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Data Article

Pulmonary function testing dataset of pressure and flow, dynamic circumference, heart rate, and aeration monitoring

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ABSTRACT

Respiratory data was collected from 20 subjects, with an even sex distribution, in the low-risk clinical unit at the University of Canterbury. Ethical consent for this trial was granted by the University of Canterbury Human Research Ethics Committee (Ref: HREC 2023/30/LR-PS). Respiratory data were collected, for each subject, over three tests consisting of: 1) increasing set PEEP from a starting point of ZEEP using a CPAP machine; 2) test 1 repeated with two simulated apnoea's (breath holds) at each set PEEP; and 3) three forced expiratory manoeuvres at ZEEP. Data were collected using a custom pressure and flow sensor device, ECG, PPG, Garmin HRM Dual heartrate belt, and a Dräeger PulmoVista 500 Electrical Impedance Tomography (EIT) machine. Subject demographic data was also collected prior to the trial, in a questionnaire, with measurement equipment available. These data aim to inform the development of pulmonary mechanics models and titration algorithms.

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Specifications Table

Subject	Biomedical Engineering
Specific subject area	Respiratory and Cardiovascular dataset to inform the development of physiological model-based assessment methods and tools.
Data format	Raw, Processed, Demographic, Code
Type of data	PQ Raw data is in .csv (venturi pressures) EIT Raw data is in .bin (EIT) format. HRM Raw data is in .csv (ECG, PPG, and HRB) Processed data is in .csv format. Demographic data is in a .csv file. Example figures are in .png format. Code files are included in .mat format.
Data collection	A custom pressure and flow meter [1], ECG [2–4], PPG [5,6], Dräeger PulmoVista 500 EIT, and Garmin HRM Dual heartrate belt were used to collect data in this trial. Data were recording over three tests for 20 subjects, evenly split by sex [7]. In all trials the subjects wore a full-face mask and filter connected in series with the pressure and flow meter [1]. Test 1 incremented PEEP settings using a Fisher and Paykel Healthcare SleepStyle SPSCAA CPAP device connected to the inspiratory pressure and flow meter inlet. Test 2 was a repeat of Test 1, with two self-timed subject breath holds at each PEEP setting to mimic apnoea. Test 3 consisted of three FEM which were performed at ZEEP.
Data source location	Low Risk Clinical Unit Mechanical Engineering Department University of Canterbury Christchurch New Zealand
Data accessibility	Repository name: PhysioNet Data identification number: https://doi.org/10.13026/e4dt-f689 Direct URL to data: https://physionet.org/content/respiratory-heartrate-dataset/1.0.0/

1. Value of the Data

- These data are valuable in the development and validation of lung mechanics models and treatment titration algorithms for outpatient respiratory care.
- Cardiovascular data is collected in conjunction with respiratory data, for analysis of inter-dependencies in these systems, and to assess multiple non-invasive measurement methods for treatment titration.
- These data are available open-access, alongside custom data collection device design files and instructions, for maximal utility and reproducibility.
- Researchers can use these data, and hardware to augment their datasets and produce patient-specific model-based monitoring algorithms.

2. Background

Current gold-standard respiratory diagnosis and monitoring tests require patients to perform a forced expiratory maneuverer (FEM), so results can be difficult to obtain, interpret, and compare between testing practices [8–11]. Reliance on FEM also exacerbates barriers to access for those who may not understand test requirements or have physical limitations performing these manoeuvres. FEM testing is also typically only conducted in a clinical setting, so data collection is intermittent, limiting use in personalising care.

Many chronic respiratory conditions are treated with positive airway pressure (PAP) in home-settings [12]. PAP is predominantly used in the treatment of obstructive sleep apnoea (OSA) to support airways prone to collapse during sleep induced muscular decruitment [13,14]. However, is also more broadly used as airway support in both inpatient and outpatient therapy for res-

piratory failure, chronic obstructive pulmonary disease (COPD), and neuromuscular diseases to support airways where muscular drive and airway support is impacted [15–17]. PAP supports airways by imposing a positive end-expiratory pressure (PEEP) to hold airways open at end-expiration [15,18]. Automated PEEP titration algorithms reduce clinical-contact time required to optimise treatment [19–21]. However, they are predominantly set using an apnoea hypopnea index (AHI) based on binary identification of abnormalities, and thus only respond to full airway closures, rather than precursor events or partial obstructions, which still affect sleep and respiration [19,20,22].

