Late-breaking abstract: The diaphragm and abdominal muscles act on the abdomen to displace blood to the extremities during exercise

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We have recently demonstrated (Aliverti et al, J Appl Physiol, 2010) that during quiet breathing the diaphragm serves the double function to ventilate the lung and to shift blood from the splanchnic vascular bed to the extremities. We hypothesized that with simultaneous contraction of abdominal muscles, such as occurs during exercise, the circulatory function of the diaphragm can be considerably enhanced.

Six healthy subject performed a submaximal constant exercise workload test (repeated foot flexion at ~60% of max workload) within a whole body plethysmography (WBP) measuring changes in body volume (dVb). Simultaneously, changes in volume of the trunk (dVtr) were measured by optoelectronic plethysmography. Blood shifts between trunk and extremities (Vbs), were determined.
1709
Right ventricular contractility at rest and during exercise in COPD
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Rationale: COPD patients show a limited stroke volume response to exercise. This is thought to be due to an increased right ventricular (RV) afterload. Whether an impairment to increase RV contractility contributes to the impaired stroke volume response is unknown. Therefore, the aim of this study is to determine whether RV contractility changes during exercise in COPD patients.

Methods: Nine patients with COPD (GOLD II-IV) underwent right heart catheterisation and subsequently cardiac MRI at rest and during submaximal exercise. With cardiac MRI RV volumes were measured. During right heart catheterisation RV pressure curves were continuously measured. As a measure of contractility, the maximum rate of rise of RV pressure (dP/dtmax) was obtained from an averaged pressure waveform over several respiratory cycles, see figure 1. Then, dP/dtmax was normalized for RV end-diastolic volume, i.e. dP/dtmax/EDV (1).

Results: In all patients dP/dtmax/EDV increased with exercise. At rest mean dP/dtmax/EDV was 3.6±1.3 mmHg/ml/m, while during exercise it was 6.9±3.7 mmHg/ml/m (p<0.001). RV end-systolic volume did not change with exercise.

Conclusions: COPD patients show an increase in RV contractility. The increase in contractility does not result in a decrease in RV end-systolic volume.

Reference:

1710
Right ventricular output in chronic obstructive pulmonary disease during expiration by reduced venous return
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Background: High positive airway pressure impedes venous return and right ventricular (RV) output in mechanically ventilated patients. Whether this is also the case in normally breathing COPD patients, where the expiratory intrathoracic pressure is increased due to airway obstruction, is unknown. We investigated the effects of intrathoracic pressure on venous return and how this perturbs RV output during expiration at rest and during exercise.

Methods: Fourteen COPD-patients (GOLD II-IV) underwent simultaneous measurements of intrathoracic, right atrial (RA) and pulmonary artery pressures at rest and during exercise. Intrathoracic and RA pressure were used to calculate RA filling pressure. Dynamic changes in pulmonary artery pulse pressure during expiration were examined to evaluate changes in RV output.

Results: Pulmonary artery pulse pressure decreased up to 40% during expiration (figure 1). This decline was associated with a low RA filling pressure (p<0.04). During exercise, a similar decline in pulmonary artery pressure was observed. Intra-thoracic pressure and RA pressure increased similar, resulting in an unchanged RA filling pressure.

Conclusions: We show that in COPD, pulmonary artery pulse pressure declines during expiration; most prominent in patients with a low RA filling pressure. This implies that, spontaneous breathing already impairs venous return and by that RV output in COPD.

1711
Effects of hyperoxia and helium-hyperoxia on the cardiocirculatory responses to incremental exercise in hypoxaemic patients with advanced COPD
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Heliox breathing might positively impact upon the haemodynamic responses to exercise in non-hypoxaemic patients with moderate-to-severe chronic obstructive pulmonary disease (COPD) (Chiappa, GR et al. Am J Respir Crit Care Med, 176:1004, 2009). There is, however, a lack of evidence of whether these beneficial effects would also be found in patients with more advanced cardiovascular impairment, i.e., hypoxaemic, GOLD stage IV patients. On a double-blind study, 13 patients (FEV1= 54±9.9 L pred; PaO2= 57±7.0 mmHg) were submitted to maximum incremental cardiopulmonary exercise tests while breathing hyperoxia (HiOX= 40% O2) or helium-hyperoxia (He-HiOX= 60% He/40% O2). Stroke volume (SV, mL) and cardiac output (CO, L/min) were non-invasively monitored by impedance cardiography (PhysioFlow®), Manatec Inc, France. Peak work rate (WR) was improved with He-HiOX compared to HiOX (52±1 W vs. 46±18 W), in addition, end-expiratory lung volume (EELV) was slightly, albeit significantly, reduced (5.50±1.25 vs 5.61±1.30 L; p<0.05). At iso-WR, He-HiOX was associated with higher SV and CO than HiOX (92±8 mL vs. 84±6 mL and 9.6±1.3 L/min vs. 8.7±1.9 L/min, p<0.05). Improvement in CO with He-HiOX was negatively related to resting EELV (r=-0.73, p=0.01) but not with baseline CO and PaO2 (p>0.05). In conclusion, hyperoxic heliox enhances the cardiocirculatory responses to exercise compared to hyperoxia alone in less hyperinflated patients with advanced, hypoxaemic COPD. These data indicate that increased operational lung volumes are related to deleterious haemodynamic effects in this patient sub-population.

