Assessing Decreased Thoracic Compliance With Forced Oscillation Technique and Spirometry

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Introduction

Spirometry provides a tool for measuring the effects of disease on lung function, airway hyper-responsiveness, and monitoring course of disease.[1] Interpreting the presence of lung disease with spirometry is dependent on patient effort and technician instructions; therefore, results can be variable.

Introduction of commercially available instruments to perform forced oscillation technique (FOT) has increased interest in this techonology.[2-4] FOT works by stimulating sinusoidal signals at 5–19 Hz that are superimposed on patient's spontaneous breathing while flow and pressure are measured throughout the respiratory cycle.[2-4] This technique allows measures of impedance to air flow resulting from airway resistance (R_{aw}) and respiratory system compliance. Lower frequency waves travel to distal airways, whereas higher frequency waves do not penetrate below larger airways, discerning differences in obstruction between large and small airways.[4] Resistance at 5 Hz reflects on air flow limitation. Reactance at 5 Hz reports on compliance.[4]

During a study to evaluate hypobaric hypoxia in normal volunteers, we used a chest-wall strapping device to reduce FVC. The goal was a reduction in FVC of 0.5 L. As FVC is effort dependent, we evaluated methods for determining the FVC change without patient effort interference. We hypothesized that reactance measured with oscillometry could be as effective as spirometry in detecting a reduction in compliance.

Methods

Healthy volunteers ($N = 15$) were consented at University of Texas Medical Branch Clinical Research Center as part of a parallel study (institutional review board number 18–0007). Volunteers underwent repeated spirometry with or without an extrathoracic restriction. Restrictions were applied using the Aspen Contour bracing system (Aspen Medical Products, Irvine, California). The brace was applied just under axilla in males and just underneath the breasts in females then tightened to subject tolerance. Restriction in all cases resulted in at least a 0.5-L reduction in vital capacity. FOT data were collected prior to FVC maneuvers.

Spirometry was performed with a KoKo Sx 1000 spirometer (KoKo PFT, KoKo, Longmont, Colorado) or the Breeze Platinum Elite system (MGC Diagnostics, Saint Paul, Minnesota). Pneumotachometers were calibrated daily with a 3-L syringe according to manufacturer and American Thoracic Society/European Respiratory Society (ATS/ERS) criteria.[1] Subjects were seated upright and after

Key words: spirometry; forced oscillation technique; decreased lung compliance; pulmonary function test.

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Mr Branson discloses relationships with Engineered Medical Systems, Pfizer, Vyaire, and Ventec Life Systems. Mr Branson is Editor-in-Chief of Respiratory Care. Dr Kinsky discloses relationship with Noninvasix. The remaining authors have disclosed no conflicts of interest.

Financial support: JSME Pilot Award, P85245B01, Smart Oxygenation Systems (SOS) Provides Early Warning of Lung Injury, US Army BA160657. Ms Khan and Mr Michaels receive salary support from a JSME Pilot Award (P85245B01). Funds for the Resmon Pro were made available from University of Texas Medical Branch capital equipment purchases.

A version of this paper was presented by Ms Khan as an Editors' Choice abstract at AARC Congress 2021 LIVE!, held virtually December 1, 2021.