More comprehensive and personalised respiratory monitoring would improve the speed, quality, and cost of diagnosis, monitoring, and treatment. The outlined dataset provides non-invasive monitoring of subjects across, PAP positive end expiratory pressures (PEEPs from zero or ZEEP), simulated apnoea's (breath holds), and forced expiratory manoeuvres [7]. These data can inform development of lung mechanics models, diagnostics, and care algorithms [23–27].

3. Data Description

The data collected is outlined in Table 1 by data type, folder, and filename/format. Files are saved for each subject (1 to 20), with the exception of heart rate belt (HRB) data was only recorded for subjects 3 to 20 [7].

4. Experimental Design, Materials and Methods

A custom pressure and flow meter was used to non-invasively monitor airway opening pressure and flow [1]. Expiratory and inspiratory pathways are split using one way valves, which allows a shutter to rapidly occlude the expiratory pathway for the identification of passive lung mechanics [1]. A filter connected to a face mask was connected in series between the patient and this pressure and flow meter for each test [1]. In tests 1 & 2 a CPAP device (SleepStyle SP-SCAA, Fisher and Paykel Healthcare, East Tamaki, Auckland, NZ) was connected to the inspiratory port of the pressure and flow meter to provide set positive end expiratory pressures (PEEPs). Each trial began and ended with the device unconnected to provide a zero end expiratory pressure (ZEEP) control.

Aeration data was collected using an electrical impedance tomography (EIT) device (Dräger PulmoVista 500, Dräger, Lübeck, Germany), throughout all tests for each subject. The EIT electrode belt was located around subject's chest circumferentially at axilla level, with reference electrode located on the subject's abdomen (in line with the umbilicus on the parasagittal plane). Once the EIT belt was fitted the subject was seated for the trial, electrode conductance was checked to be acceptable, and the EIT belt was calibrated. EIT electrode conductance acceptability was defined by the EIT devices electrode check function, and if insufficient, subjects were asked to lean back against the chairs backrest and additional electrode gel was used.

Heart rate monitoring (HRM) data were collected in this trial using electrocardiography (ECG) [2–4], photoplethysmography (PPG) [5,6], and heart-rate belt (HRB) (Garmin HRM Dual, Garmin Ltd, Olathe, KS, USA) devices. ECG electrodes were located on the subject's chest in the space between the shoulder joint and thoracic cage under both left and right clavicles, and on the abdomen on the opposite side to the EIT reference electrode (on the parasagittal plane in line with the umbilicus). A PPG finger sensor was attached to the subjects left index finger (which consisted of three parallel LED PPG arrays). The HRB was located around the subject's chest under their pectoral muscles. HRM recordings were taken continuously over all three tests. For some subjects, ECG and PPG recordings were paused between tests, which is reflected in the time arrays.

Demographic data was collected for each subject using a questionnaire and basic measurement equipment (scales and tape measures) prior to testing. These data (Table 1) aim to characterise significant differences in subject physiology, particularly thoracic size extra-thoracic tissue

Table 1
Data Description.

