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BRIEF REPORT

Glossopharyngeal Insufflation and Breath-Hold Diving: The More, the Worse?

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Objective.—The glossopharyngeal insufflation maneuver (lung packing) is largely performed by competitive breath-hold divers to improve their performance, despite observational evidence of fainting and loss of consciousness in the first seconds of apnea.

Methods.—We describe here the time course of hemodynamic changes, induced by breath-holding with and without lung packing, in 2 world-class apnea competitors.

Results.—When compared with apnea performed after a deep breath (100% vital capacity), lung packing leads to a decrease in cardiac output, blood pressure, and cerebral blood flow during the first seconds after the beginning of apnea. The major hemodynamic disorders were observed in diver 1, who exhibited the greater increase in pulmonary volume after lung packing (+22% for diver 1 vs +10% for diver 2). After the initial drop in both cardiac output and blood pressure, the time course of hemodynamic alterations became quite similar between the two apneas.

Conclusions.—Some recommendations, such as limiting the number of maneuvers and performing lung packing in the supine position, should be expressed to avoid injuries secondary to the use of glossopharyngeal insufflation.

Key words: cardiac function, echocardiography, apnea, cerebral blood flow, heart lung interaction, transcranial Doppler ultrasound, immersion pulmonary edema

Introduction

The glossopharyngeal insufflation maneuver, also called lung packing, is used to increase the volume of air in the lungs above physiological total lung capacity. After taking a deep breath, the divers pump air into the lungs using the oropharyngeal musculature. It has been previously reported that breath-hold divers were able to increase gas volume up to 4 L above their total lung capacity (commonly from 0.5 to 3 L). Apnea divers use lung packing to increase both diving depth and duration by increased oxygen stores, attenuation of the consequences of hyperbaria on the chest, and facilitation of pressure equalization in the ear during descent toward the bottom.[1] However, lung packing also leads to profound hemodynamic changes resulting in a prompt drop in systemic arterial blood pressure.[2] The major decrease in cardiac output observed after lung packing has been related to an increase in transpulmonary pressure and autonomous nervous system alterations.

Observational evidence of fainting and loss of consciousness, called "packing blackout," in the first seconds of apnea[3] supported the suggestion that lung packing could be responsible for a major decrease in cerebral blood flow. Conversely, during a conventional apnea without lung packing, syncope occurred after several minutes of breath-holding or immediately after the end of apnea. Therefore, we hypothesize that in the first seconds of apnea the decrease in cerebral blood flow is more pronounced after lung packing than after deep breath. We compared the cardiovascular alterations induced by a 4-minute duration apnea performed at 100% of vital capacity (VC) and after lung packing in 2 world-class competitive breath-hold divers (BHD).

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Methods

The 2 world-class competitive BHD studied (diver 1, aged 32 years, height 182 cm, weight 73 kg; diver 2, aged 35 years, height 193 cm, weight 80 kg) are participating in apnea world championships. One of them is the current world champion of free diving (constant weight apnea without fins). They regularly use lung packing during competition and have determined their own optimal lung packing effort to improve their performance. Studies were carried out in a quiet, temperature-controlled room maintained at 27ºC to 28°C. All investigations were performed in the morning, 3 hours after a light breakfast. The 2 subjects performed warm-up apneas before each session. The local Ethics Committee at Aix-Marseille University approved the study, and the subjects provided informed consent.

A preliminary study was conducted to assess the respiratory changes induced by lung packing. Dynamic spirometry and end-tidal o_2 concentration measurements were performed using a spirometer and gas analyzer (K4B2 PFT, Cosmed, Rome, Italy). Pulmonary function was studied according to American Thoracic Society standards. Forced expiratory volume in 1 second (FEV_1) and VC were measured at baseline. Furthermore, it was recommended to the subjects to completely exhale to residual volume to measure the end-tidal o_2 concentration ($Peto_2$). The same measurements were repeated in the 2 subjects after lung packing. Thereafter, the impact of lung packing on the cardiovascular alterations induced by a 4-minute duration apnea was investigated. For this purpose, the BHD were investigated in the supine position during 2 different apneas, 1 after a deep breath (ie, 100% VC) and 1 after lung packing. The divers underwent the 2 apneas in a randomized order. The apneas were separated by a rest period of normal breathing of 15 minutes. Pulse oximetry o_2 saturation was continuously monitored using a earlobe pulse oximeter Nellcor N-595 (Nellcor Inc, Pleasanton, CA).

CARDIAC FUNCTION TESTING

Heart rate (HR) was recorded using an analog 3-lead electrocardiogram (BIOPAC Systems, Goleta, CA). Continuous finger blood pressure (Finapres model 2300, Ohmeda Monitoring Systems, Englewood, CO) was sampled at 1 kHz (by an analog-to-digital converter, MP 150, BIOPAC Systems).

Stroke volume (SV) was assessed by echocardiography and Doppler (MyLab 30CV, Esaote, Genoa, Italy) from the combination of the aortic cross-sectional area (ACSA) and the aortic blood flow recorded on the same site. Aortic velocity envelope (AoVTI) was recorded from the ascending aorta using a 2-MHz Doppler ultrasound probe positioned in the suprasternal notch.

The SV and cardiac output (CO) were calculated as follows: SV = AoVTI × ACSA; CO = SV × HR. Systemic vascular resistance (SVR) was calculated as mean blood pressure divided by cardiac output. Blood flow velocities of the right middle cerebral artery were continuously recorded using transcranial Doppler ultrasonography (Waki TCD, Atys Medical, Soucieu en Jarrest, France).

Results

BASELINE MEASUREMENTS

In diver 1, VC was measured at baseline to 6.85 L and after lung packing reached 8.37 L (+22%). In diver 2, VC was measured at baseline to 7.43 L and after lung packing reached 8.21 L (+10%). After lung packing, an increase in $PetO_2$ was found in the 2 BHD in comparison with baseline: in diver 1, $PetO_2$ was measured at 15.7 kPa at baseline (VC) and reached 17.6 kPa after lung packing (+12%); in diver 2, $PetO_2$ was measured at 16.1 kPa and reached 17.9 kPa after lung packing (+11%).

INVESTIGATIONS DURING APNEAS

The easy phase is the initial phase of apnea in which the subject feels no urge to breathe, in contrast with the second phase, called the "struggle" phase, during which involuntary breathing movements start. During apneas after lung packing, the duration of the easy phase was prolonged from 80 seconds to 120 seconds for diver 1 (+50%) and from 110 seconds to 130 seconds for diver 2 when compared with apnea performed at VC (+18%). Comparisons between the 2 apneas, preceded or not preceded by lung packing, are shown in Figures 1 and 2.

HEART RATE

After an initial tachycardia, HR gradually decreased both at VC and after lung packing. For diver 1, who exhibited the greater increase in pulmonary volume by lung packing, tachycardia was more pronounced at the beginning of apnea after this maneuver. For diver 2, HR time courses were similar during the 2 apneas.

STROKE VOLUME

A decrease in SV was observed in the 2 subjects at the beginning of apneas. This decrease was more marked when the divers used lung packing, and reached −60% (from 90 mL to 37 mL) for diver 1 and −43% (from 114 mL to 66 mL) for diver 2 after these maneuvers.