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DOI: 10.4187/respcare.09859

Table 1. Subject Demographics and Pulmonary Function Data

Subject	Age, y	Sex	Height	FVC Pre (L)	FVC Predicted	FVC Lower Limit of the Normal Range	FVC Z Score	FVC Post (L)	FVC Z score	Restriction Value <Lower Limit of the Normal Range	X5Hz Pre	X5Hz Lower Limit of the Normal Range	X5Hz Post	Restriction Value <Lower Limit of the Normal Range
1	24	M	177.8	5.60	5.54	4.49	0.08	4.07	−2.30	Yes	−0.38	−1.33	−0.55	No
2	62	M	172.7	4.60	3.90	3.09	1.23	3.76	−0.28	No	−0.76	−1.96	−1.99	Yes
3	29	M	170.2	3.97	4.15	3.28	−0.35	3.15	−1.90	Yes	−1.81	−1.92	−3.03	Yes
4	34	F	157.5	2.88	3.02	2.38	−0.35	2.33	−1.79	Yes	−1.29	−1.88	−2.89	Yes
5	35	M	180.3	4.42	4.92	3.91	−0.81	3.79	−1.84	Yes	−1.18	−1.69	−1.91	Yes
6	29	M	175.3	5.48	5.28	4.26	0.31	3.67	−2.60	Yes	−0.78	−1.55	−2.00	Yes
7	36	F	152.4	3.76	3.23	2.58	1.28	3.18	−0.14	No	−1.15	−2.08	−2.66	Yes
8	22	F	157.5	4.33	3.54	2.83	1.74	3.52	−0.63	No	−0.74	−1.58	−1.50	No
9	29	F	164.1	4.53	3.88	3.10	1.31	3.40	−1.02	No	−0.87	−1.09	−2.05	Yes
10	33	M	173.0	5.91	4.64	3.77	2.36	4.61	−0.06	No	−0.73	−1.26	−1.67	Yes
11	22	M	185.4	6.38	6.12	4.96	0.35	4.74	−1.97	Yes	−0.34	−1.19	−0.54	No
12	29	M	180.3	6.59	5.20	4.24	2.34	4.65	−0.95	No	−0.66	−1.47	−1.60	Yes
13	32	F	160.0	4.35	3.36	2.72	2.43	3.42	0.14	No	−0.79	−2.30	−1.54	No
14	25	M	182.9	6.63	5.92	4.79	1.01	3.52	−3.52	Yes	−0.52	−1.46	−2.13	Yes
15	25	M	172.7	4.70	5.15	4.17	−0.76	2.81	−3.95	Yes	−1.62	−1.73	−2.14	Yes
Avg (SD)	31 (10)		170.8 (10.3)	4.94 (1.11)	4.58 (0.98)	3.67 (0.81)		3.64 (0.68)*			−0.94 (0.50)		−1.85 (0.71)*	

Fifteen healthy subjects had pulmonary function assessed by spirometry and forced oscillation technique before and after chest restriction.
* $P < .01$.
X5Hz = reactance measured at 5 Hz frequency