Data Type	Folder	Sub-Folder	File name(s) / format(s)		Data
Processed datasets	*'Processed_ Dataset'*		*'ProcessedData_Subject01_PEEP.csv'* *'ProcessedData_Subject01_PEEP_ BH.csv'* *'ProcessedData_Subject01_ FEM.csv'*	For each subject	- Pressure, flow, & tidal volume data time [s] - Gauge pressure [cmH2O] - Inspiratory differential pressure [cmH2O] - Expiratory differential pressure [cmH2O] - Flow [L/s] - Tidal volume [L] - Pressure, flow, and tidal volume data inspiratory indices - Aeration data time [s] - Global aeration - ECG data time [s] - ECG signal [mV] - PPG data time [s] - Three PPG signals (PPG0, PPG1, and PPG2) - Heart rate belt data time [s] - Heart rate belt heartrate [bpm] - Heart rate belt RR Interval [ms]
Pressure and flow (PQ) data (units processed)	*'PQ_rawData'*		*'Subject1_PEEP.csv'* *'Subject1_PEEP_BH.csv'* *'Subject1_FEM.csv'*		- Time [s] - Gauge pressure [cmH_2O] - Inspiratory differential pressure [cmH_2O] - Expiratory differential pressure [cmH_2O] - Recording start time in 'HH:mm:ss' format
Raw pressure and flow (PQ) data			*'Subject1_PEEP_raw.csv'* *'Subject1_PEEP_BH_raw.csv'* *'Subject1_FEM_raw.csv'*		- Time - Gauge pressure - Inspiratory differential pressure - Expiratory differential pressure - Recording start time in 'HH:mm:ss' format
Raw heart rate monitoring (HRM) data	*'HRM_rawData'*	*'ECG'*	'S01_ECG.csv'		- Time array data in 'HH:mm:ss.SSS' format - ECG data array [mV]
		'PPG'	'S01_PPG.csv'		- Time array data in 'HH:mm:ss.SSS' format - Three corresponding PPG data arrays for each of the three LED sensors on the device ('PPG0','PPG1', and 'PPG2')
		'HRB'	'3.txt'		- Time array in 'HH:mm:ss.SSSSSS"'Z' format - Message ID array - RR interval data array - Heart-rate data array [BPM]

(*continued on next page*)

Table 1 (*continued*)

Data Type	Folder	Sub-Folder	File name(s) / format(s)	Data
Raw Electrical Impedance Tomography (EIT) data	*'EIT_rawData'*		*'S01_PEEP.bin'* *'S01_PEEP_BH.bin'* *'S01_FEM.bin'*	These files contain data as a matrix of pixel values representing regional aeration for a cross-sectional image (32×32 frame) over time (with 50 Hz sampling)
Code	*'Code'*		*'DataCollection_PQ.m'* *'DataProcessing.m'* *'FigureGeneration.m'* *'read_binData.m'*	- Pressure and flow device data collection code - Data processing code - Figure generation code - EIT bin file reading function
Demographic data			*'subject-info.csv'*	- Sex [M/F] - Height[cm] - Weight [kg] - Age [years] - Bra size (if applicable) - History of asthma - History of smoking - History of vaping
Figures			'Figure1.png' 'Figure2.png' 'Figure3.png'	Subject 3 PEEP test processed data plot Subject 3 PEEP_BH test processed data plot Subject 3 FEM test processed data plot

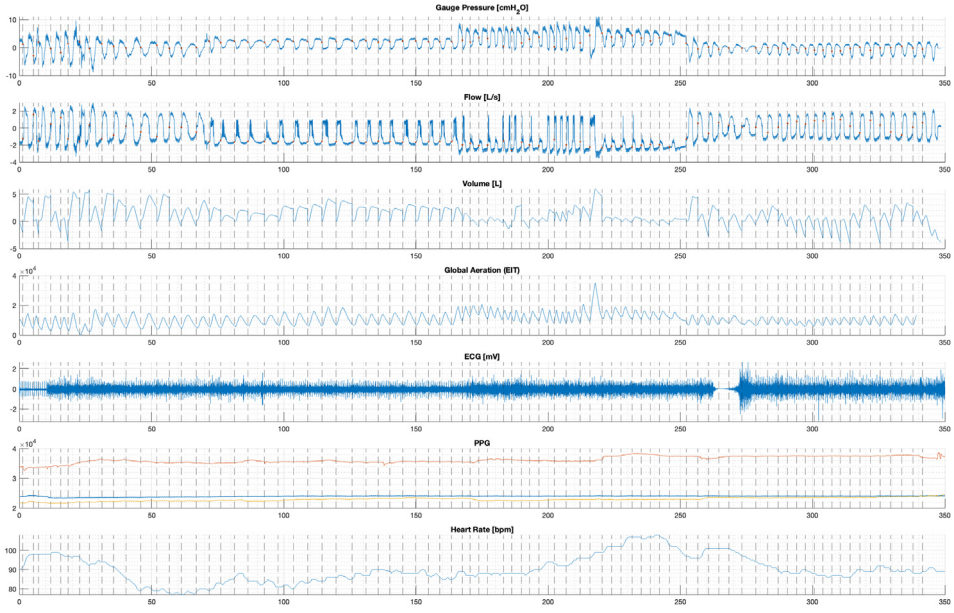

Fig. 1. Processed data from Subject 3 PEEP trial.

