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Chest wall kinematics and breathlessness during unsupported arm exercise in COPD patients

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ABSTRACT

We hypothesised that chest wall displacement inappropriate to increased ventilation contributes to dyspnoea more than dynamic hyperinflation or dyssynchronous breathing during unsupported arm exercise (UAE) in COPD patients. We used optoelectronic plethysmography to evaluate operational volumes of chest wall compartments, the upper rib cage, lower rib cage and abdomen, at 80% of peak incremental exercise in 13 patients. The phase shift between the volumes of upper and lower rib cage (RC) was taken as an index of RC distortion. With UAE, no chest wall dynamic hyperinflation was found; sometimes the lower RC paradoxed inward while in other patients it was the upper RC. Phase shift did not correlate with dyspnoea (by Borg scale) at any time, and chest wall displacement was in proportion to increased ventilation. In conclusions neither chest wall dynamic hyperinflation nor dyssynchronous breathing *per se* were major contributors to dyspnoea. Unlike our prediction, chest wall expansion and ventilation were adequately coupled with each other.

1. Introduction

Patients with chronic obstructive pulmonary disease (COPD) complain of severe dyspnoea while performing simple daily-life activities with arms, during which they develop rapid shallow breathing (Tangri and Wolf, 1973). Celli et al. (1986) report that dyspnoea is associated with dyssynchronous breathing characterized by abdominal paradox during unsupported arm exercise (UAE) in some severely obstructed patients. They also found that most of the ventilatory load is shifted from respiratory muscles of the rib cage to the diaphragm and expiratory muscles during either unsupported arm exercise (UAE) (Criner and Celli, 1988), or simple arm elevation (Martinez et al., 1991, 1993) in the majority of their patients. Nonetheless, they do not provide a clear reason for breathlessness associated with dyssynchronous breathing during UAE (Celli et al., 1986; Criner and Celli, 1988; Martinez et al., 1991, 1993).

Healthy subjects describe dyspnoea as an increased perception of respiratory effort which reflects heightened central motor command to the respiratory muscles with a copy to the sensory cortex which is informed of the voluntary effort to increase ventilation (McCloskey, 1981; O'Donnell et al., 2007). By contrast, expiratory flow limitation and dynamic hyperinflation in exercising COPD patients result in less volume displacement than that dictated by the respiratory motor command (O'Donnell et al., 2006, 2007), and a steeper increase in dyspnoea is described as inspiratory difficulty and respiratory effort (Gigliotti et al., 2003; O'Donnell et al., 2006, 2007).

Arm elevation increases functional residual capacity mildly (Martinez et al., 1991), if at all (Couser et al., 1992; Dolmage et al., 1993; Romagnoli et al., 2006), while diverting rib cage muscles from ventilatory function to postural function gives rise to rib cage distortion (Romagnoli et al., 2006). Rib cage distortion prevents a proportional inflation of the rib cage and abdomen and limits chest wall displacement in the face of increased ventilation. We hypothesised that inappropriate chest wall displacement contributes to dyspnoea rather than chest wall dynamic hyperinflation or dyssinchronous breathing during UAE in patients with COPD.

To validate the above hypothesis we carried out the present investigation.

2. Patients and methods

2.1. Subjects

Thirteen COPD patients (12 males) with moderate-to-severe airway obstruction, participated in the study. COPD was diagnosed on

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the basis of history, physical examination, chest radiograph, and results of pulmonary function studies. All patients were clinically stable and on appropriate medication.

2.2. Study design

The study was conducted over 3 days: baseline lung function (day 1), incremental UAE test (day 2) and constant load UAE test (day 3). Compartmental chest wall volumes were evaluated on day 3 at rest and constant load UAE. All subjects were well acquainted with the experimental protocol and equipment used.

The research was carried out at the clinic of the Don Gnocchi Foundation. The study was approved by the local ethics committee and subjects gave their informed consent at the time of first assessment.

2.3. Pulmonary function assessment

Routine spirometry and lung volumes, obtained with subjects seated in a comfortable armchair, were measured according to ATS/ERS guidelines (Miller et al., 2005). Functional residual capacity (FRC) was measured with a body plethysmograph (Autobox DL, 6200; SensorMedics; Yorba Linda, CA) according to a standardized procedure (Wanger et al., 2005). The normal values for lung function were those of the European Community for Coal and Steel (European Community for Coal and Steel, 1993). Patients breathed through a mass flow meter (Vmax 229; SensorMedics; 70 ml dead space) attached to the mouthpiece, and its integral was used to display the flow volume loop and, if any, expiratory flow limitation (EFL). EFL was considered present at rest when >50% of the tidal breath met or exceeded the expiratory boundary of the maximal flow-volume loop (Johnson et al., 1999).

