CHEST

Lung Volume Reduction in Emphysema Improves Chest Wall Asynchrony

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BACKGROUND: Lung volume reduction (LVR) techniques improve lung function in selected patients with emphysema, but the impact of LVR procedures on the asynchronous movement of different chest wall compartments, which is a feature of emphysema, is not known.

METHODS: We used optoelectronic plethysmography to assess the effect of surgical and bronchoscopic LVR on chest wall asynchrony. Twenty-six patients were assessed before and 3 months after LVR (surgical [n = 9] or bronchoscopic [n = 7]) or a sham/unsuccessful bronchoscopic treatment (control subjects, n = 10). Chest wall volumes were divided into six compartments (left and right of each of pulmonary ribcage [Vrc,p], abdominal ribcage [Vrc,a], and abdomen [Vab]) and phase shift angles (θ) calculated for the asynchrony between Vrc,p and Vrc,a (θRC), and between Vrc,a and Vab (θDIA).

RESULTS: Participants had an FEV_1 of 34.6 ± 18% predicted and a residual volume of 217.8 ± 46.0% predicted with significant chest wall asynchrony during quiet breathing at baseline (θRC, 31.3° ± 38.4°; and θDIA, −38.7° ± 36.3°). Between-group difference in the change in θRC and θDIA during quiet breathing following treatment was 44.3° (95% CI, −78 to −10.6; *P* = .003) and 34.5° (95% CI, 1.4 to 67.5; *P* = .007) toward 0° (representing perfect synchrony), respectively, favoring the LVR group. Changes in θRC and θDIA were statistically significant on the treated but not the untreated sides.

CONCLUSIONS: Successful LVR significantly reduces chest wall asynchrony in patients with emphysema.

CHEST 2015; 148(1):185-195

Manuscript received September 24, 2014; revision accepted December 11, 2014; originally published Online First February 5, 2015.

ABBREVIATIONS: 3-D = three-dimensional; 6MWD = 6-min walk distance; Ab = abdominal compartment; BLVR = bronchoscopic lung volume reduction; EELV = end-expiratory lung volume; FRC = functional residual capacity; HRCT = high-resolution CT; IC = inspiratory capacity; LVR = lung volume reduction; LVRS = lung volume reduction surgery; OEP = optoelectronic plethysmography; RC,a = abdominal ribcage compartment; RC,p = pulmonary ribcage; RV = residual volume; SGRQ = St. George's Respiratory Questionnaire; θDIA = phase shift angle between pulmonary ribcage compartmental volume and abdominal ribcage compartmental volume; θRC = phase shift angle between pulmonary ribcage compartmental volume and abdominal ribcage compartmental volume; TLC = total lung capacity; Tlim = exercise time to limitation on cycle ergometer at 75% of the maximum achieved workload on a previous incremental peak exercise test; Vab = abdominal compartmental volume; Vrc,a = abdominal ribcage compartmental volume; Vrc,p = pulmonary ribcage compartmental volume

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FUNDING/SUPPORT: This study was supported by the National Institute for Health Research Respiratory Biomedical Research Unit at the Royal Brompton and Harefield National Health Service Foundation Trust and Imperial College, London who funded the optoelectronic plethysmography assessments and partly funded the salaries of Drs Zoumot and Polkey.

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DOI: 10.1378/chest.14-2380

In health, expansion and contraction of the ribcage and abdomen during breathing occur in tandem. During inspiration, the contracting diaphragm pushes the abdominal contents downward and the abdominal wall outward. Simultaneously, acting through its zone of apposition to the ribcage, the contacting diaphragm together with the intercostal and accessory muscles of respiration act to elevate and expand the ribcage.[1] The ribcage has two components, which are subject to different pressures: the diaphragm-apposed part of the ribcage (abdominal ribcage compartment [RC,a]) and the upper ribcage (pulmonary ribcage [RC,p]) apposed to the visceral pleura. In COPD, lung hyperinflation means that the diaphragm is flattened and straightened, altering the angle at which it acts on RC,a. The result is mechanical distortion leading to asynchronous movement of ribcage compartments, with negative impacts on ventilatory mechanics[2,3] as abdominal muscles are also recruited during quiet breathing. This characteristic paradoxical respiration has long been recognized clinically in COPD as the Hoover sign,[4] although the original description is from Flint.[5] Correlations between asynchrony of chest wall movements and the degree of airflow obstruction,[3] breathlessness,[6] and an earlier onset of dynamic hyperinflation during exercise[7] have been reported.

