ORIGINAL ARTICLE

Lung Volume Recruitment Slows Pulmonary Function Decline in Duchenne Muscular Dystrophy

Douglas A. McKim, MD, Sherri L. Katz, MDCM, Nicholas Barrowman, PhD, Andy Ni, MSc, Carole LeBlanc, RRT

ABSTRACT. McKim DA, Katz SL, Barrowman N, Ni A, LeBlanc C. Lung volume recruitment slows pulmonary function decline in Duchenne muscular dystrophy. Arch Phys Med Rehabil 2012;93:1117-22.

Objective: To evaluate the long-term effect on measures of forced vital capacity (FVC) before and after the introduction of regular lung volume recruitment (LVR) maneuvers (breath-stacking) in individuals with Duchenne muscular dystrophy (DMD).

Design: Retrospective cohort study of pulmonary function data, including FVC, cough peak flow (CPF), maximum inspiratory pressure (MIP), and maximum expiratory pressure (MEP). Data were collected for 33 months prior to and 45 months after LVR introduction.

Setting: Ambulatory care in a tertiary level regional rehabilitation center in Canada.

Participants: All individuals (N=22) with DMD (mean age ± SD, 19.6±2.4y), who were prescribed LVR and reported adherence with therapy.

Interventions: Introduction of regular LVR (breath-stacking); 3 to 5 maximal lung inflations (maximum insufflation capacity [MIC]) using a hand-held resuscitation bag and mouthpiece, twice daily.

Main Outcome Measures: Measures included the rate of decline of FVC in percent-predicted, before and after the introduction of regular LVR. Changes in maximum pressures (MIP, MEP), MIC, and cough peak flows were also measured.

Results: At LVR initiation, FVC was 21.8±16.9 percent-predicted, and cough peak flows were <270L/min (144.8±106.9L/min). Annual decline of FVC was 4.7 percent-predicted a year before LVR and 0.5 percent-predicted a year after LVR initiation. The difference, 4.2 percent-predicted a year (95% confidence interval, 3.5–4.9; $P<.000$), represents an 89% improvement in the annual rate of FVC decline.

Conclusions: The rate of FVC decline in DMD patients improves dramatically with initiation of regular LVR.

Key Words: Muscular dystrophy, Duchenne; Rehabilitation; Respiratory function tests; Vital capacity.

RESPIRATORY COMPLICATIONS are the primary cause of morbidity and mortality in Duchenne muscular dystrophy (DMD) as progressive respiratory muscle weakness leads to hypoventilation[1-7] and/or recurrent atelectasis and pneumonia,[8,9] secondary to decreased cough effectiveness.[10-12] Furthermore, it has been postulated that because of the decreased range of motion of the chest wall and lungs, stiffening of the ribcage may occur, reducing chest wall and lung compliance.[13]

Lung volume recruitment (LVR) (also known as breath-stacking)[12] is a means of stacking breaths by applying an inspiratory pressure, transmitted to the airways through an airtight facemask or mouthpiece, causing lung inflation, which is followed by a spontaneous or assisted forced expiratory maneuver.[8,10,14,15] LVR achieves maximal lung insufflation capacity, expanding the chest wall and filling the lungs with air, so that an effective cough can be generated. In addition to improving cough efficacy and airway clearance, insufflation may also maintain chest wall range of motion and lung compliance[16] by preventing atelectasis and contractures of the muscles of the thoracic cage.

The cough peak flow (CPF), a measure of cough capacity, achievable with the manual LVR technique, is 1.8 times greater than with an unassisted cough[17,18] and is comparable with that obtained with a mechanical in-exsufflator.[17,19-22] Furthermore, maximum insufflation capacity (MIC), the maximum volume of air that can be held in the lungs after breath-stacking, has been shown to improve, despite a decrease in vital capacity, over 0.5 to 24 years of follow-up in 282 patients with neuromuscular disease.[23]

A combination of the mechanical in-exsufflator and LVR, into an overall plan of care, has also been successful in some case series in avoiding hospitalization, pneumonia, episodes of respiratory failure, and tracheostomy.[8,24-28] The precise contribution of LVR alone in these studies, however, is difficult to determine, because many treatment variables were simultaneously manipulated. A single cohort study[13] of adults and children using LVR twice daily did demonstrate improvement in MIC and CPF over time.

The efficacy of LVR in slowing the progression of restrictive respiratory impairment, such as decline in forced vital capacity (FVC), has not been evaluated in long-term studies. As a result,

List of Abbreviations

ALS	amyotrophic lateral sclerosis
CI	confidence interval
CPF	cough peak flow
DMD	Duchenne muscular dystrophy
FVC	forced vital capacity
LVR	lung volume recruitment
MEP	maximum expiratory pressure
MIC	maximum insufflation capacity
MIP	maximum inspiratory pressure
NIV	noninvasive ventilation

From the Division of Respiratory Medicine, The Ottawa Hospital Rehabilitation Centre, Ottawa, ON (McKim, LeBlanc); The University of Ottawa, Ottawa, ON (McKim, Katz); and Division of Respiratory Medicine (Katz) and Clinical Research Unit (Barrowman, Ni), Children's Hospital of Eastern Ontario Research Institute, Ottawa, ON, Canada.

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Correspondence to Douglas A. McKim, MD, The Ottawa Hospital Rehabilitation Centre, 1201-505 Smyth Rd, Ottawa, ON, Canada K1H 8M2, e-mail: *dmckim@Ottawahospital.on.ca*. Reprints are not available from the author.