2.4. Operational lung and chest wall volume measurements

Optoelectronic plethysmography (OEP) allows accurate 3-dimensional computation of the volume of the chest wall (Vcw) based on coordinates from 89 surface markers attached to the chest wall surface. Details of this technique have been thoroughly described previously (data online) (Aliverti et al., 1997, 2009; Binazzi et al., 2008; Cala et al., 1996; Filippelli et al., 2001; Gorini et al., 1999; Romagnoli et al., 2006). Vcw was modelled as the sum of volume of the rib cage apposed to the lung ($Vrc_{,p}$), volume of the rib cage apposed to the abdomen ($Vrc_{,a}$) and volume of the abdomen (Vab).

2.5. Unsupported arm exercise (UAE)

The test consists of 3 sessions: (i) subjects sat with arms kept straight alongside their body after closing the glottis at related FRC then raised symmetrically and laterally their arms at a fixed 90° angle and returned to baseline again. Arms were not raised above their heads. (ii) After repeating the arm movement for 3 min of spontaneous breathing (warm up), they lifted an incremental weight of 0.2 kg (from 0.2 to 0.8 kg) on each forearm at 30 revolution min^{-1}. Peak achieved was defined in each patient. (iii) Each subject performed a symptom-limited exercise test at a constant power equal to 80% of their maximal work rate. Subjects wore a nose-clip and breathed through a low dead space mouthpiece. During the test flow rate at the mouth and gas exchange were recorded breath-by-breath. Expired gas was analysed for oxygen uptake (VO_2), and carbon dioxide production (VCO_2). Cardiac frequency was continuously measured using a 12-lead electrocardiogram and oxygen saturation was measured using a pulse oxymeter (NPB 290; Nellcore Puritan Bennett, Pleasanton, CA, USA). The V-slope technique was measured to identify the VCO_2 at which the anaerobic threshold occurred (Wasserman et al., 1999). The flow signal was synchronized to that of the motion analysis used for OEP and sent to a personal computer for subsequent analysis. The respiratory sensation(s) were quantified (Borg) (Borg, 1982) and qualified (see supplement). Subjects were also requested to define the reason for stopping (arm, breathlessness, or both).

2.6. Analysis of the data

The time course of the volume of each region ($Vrc_{,p}$, $Vrc_{,a}$ and Vab) along their sum (Vcw) was processed to obtain a breath-by-breath assessment of both ventilatory pattern and operational chest wall volume (Gorini et al., 1999; Johnson et al., 1999). Because most patients were unable to relax their respiratory muscles enough to yield accurate and meaningful relaxation volume–pressure curves of the thorax, the presence of rib cage distortion was established by: (1) comparing the time courses of $Vrc_{,p}$ *vs* $Vrc_{,a}$ and (2) by the phase shift between $Vrc_{,p}$ and $Vrc_{,a}$ when these two volumes were plotted against each other. This was measured as the ratio of distance delimited by the intercepts of $Vrc_{,p}$ *vs* $Vrc_{,a}$ dynamic loop on a line parallel to the *X*-axis at 50% of $RC_{,p}$ tidal volume (m), divided by $RC_{,a}$ tidal volume (s), as $\theta = \sin^{-1}(m\,s^{-1})$, a previously adopted approach (Fig. 1) (Aliverti et al., 2009). In this system a phase angle of zero represents a completely synchronous movement of the compartments and 180° total asynchrony. Rib cage (RC) to abdomen (AB) displacement was assessed by the ratio of changes in Vrc to change in Vab.

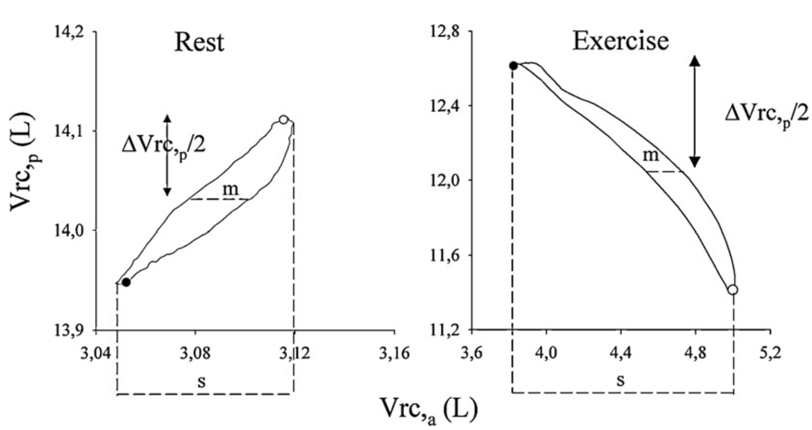

Fig. 1. Plots of the volume of rib cage apposed to the lung ($Vrc_{,p}$) to the volume of rib cage apposed to the abdomen ($Vrc_{,a}$) in patient #FP at rest and during exercise. The loop during exercise shows paradox inward of upper rib cage. m, line parallel to the *X*-axis at 50% of pulmonary rib cage (RC_p) tidal volume; s, abdominal rib cage (RC_a) tidal volume. The phase shift is calculated as $\theta = \sin^{-1}(m\,s^{-1})$. Closed circle, end-expiration; open circle, end-inspiration. Arrows indicate the direction of dynamic loops.