Lung volume reduction (LVR) in patients with COPD through either surgical (LVR surgery, [LVRS]) or bronchoscopic methods seeks to correct lung hyperinflation. LVRS has been clearly shown to improve lung function, exercise capacity, and survival in selected patient groups.[8-10] Similarly, less invasive methods of reducing lung volume, such as bronchoscopically placed endobronchial valves and LVR coils, have also been shown to improve clinical outcomes,[11,12] including dynamic hyperinflation.[13] Longer-term follow-up data of patients with COPD treated with endobronchial valves suggest a survival advantage when atelectasis is successfully induced.[14,15]

The physiologic basis for benefit from LVR in emphysema was reviewed by Fessler et al,[16] with mechanisms including increased elastic recoil and vital capacity, reduced dynamic hyperinflation, and the restoration of respiratory muscle mechanics (as the size of the treated lungs is reduced to better match the thoracic cavity and the diaphragm is restored to a more advantageous point on its length-tension relationship and a more curved configuration). In addition to these mechanisms, improvement in chest wall asynchronous movements following LVR may play a significant role. Bloch et al[17] reported reductions in phase shift between the ribcage (as a single compartment) and the abdomen in 19 patients after LVRS. Inductive bands measuring in two dimension the lateral and anteroposterior dimensions of the ribcage and abdomen were used (RespitracePT; Non-invasive Monitoring Systems, Inc). More recently, optoelectronic plethysmography (OEP), a system that allows accurate three-dimensional (3-D) measurements of chest wall volumes, has been used to assess chest wall asynchrony in COPD in much more detail.[7,18,19] The resultant multidimensional calculations of ribcage volumes identified asynchrony within the thorax, which is asynchronous movements between RC,a and RC,p, along with asynchrony between the abdominal compartment (Ab) and RC,a.[7,18,19] To our knowledge, OEP has not previously been used to assess the effect of LVR on chest wall asynchrony in patients with severe COPD undergoing LVRS, and no previous studies have examined the effect of bronchoscopic LVR (BLVR) on chest wall asynchrony. We hypothesized that successful LVR, whether by LVRS or BLVR, would improve chest wall asynchrony and correlate with clinical benefit. The aims of this study, therefore, were to characterize chest wall asynchrony and assess changes therein in patients with severe COPD undergoing LVR.

Materials and Methods

Study Design and Participants

We recruited consecutive patients with severe COPD being assessed for LVR procedures at our institution between July 2011 and March 2013 as part of routine clinical care (unilateral LVRS[10]) or interventional BLVR trials (unilateral endobronchial valves,[20] unilateral autologous blood instillation as a profibrotic agent[21]). All subjects had severe COPD (FEV_1 to FVC ratio of <0.7, and FEV_1 of $<50\%$ predicted) with hyperinflation (residual volume [RV] $>150\%$ predicted). The study was approved by the National Research Ethics Committee London-Westminster (approval number 11/LO/0633). All patients provided written informed consent.

Patients enrolled in BLVR trials were randomized to have either bronchoscopy with treatment (endobronchial valves or endobronchial autologous blood instillation depending on the trial) or bronchoscopy with a sham treatment (pretend valve insertion or endobronchial instillation of normal saline). Patients who had BLVR treatment were deemed to have had successful LVR ("responders") if there was posttreatment radiologic evidence of significant volume reduction on high-resolution CT (HRCT) scan, defined as lobar or segmental collapse with displacement of the interlobar fissures or a $>33\%$ reduction in the size of a giant bullae on visual inspection of HRCT scan with interlobar fissure displacement and adjacent parenchyma reexpansion. In the absence of LVR following BLVR ("nonresponders"), subjects were considered to have had the equivalent of a sham bronchoscopy and their data added to sham bronchoscopy patients in a group labeled "control subjects."

Assessment Visits

Baseline assessments were performed within 2 weeks prior to the surgical or bronchoscopic procedure. Data collected included demographics, pulmonary function tests (static and dynamic lung volumes and gas