1712
Predictors of improvement in peak exercise capacity with helium-hyperoxia in severely-impaired COPD patients under long-term oxygen therapy
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Heliox can improve exercise tolerance in ventilatory-limited patients with chronic obstructive pulmonary disease (COPD). Unfortunately, however, these benefits are quite heterogeneous in patients with similar levels of resting airflow obstruction. In order to gain further insight into the determinants of such variability in hypoxaemic patients with advanced COPD, we evaluated 24 males (GOLD stage IV) who were under long-term O2 therapy. Patients underwent maximum incremental cardiopulmonary exercise tests while breathing hyperoxia (HiOX= 40% O2) or helium-hyperoxia (He-HiOX=60% He/40% O2). Peak work rate (WR) was significantly improved with He-HiOX compared to HiOX (54±26 W vs. 48±23 W). This was associated with increased mean ins and expiratory flows and
larger tidal volumes; in addition, end-expiratory lung volume was lower at peak exercise (5.57±1.12 L vs 5.65±1.13 L; p<0.05). Δ[He-HiOX - HiOX] WR was positively related to markers of lung hyperinflation including total lung capacity and residual volume (r=0.52 and r=0.40, p<0.05). Interestingly, however, fat-free mass (FFM) also showed to be strongly related to ΔWR; in fact, FFM was the only independent predictor of ΔWR on a multiple regression analysis (r²=0.66; p<0.001). We conclude that once patients with advanced COPD are relieved from the “central” ventilatory constraints by breathing hyperoxic heliox, appendicular muscle mass becomes an important determinant of maximal exercise capacity. These data lend support to the notion that preserved muscle mass is important for improved respiratory mechanics be translated into enhanced peak exercise capacity in these patients.

1713 Tissue deoxygenation kinetics induced by acute hypoxic exposure at rest in humans
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The impact of hypoxia on tissue oxygenation per se involves complex mechanisms. How muscle and brain face the hypoxic stress over several hours of hypoxic exposure (HE) remain unknown. Therefore, this study aimed to investigate the effects of 4-hours HE at rest on muscle and cerebral (de)oxygination kinetics. Twelve healthy males seated quietly while breathing the appropriate gas mixtures. After 10-min of normoxia (FiO2=0.21), subjects were exposed for 4 h to hypoxia (HE, FiO2=0.12) or normoxia (control condition), and then again to normoxia for 15 min. Muscle and cerebral oxygenation (NIRS), pulse oxygen saturation (SpO2) and heart rate variability were measured continuously. The outflow of blood from the splanchnic vasculature (Aliverti et al, J Appl Physiol, 2009). By using DBP, we have recently shown that significant blood volume changes occur during expulsive maneuvers and that abdominal pressure controls the amount of blood displaced from the splanchnic vasculature (Aliverti et al, J Appl Physiol, 2010). We hypothesized that also during cough a significant amount of blood can be displaced from the trunk to the extremities. We studied 7 healthy subjects (age: 28.6±2.5 yrs) during series of voluntary coughs at four different operating volumes: functional residual capacity (FRC), total lung capacity (TLC) and two intermediate volumes between FRC and TLC (namely, FRC+ and FRC++). BS from the thorax to the extremities were measured by DBP during quiet breathing and during cough at each operating lung volume. The results are shown in figure. BS during cough resulted significantly higher than during QB (p<0.001). BS increase with increasing operating volume, being maximal at total lung capacity (figure). These findings might help to better understand the cardiopulmonary interactions during cough and the mechanism by which coughing during asystolic cardiac arrest can maintain consciousness in human subjects.

1715 Regional chest wall volume variations in heart failure patients during inspiratory muscle training
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It is known how heart failure (HF) and cardiomegaly associated with diaphragmatic weakness affects chest wall function. Therefore, we evaluated in these patients the distribution of volume variations into the different thoracoabdominal compartments during quiet breathing and during inspiratory muscle training. Thirty-one individuals were evaluated and divided into two groups: HF (17 patients with functional class II and III chronic heart failure associated with cardiomegaly) and control (12 healthy volunteers). All subjects were evaluated by spirometry, six-minute walking test (6MWT), and optoelectronic plethysmography (OEP) during threshold inspiratory muscle training (MIT). OEP allowed to assess right-left asymmetries in the volume changes of upper thoracic (Vrca), lower thoracic (Vab) and abdominal (Vab) compartments. While no significant differences were present between right and left sides in the control group during MIT, in HF patients volume variations of Vrca were 45.30±9.10 and 54.33±12.9, respectively in the left and right sides (p=0.03). This was associated to a significant decrease, compared to normals, of Vrca variations; in addition, a positive correlation between the%Vra,left and ejection fraction of left ventricle (r=0.468 and p=0.049), and a negative correlation between the Borg scale after the 6MWT and the%Vra, left side (r=0.878 and p<0.01) were found. In conclusion, HF patients have a reduced displacement of the lower rib cage of the left compared to right side, suggesting the influence of cardiomegaly on diaphragmatic weakness and an increased perception of dyspnea during submaximal exercise.