Influence of tracer gas delay-time on FRC and Lung Clearance Index from multi-breath nitrogen washout

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Aim of the study

The measurement of Functional Residual Capacity (FRC) and Lung Clearance Index (LCI) based on multiple-breath gas washout is increasingly used for diagnostic purposes. Precise flow and gas sensors are mandatory for this measurement; in addition the time-alignment of gas and flow signals has great influence on FRC and LCI.

The delay-times between flow and gas signals depend on the gas transport-times from the main-stream flow sensor near the patients mouth to the side-stream gas analyzer(s) as well as on the response-times of the gas analyzer(s). We investigated the influence of varying 'main-stream flow' to 'side-stream gas signal' delay-times on FRC and LCI.

Methods

For this study an EasyOne Pro LAB system (ndd Medical Technologies, Switzerland) with ultrasonic flow and molar mass sensor was used. The EasyOne Pro LAB system is a compact and portable device for spirometry, single-breath DLCO and multiple-breath nitrogen (N_2) washout measurements in adults and children.

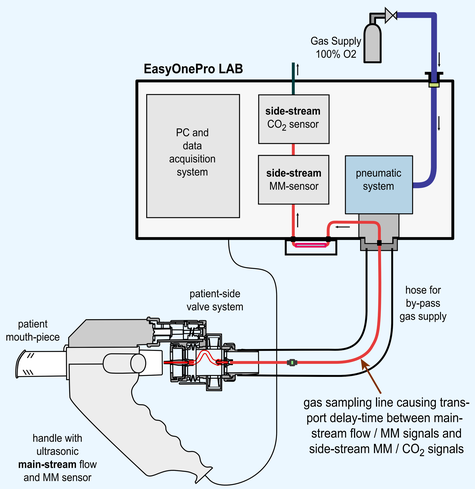
The system consists of a main unit with integrated, touch-screen based PC and a handle type sensor with an attached gas supply system.

The N_2 multiple-breath washout measurement for FRC and LCI determination is based on a side-stream molar mass (MM) sensor combined with an infrared CO_2 sensor.

A total of 27 raw data files from 9 patients (6 healthy, 3 patients with CF; 44% female) were analyzed. Patient age ranged from 7 to 49 years. The raw data files from the multiple-breath N_2 washout tests contain flow, main-stream MM, and side-stream MM and CO_2 signals, all recorded with a sampling rate of 200 Hz.

For each data file the reference delay-time was determined by cross-correlation of the side-stream gas sensor signals (MM and CO_2) with the main-stream MM signal. Starting from this reference the delay-time was varied from -50 to +50 ms in steps of 10 ms; FRC and LCI were computed for each delay-time and compared to the reference values.

The following schematic illustrates the system setup. The gas sampling line causing the delay-time between main- and side-stream sensors is highlighted in red color.



Results

The reference FRC values varied from 0.8 to 4.5 l (mean 2.33, sd 0.99 l), LCI varied from 5.5 to 9.9 (mean 7.0, sd 1.1).

For each multiple-breath washout file analyzed the computed FRC increased almost linearly over the -50 to +50 ms delay-time change (Figure 1a); mean reference delay-time was 1107 ms (sd 28 ms).

Rationale: With increased delay-time the N_2 curve moves toward the beginning of the expiration, therefore more N_2 is integrated and the computed FRC increases as well.

The change in the computed FRC per 10 ms delay-time change depends on the respiratory rate of the patient (R^2 = 0.78, Figure 1b). Inaccurate delay-time therefore influences FRC computation more if breathing frequency is elevated. Respiratory rate varied between 11.7 and 32.3 min^{-1}.

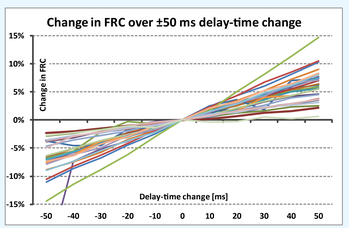


Figure 1a: Percentage change in FRC with delay-time variation

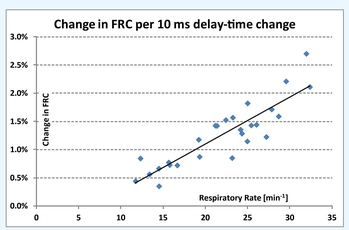


Figure 1b: Percentage change in FRC with respiratory rate

As expected an increasing delay-time decreased the LCI (Cumulative Expired Volume divided by FRC), see Figure 2a. The change in the computed LCI also depends on the breathing frequency (R^2 = 0.63), see Figure 2b.

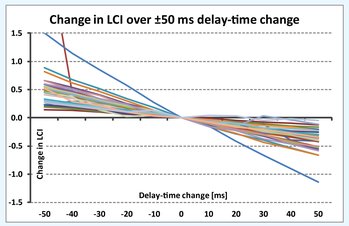


Figure 2a: Absolute change in LCI with delay-time variation

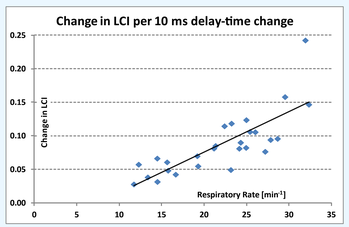


Figure 2b: Absolute change in LCI with respiratory rate

For a delay-time change of 10 ms and a mean respiratory rate of 30 min^{-1} FRC and LCI varied approx. 2%.

Conclusion

For accurate FRC and LCI measurements precise determination of the delay-time is essential and should be reported. Miscalculation of the delay-time will significantly alter results. We recommend that the delay-time is determined with an accuracy of at least 10 ms, this is especially true when analyzing files of patients with high respiratory rates (e.g. small children). Sampling rate of flow and gas signals should therefore be at least 100 Hz (200 Hz preferred).