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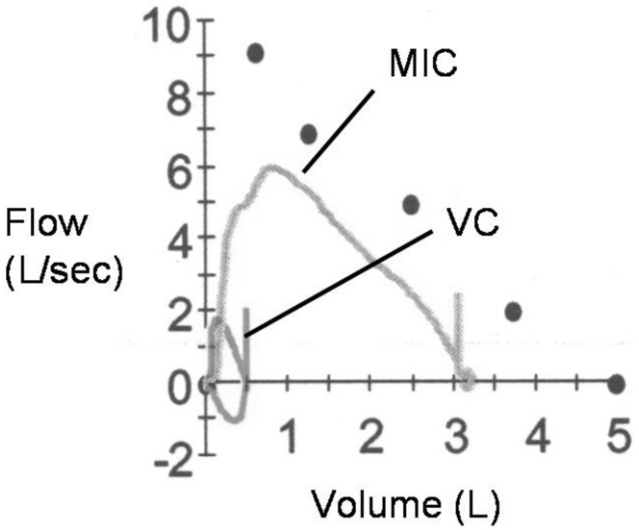

Fig 1. Illustrative case. Flow volume loop for a patient demonstrating the marked improvement in MIC after LVR. The MIC-VC difference was 3.22–0.46=2.76L, after LVR. Abbreviation: VC, spontaneous vital capacity.

LVR has not been uniformly adopted as a treatment strategy.[10,29,30] FVC is an important prognostic marker in DMD, which is routinely measured in clinical practice. The rate of decline of this pulmonary function variable predicts survival.[31] Therefore, if the regular performance of LVR is able to slow the inevitable decline in FVC in this population, it would represent a significant clinical benefit, which may ultimately contribute to longevity. We hypothesize that long-term decline in FVC is attenuated by use of regular LVR therapy in individuals with DMD. The aim of this study was therefore to evaluate the impact on FVC of regular long-term use of LVR in individuals with DMD.

METHODS

All individuals with confirmed DMD at the Ottawa Hospital Rehabilitation Centre, for whom pulmonary function tests were available and who reported adherence with LVR, were included. Ethics approval was obtained from the Ottawa Hospital Research Ethics Board. LVR was administered by providing positive pressure, via tubing, and a mouthpiece, and was applied using a self-inflating resuscitation bag[a] containing an inline 1-way valve.[32] The number of breaths provided for LVR, per lung inflation, was determined by clinical evaluation consisting of visual inspection of chest wall excursion, patient comfort, and ability to hold a maximal volume. Positive pressure breaths were delivered in coordination with the patient's own inspiratory effort, over 2 to 3 seconds. Three to 5 breaths were delivered in order to achieve an MIC for a total of 3 to 5 cycles, as tolerated**.** Illustrations of the patients' own flow volume loop and MIC response were used to educate and encourage adherence with LVR (fig 1). LVR was prescribed twice daily. If secretions were present, a manually assisted cough (abdominal thrust) while the subject was at MIC was also recommended.

Retrospective analysis of pulmonary function data was carried out. Data were compared for a median of 33.5 months prior to the initiation of LVR treatment and a median of 45 months afterwards. Measures of spontaneous, unassisted FVC were obtained at each clinic visit during long-term follow-up. The rate of FVC (percent-predicted) decline in the months before and after LVR initiation was compared.

Measurements

Spirometry was performed according to American Thoracic Society standards.[33] Extended arm span, in centimeters, was used to estimate height in all patients. Measurements included FVC, CPF, maximum inspiratory pressure (MIP), and maximum expiratory pressure (MEP). FVC measurements were spontaneous and unassisted. MIC was measured after LVR and represented the largest volume achieved with LVR (see fig 1).

FVC and MIC values were measured using a spirometer (Profiler and CPSF/D[b]). Predicted values were those of the third National Health and Nutrition Survey (NHANES III).[34] MIP and MEP were measured using a Micro RPM[c] and predicted values were from Black and Hyatt.[35] MIP was measured beginning at residual volume, and MEP was measured while at total lung capacity. Cough flows were measured using a peak flow meter (Mini-Wright[d]).

Statistics

A piecewise linear mixed-effects regression model was used to analyze longitudinal measurements of FVC percent-predicted over time within individuals. The model included a parameter representing a change in the rate of decline of FVC percent-predicted at the introduction of LVR. A random intercept was used for each patient. The estimated rates of decline prior to initiation and after initiation of LVR were estimated, together with 95% confidence intervals (CIs). Statistical modeling was performed using R software version[e] 2.13 (2011-04-13).[36]

RESULTS

A total of 22 individuals were included in this study. Demographic features are described in table 1. Not all measures were available for all patients at each assessment. At the time of LVR initiation, all participants had severe restrictive respiratory compromise (FVC, 21.8±16.9; percent-predicted, 1.0±0.7L) and CPF below 270L/min (144.8±106.9L/min), which is associated with decreased cough efficacy.[17,37,38] All but 2 patients had a mechanical in-exsufflator available to them for use at home at times of respiratory infection. At the beginning of the study period 86% of patients were already using noninvasive ventilation (NIV). Two of the remaining 3 patients started NIV treatment during the study period, after the initiation of LVR. Four patients were receiving systemic steroids throughout the study period.

The trajectory of decline of FVC percent-predicted was substantially slower after the initiation of LVR (fig 2). Prior to

Table 1: Demographics at LVR Initiation

Demographics	Mean ± SD	n
Age (y)	19.6±2.4	22
FVC (%-predicted)	21.8±16.9	21
FVC (L)	1.0±0.7	21
MIC (%-predicted)	35.8±18.1	22
MIC (L)	1.6±0.9	21
MIC–VC (L)	0.7±0.5	21
CPF spontaneous (L/min)	144.8±106.9	20
CPF with bag (L/min)	232.8±103.3	16
MIP (cmH_2O)	−22.2±15.0	21
MEP (cmH_2O)	23.6±10.7	21

Abbreviation: VC, vital capacity.