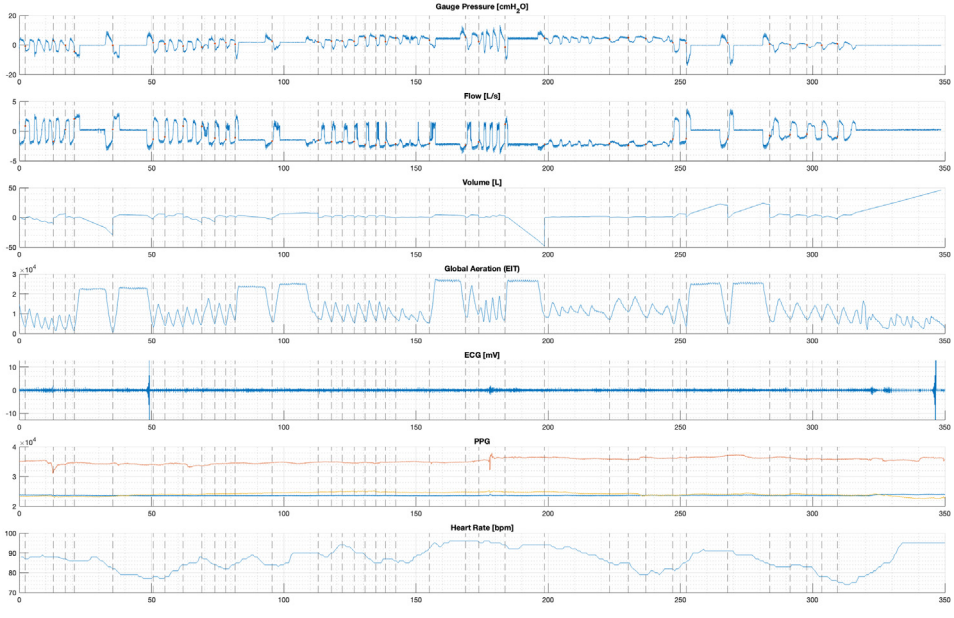

Fig. 2. Processed data from Subject 3 PEEP trial with breath hold simulated apnoea's.

volume, which have a strong effect on recruited lung volumes [28–30]. Thus, they help further characterise flow based respiratory measurements, as well as electrode conductance, and breathing patterns/modes.

For each subject, 3 tests were conducted. In the test 1 (PEEP), subjects were instructed to breathe normally throughout, and the CPAP PEEP settings were adjusted. 30 s adjustment win-

