable to other studies of recreational divers reporting 93.7% of divers engaging in physical activity other than work-related (20). While the IPAQ-LF (long form) questionnaire has previously shown overall reliability and validity, studies done in Malaysia recorded that self-assessment of physical activity instruments including IPAQ overestimated physical activity among participants (22-24). Others have also shown that there was poor agreement between IPAQ and accelerometer data among multi-ethnic Singaporean subjects (25). This might in part explain the discordance between the reported high levels of physical activity among our subjects and their low baseline CRF.

This study demonstrated that dive training consisting of four open water dives as required for beginner open water dive certification induces significant increase in VO_{2max}. In this study, VO_{2max} increased 24 hours post-dive. Although similar improvement in VO_{2max} had been seen in previous studies, ours is the first among novice recreational divers (16, 26). The main determinants of VO_{2max} are genetics and quantity of exercising muscles, as well as age, sex, body size and training (27). Energy requirements of recreational diving has been estimated at METS (metabolic equivalent) of 13 (28). This is a significant workload equivalent to swimming against a one knot current with full scuba gear on. A subsequent study valued that a single bout of recreational air dive to a depth of an average of 20 m required moderate-intensity energy expenditure, with a 7-MET capacity being generally adequate (29). MET value of an activity is a measure of absolute exercise intensity. Our study had participants diving to a maximum depth of 18 m. Taking the 7-MET estimation for a 20 m diving depth, recreational scuba diving in this study was still within the range of equivalent vigorous physical activity. The vigorous intensity physical activity of recreational scuba diving would possibly explain the improved VO_{2max} among our study participants after dive training. In this study, baseline CRF was lower (mean VO_{2max} 25.8 mL·kg^{-1}·min^{-1}) compared to previous studies of professional divers at 53.8 mL·kg^{-1}·min^{-1}, of sport divers at 38.9 mL·kg^{-1}·min^{-1} and of other recreational divers at 31.6 mL·kg^{-1}·min^{-1} (4, 16, 30). Classification by ACSM puts participants' baseline VO_{2max} as very poor CRF (8). This lower exercise capacity may have also contributed to our participants responding positively to scuba diving training.

A significant increase was seen in ventilatory drive (VE/VCO_2 slope) of our study participants post-dive. VE/VCO_2 relationship reflects ventilation efficiency during exercise with higher slope indicating reduced efficiency (19). As explained in other studies, scuba diving is associated with an increase in extravascular lung fluid present after diving due to an increase in hydrostatic pressure gradient towards the thorax during immersion (31, 32). This leads to a ventilation perfusion mismatch seen with an increase in VE/VCO2 ratio post-diving. The higher slope in our study indicates ventilation inefficiency similar to that seen in previous studies looking at VE/VCO_2 ratios after a single scuba dive (4). Post-dive lung conditions and VE/VCO_2 ratios are also similar to that seen in previous research looking at after exercise following acute saline infusion (33, 34). Our study supports that exposure to recreational scuba diving is associated with an increase in extravascular lung fluid as demonstrated by an increase in VE/VCO_2 ratios persisting to 24 hours post-dive.

This increase upon dynamic testing via CPET was not accompanied by changes in lung function parameters at rest. Information obtained from tests performed in a resting state may not accurately represent physiology on exertion (35). Studies have shown that in situations with increase in functional dead space leading to ventilation/perfusion mismatch, VE/VCO_2 ratio on exercise is present with largely preserved FEV_1 at rest (36). While dynamic measures of ventilation efficiency during exertion showed changes, measurements of FEV_1, FVC and MEF_{50} taken at rest and 24 hours post-diving showed no significant differences in our study. Timing of test and method of testing may have both played a role. Previous studies have shown that normalisation of FEV_1 and FVC occurred 24 hours after a single dive exposure when tested with a lung spirometry while more acute testing at 2 hours post-dive with CPET showed an increase in VE/VCO_2 ratio (4, 37). This could reflect that while lung function parameters at rest normalize 24 hours after last dive exposure, there is the possibility of persistent subclinical fluid within lung vasculature manifesting during exertional testing.

In our study, ventilatory anaerobic threshold (VAT) showed no significant changes. Similar preservation of anaerobic threshold was also seen in other study (4). This reflects that exercise intensity during recreational scuba diving does not affect the anaerobic threshold limit, which leads to a preservation of VAT after diving exposure as seen in this study. Hemodynamic parameters including blood pressure and heart rate measured at rest 24 hours after last dive also showed no significant changes (Table 2). This is similar to previous studies and could be attributed to normalisation of parameters given the duration of testing (3).

Conclusion

To our knowledge, this study was the first to investigate the effects of scuba diving on exercise response in novice divers. In summary, we found repeated scuba diving in novice recreational divers resulted in increased CRF as demonstrated by improvements in VO_{2max} after open water scuba diving certification. Given that CRF is an independent protective factor in all-cause mortality and overall health parameters, our study is novel in the possible role of recreational scuba diving in exercise and health promotion in the future.

Study limitations included the inability to definitively rule out the effect of other physical activity within the study period on CPET results. Further corroborating studies with more comprehensive acute testing and with longer follow-up times post-dive are needed to establish duration and significance of post-dive CRF among novice divers. Studies with larger cohorts from other scuba diving backgrounds are also needed to determine whether these findings would be replicated.

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Competing interests

The authors declare that no competing interests.

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