

Quantification of Flow-Volume Loops Using a Non-Invasive Respiratory Volume Monitor

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Introduction: Pulmonary function tests utilize flow-volume loops (FVLs) to help detect, diagnose, and monitor the long-term progression lung disorders such as COPD and asthma. Spirometry is the gold standard for generating FVLs via a forced vital capacity test, which measures the amount of air a subject can forcefully exhale. This test requires the patient to be awake, alert, and cooperative which is not always possible, especially for pediatric or geriatric patients. In addition, tidal breathing FVLs have been used to analyze respiratory function under baseline conditions and monitor real time changes in breathing using respiratory inductance plethysmography (RIP) bands. Monitoring tidal breathing FVLs has been proposed as means of monitoring disease progression, responsiveness to therapy, reaction to broncho-constrictive agents, and changes in breathing during exercise, but has not been widely adopted due to technology limitations. The objective of this study was to demonstrate the utility of a non-invasive respiratory volume monitor (RVM) in measuring continuous tidal FVLs in healthy volunteers breathing at a variety of breathing rates in lieu of RIP bands or a spirometer.

Methods: Continuous respiratory data including volume traces were collected using an RVM (ExSpirom 1Xi, Respiratory Motion, Inc., Waltham, MA) from volunteer subjects. Each subject performed 6 breathing trials at 3 different prescribed respiratory rates. In trials 1 and 6, subjects were instructed to breathe normally. In the middle four trials, the subject alternated between fast (25 bpm) and slow (5 bpm) breathing as set by a metronome. Flow traces were generated by taking the first derivative of the volume traces. To reduce breath-to-breath variability, individual breaths were aligned at the start of inhalation with volume and flow set to “zero”. For each breathing trial, breaths were divided into equal time segments and averaged across all breaths within each trial to generate an average “representative” FVL. We assessed the characteristics of the shape of FVLs for different breathing trials.

Results: 48 subjects (15 females/33 males, age: 46.1 ± 14.3 years; BMI: 27.6 ± 6.2 kg/m², mean \pm SD) completed the study. Respiratory rates for the normal, fast, and slow breathing trials were 12.6 ± 0.6 min⁻¹, 24.6 ± 0.1 min⁻¹, and 6.9 ± 0.3 min⁻¹ (mean \pm SEM), respectively. Figure 1 depicts representative volume (top row), flow (middle row), and FVLs (bottom row) for normal, fast, and slow breathing trials. The FVLs display all breaths during the breathing trials as well as the average inspiratory (green) and expiratory (red) curves. For the normal breathing trial (left column), the FVL has a convex shape with a steady flow during the second half of the expiratory limb. The FVLs during the fast breathing trial are elliptical with a major axis with a steep slope. During the slow breathing protocol, a concave expiratory limb is observed near the end of expiration indicating an expiratory flow limitation which is observed in patients with obstructive lung diseases such as COPD.

Conclusion: In this study we demonstrated the capability of the non-invasive RVM in generating continuous tidal FVLs in healthy volunteers. We observed distinctive shapes of the FVLs when the subjects varied their respiratory rate. While this study was done in healthy volunteers, the results indicate that FVLs generated by the RVM have sufficient sensitivity to be able to identify abnormalities observed in patients with lung diseases. The RVM eliminates the need for a spirometer and vastly expands the potential applications in which FVL can be measured.

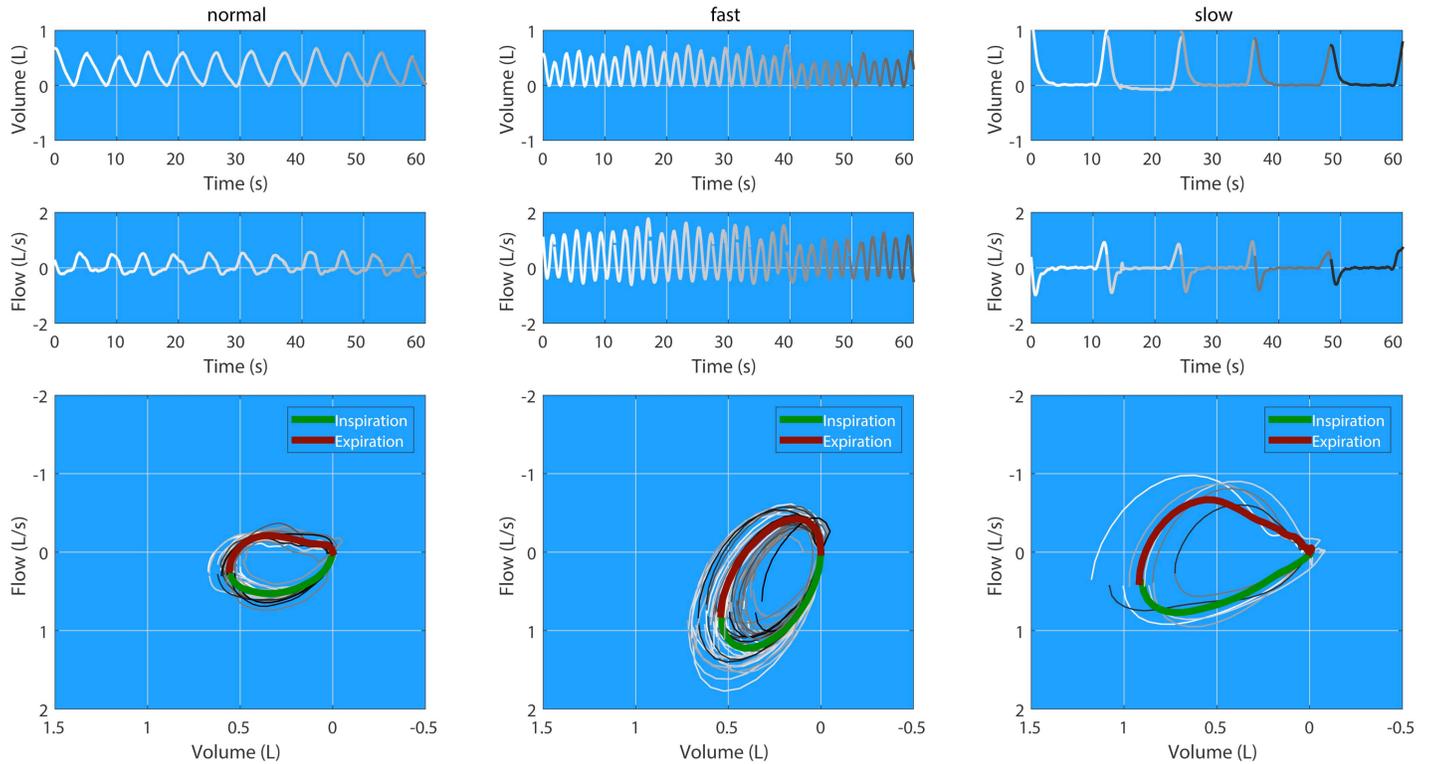


Figure 1. Representative volume (top row), flow (middle row), and flow-volume loops (bottom row) for normal (left column), fast (middle column), and slow (right column) breathing trials. The flow-volume loops display all breaths during the breathing trials as well as the average inspiratory (green) and expiratory (red) curves. Note that both axes are reversed in accordance with common presentation of flow-volume loops.