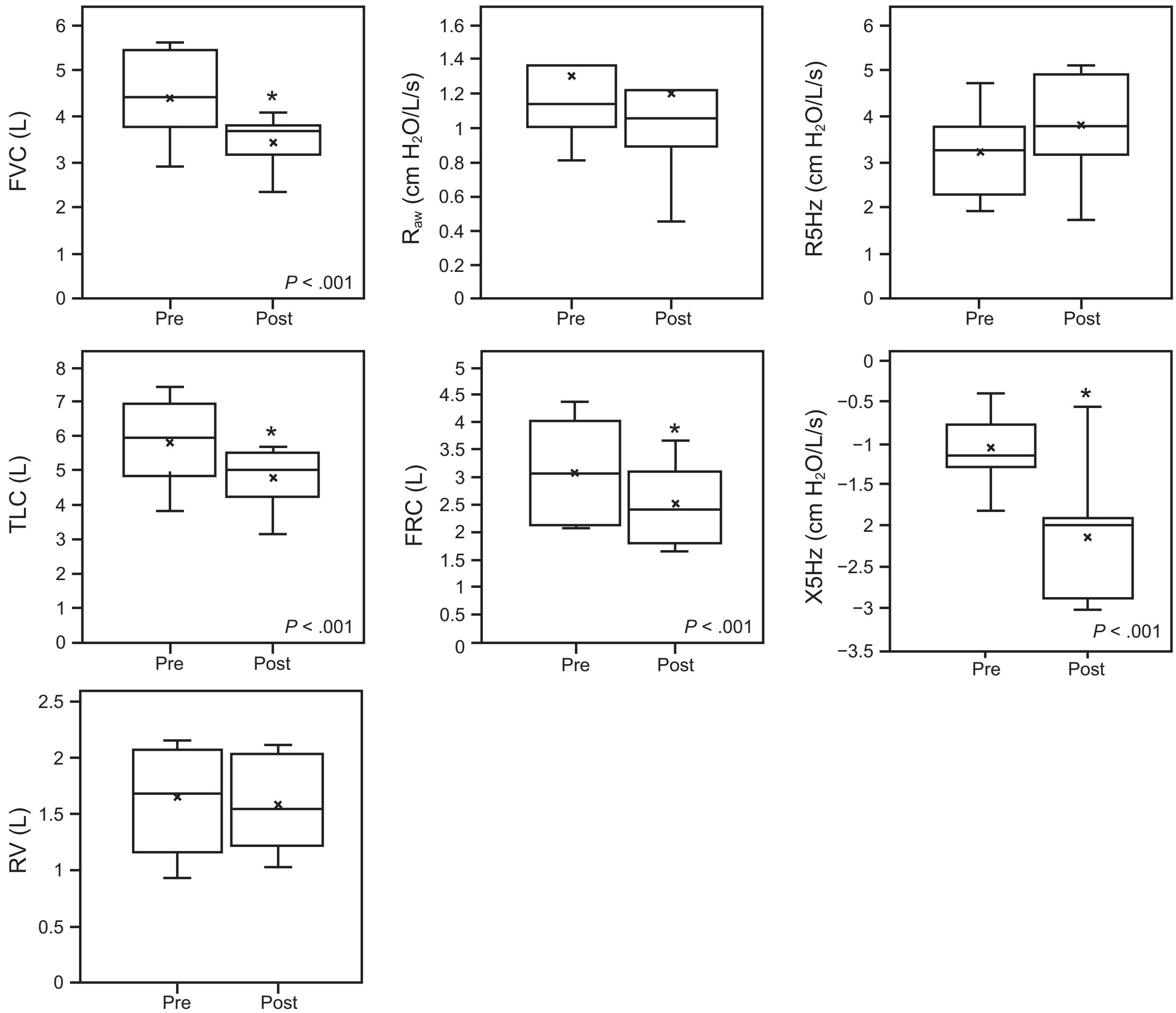

Fig. 1. Flow chart. RV = residual volume; TLC = total lung capacity; FRC = functional residual capacity; R_{aw} = airway resistance.

4 resting tidal breaths performed a forced inspiration followed by forced maximum expiration and at end exhalation performed a forced maximum inspiration to complete a flow-volume loop. For spirometry, at least 3 acceptable, reproducible FVC maneuvers were collected, and the maneuver with largest FVC was used for analysis. The 2012 Global Lung Function Initiative reference equations were used to calculate predicted values and Z score.[5]

Plethysmography was performed using the MGC Breeze Platinum Suite (MGC Diagnostics) in 7 subjects to validate effect of chest restriction on total lung capacity (TLC), lung volumes, and R_{aw}. The unit was calibrated daily according to manufacturer and ATS/ERS criteria. Subjects performed 4 tidal breaths to establish resting expiration, then were instructed to perform open-shutter panting (frequency 1.5–2.0 Hz) followed by a closed-shutter panting maneuver (frequency 0.5–1.0 Hz). Upon shutter opening, subjects were instructed to exhale to residual volume (RV) followed by an inspiratory vital capacity maneuver. Three to 5 efforts were performed; average of acceptable/reproducible efforts was used to determine lung volumes and R_{aw}.[6]

Oscillometry measures were performed with Resmon Pro V3 (MGC Diagnostics). The unit was calibrated daily according to manufacturer's guidelines. Subjects were seated upright and instructed to breathe normally through a viral/bacterial filter, with hands placed on cheeks to prevent stimulating waveform distortion. Waveforms at 5, 11, and 19 Hz frequency were applied and superimposed on the subjects' normal breathing. Measurements were collected over 10 spontaneous breaths. Software algorithm discarded nonphysiological and noncoherent breaths and reported a coefficient of variance (CoV), resistance, and reactance of the breaths at the 3 measured frequencies. CoV was < 10% in all analyzed data. Reactance becomes more negative in conditions of airway closure and decreased compliance. Reference equations by Oostveen et al[7] were used to calculate predicted and lower limit of the normal range values.

Measures of continuous variables were reported as mean ± SD. Pulmonary function variables were compared pre- and post-restriction with paired Student *t* test and Pearson correlation using IBM SPSS Version 25 (IBM, Armonk, New York). Significance was determined by a *P* value of < .05.

Results

Fifteen healthy subjects (31 ± 10 y) had pulmonary function assessed with spirometry before and after chest restriction. All subjects were able to tolerate chest restriction without complication. Table 1 shows summary of spirometry and FOT data. Restriction resulted in an average 1.3-L reduction in measured FVC (Fig. 1) (pre 4.94 ± 1.11 L vs post 3.64 ± 0.68 L; mean ± SD; $P < .001$). Post-restriction, 53% of the subjects had an FVC < lower limit of the normal range.

