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
 - Forced Vital Capacity test: measures total air a subject can forcefully exhale. Requires awake, alert, and cooperative patients.
- Tidal breathing FVLs
 - Can be used to analyze respiratory function under baseline conditions and monitor real time changes in breathing.
 - Proposed as means of monitoring disease progression, responsiveness to therapy, reaction to bronchoconstrictive agents, and changes in breathing during exercise.
 - Typically measured using Respiratory Inductance Plethysmography (RIP) bands but are not widely adopted due to technology limitations.
- Objective:** 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.

Figure 1. Non-invasive RVM that provides continuous, real-time measurements of MV, TV, and RR. Figure shows standard PadSet placement: sternal notch, xiphoid, and right mid-axillary line at the level of the xiphoid.

Methods

- Continuous respiratory data including volume traces were collected using an RVM (ExSpiron 1Xi, Respiratory Motion, Inc., Waltham, MA) from 48 volunteer subjects (Table 1).

Table 1. Subject cohort anthropometrics

Anthropometrics	Mean	SD	Range
Number of Patients	48		
Males / Females	33/15		
Age, years	44.4	14.0	18.0-70.0
Weight, kg	82.5	22.9	45.4-139.7
Height, cm	171.3	10.5	152.4-193.0
BMI, kg/m ²	27.9	6.5	18.9-42.8

- Study approved by the Schulman Associates Institutional Review Board, Cincinnati, OH (201102306). All patients gave written informed consent.
- Each subject performed 6 breathing trials at 3 different prescribed respiratory rates.
 - Trials 1 and 6: normal breathing
 - Trials 2 and 4: fast breathing (25 bpm, set by metronome)
 - Trials 3 and 5: slow breathing (5 bpm, set by metronome)
- Flow traces 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.”
- 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

- Figure 2. Representative Flow, Volume, and Flow-Volume Traces**
- 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.
- Flow-volume loops display all breaths during the breathing trials as well as the average inspiratory (green) and expiratory (red) curves.
- Note: both axes are reversed in accordance with common presentation of flow-volume loops.
- Normal:** FVL has a convex shape with a steady flow during the second half of the expiratory limb.
- Fast:** FVLs are elliptical with a major axis with a steep slope.
- Slow:** 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.

Table 2. Average (SEM) Respiratory Metrics

Prescribed Respiratory Rate:	Normal	Fast	Slow
Respiratory Rate (RR), min ⁻¹	12.7 (0.6)	24.6 (0.1)	6.9 (0.7)
Tidal Volume (TV), mL	820 (55)	824 (63)	825 (51)
Minute Ventilation (MV), L/min	10.4 (0.7)	20.1 (1.5)	5.9 (0.5)

- Respiratory rates for the normal, fast, and slow breathing trials were 12.6, 24.6, and 6.9 bpm, respectively.
- Tidal Volume did not change between the different breathing trials ($p = 0.998$, 1-way ANOVA).

Conclusions

- 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 such as asthma and COPD.
- The RVM eliminates the need for a spirometer and vastly expands the potential applications in which FVL can be measured.