R_{aw} and lung reactance measured with FOT before and after chest restriction also showed a significant decrease with restriction. Although change in resistance at 5 Hz was statistically significant, it only changed 17% (pre 3.13 ± 0.78 cm H_2O/L/s vs post 3.65 ± 1.09 cm H_2O/L/s, $P = .005$). Lung reactance changed by 96% (pre −0.94 ± 0.50 cm H_2O/L/s vs post −1.85 ± 0.71 cm H_2O/L/s, $P < .001$).

To validate the changes in lung volume and determine if all lung volumes were affected by restriction, a subset of 7 subjects had lung volumes and R_{aw} measured with plethysmography. Percent change in FVC by spirometry and TLC by plethysmography was similar (Fig. 1) (FVC 21 ± 7% vs TLC 18 ± 6%). TLC and functional residual capacity measured by plethysmography (FRCpleth) were significantly reduced by restriction (TLC: pre 5.85 ± 1.29 L vs post 4.78 ± 0.88 L, $P < .001$; FRCpleth: pre 3.08 ± 0.96 L vs post 2.52 ± 0.77 L, $P < .001$). RV and R_{aw} were decreased slightly, although not significantly (RV: pre 1.65 ± 0.46 L vs post 1.57 ± 0.41 L, $P = .18$; R_{aw}: pre 1.30 ± 0.57 cm/L/s vs post 1.21 ± 0.75 cm/L/s, $P = .34$).

Resistance measured at 5 Hz was on average 1.92 cm H_2O/L/s greater than that measured with plethysmography ($P = .01$). Resistance measured with FOT increased by 18% with restriction, but there was no significant change by plethysmography ($P = .17$).

Lung reactance measured at 5 Hz decreased 96% with all 15 subjects (X5Hz: pre −0.94 ± 0.50 cm H_2O/L/s vs post −1.85 ± 0.71 cm H_2O/L/s, $P < .001$). We assessed the correlation between FVC and X5 before and after restriction and observed a positive correlation. (pre 0.593, $P = .02$; post 0.668, $P = .006$).

Discussion

We found that FOT was a reliable method for monitoring changes in compliance and resistance in volunteers with chest wall restriction. We found that significant changes in FVC and lung reactance at 5 Hz were observed. Restriction decreased FVC by 26% versus 96% decrease in reactance. Our observation of reactance change is like that reported by Nakano et al[8] in the immediate postoperative period, although they did not measure spirometry. FOT compared favorably with spirometry and plethysmography but was independent of patient effort, while being simple to perform. These features of FOT may lend its use in several other scenarios.

Spirometry remains the standard for classifying obstructive and restrictive disease. However, there are several limitations associated with spirometry that might be overcome by FOT. FOT can assess R_{aw} and lung reactance and has been used to assess response to bronchodilator in patients with asthma and peripheral airway disease in COPD.[3,4]

Thoracic restriction resulted in impedance to stimulating waveform and impacted R^{aw}, although not to the same degree as reactance (17% vs 96% change). Changes in resistance were also seen with plethysmography. In our experimental protocol, R5Hz was on average 1.92 ± 0.90 cm H_2O/L/s greater than that measured by plethysmography. Others have reported a bias in measures of resistance by FOT and impulse oscillometry suggested to be related to differences in oscillation signal.[9] Although differences in resistance measures were statistically significant, it may not be physiologically significant. Decreased compliance significantly reduced TLC and FRCpleth but not RV. It is likely that time point of experimental protocol was too short to note predicted reduction in RV resulting from decreased thoracic recoil. Limitations of our study include use of healthy volunteers and the artificial change in chest wall compliance.

FOT is a sensitive measure of changes in resistance/reactance, requires minimal patient effort, is simple to perform, and may result in less cough or dizziness in patients with restrictive lung disease. Sensitivity to changes in compliance and resistance could prove useful in monitoring the course of lung disease. This methodology does not present risk of aerosolization as does spirometry.

ACKNOWLEDGMENTS

The authors would like to acknowledge Khamron Michaels MHA RRT for his assistance in collecting plethysmography data.

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