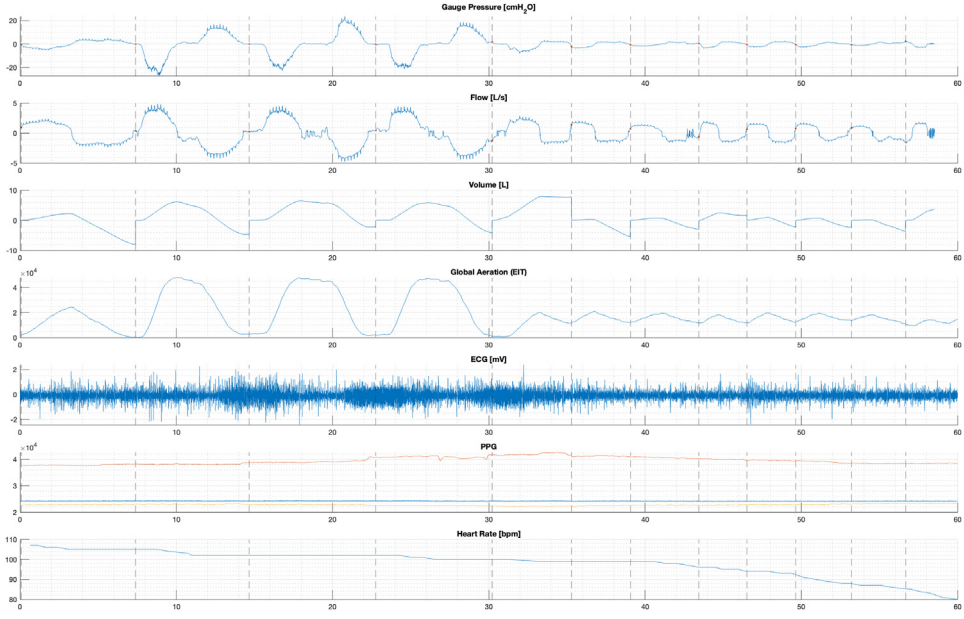

Fig. 3. Processed data from Subject 3 FEM trial.

dows were allocated in the cueing system to change PEEP settings, and data was recorded for 1 min at each setting. The test began with the CPAP disconnected (at ZEEP), the CPAP was then connected with a PEEP setting of 4 cmH2O, and then increased to 8 cmH2O, before a final ZEEP recording with the CPAP disconnected. Test 2 (PEEP_BH) was a repeat of the first test (PEEP), with the addition of two subject self-timed breath holds to simulate apnoea, at each PEEP setting. Subjects were provided with a stopwatch to time their breath holds. Test 3 (FEM) was conducted at ZEEP without CPAP, and subjects were asked to perform three forced expiratory manoeuvres (FEMs). A FEM was described to the subject as breathing out as much as possible then taking the biggest breath in possible and breathing back as far as possible. Subjects were also instructed that these repeats did not have to be in immediate succession, and they could take intermediate recovery breaths.

Flow meter data was collected, and all data was processed in MATLAB (Matlab 2021b, The Mathworks Inc, Natick, MA, USA). Data collection and processing software is included in the dataset [7]. Example figures of processed datasets, and the corresponding code is also included [7]. Breath indices were identified in this code from the flow-meter data to compute tidal volume. Inaccuracy in tidal volume is anticipated from leakages and errors in identifying the correct breath start time from the data. However, all raw data is included, so these indices can be easily modified to suit applications to identify alternative and additional desired breath sections.

Limitations

To further the utility of this testing and model development, repeating this trial in clinical populations with specific, known cases of respiratory dysfunction would be useful. This dataset and trial aimed to provide evidence of efficacy and feasibility to extend testing to these populations. Known, diagnosed cases of respiratory disease would then provide evidence of model parameter identification accuracy, and hardware efficacy in enabling these models.

In addition, testing against current gold-standard methods would also validate the potential clinical utility of the respiratory mechanics models developed using these and other data.

Spirometry or full-body plethysmography would be a suitable comparison. Such testing would also logistically integrate well in clinical testing of people with known respiratory disease.

Tidal volume deficits in this dataset are expected due to leakages typical of full-face masks [31]. However, additional system leakages and sensor accuracy could also impact these deficits, as well as data processing indexing errors. Future testing could consider comparing a nose-clip and mouthpiece patient interface to full-face mask to reduce leakages.

Ethics Statement

Ethical consent for the trial was granted by the Human Research Ethics Committee at the University of Canterbury (Ref: HREC 2023/30/LR-PS) on 24 April 2023. Subjects gave written consent prior to the trial after both written and verbal explanation of the procedure. Subjects consented to the publication of their de-identified data.

Data Availability

Respiratory and heart rate monitoring dataset from aeration study (Original data) (PhysioNet).

CRediT Author Statement

Ella F.S. Guy: Conceptualization, Methodology, Software, Validation, Investigation, Data curation, Writing – original draft, Visualization; **Isaac L. Flett:** Conceptualization, Methodology, Software, Validation, Investigation, Data curation; **Jaimey A. Clifton:** Conceptualization, Investigation; **Trudy Calje-van der Klei:** Conceptualization, Investigation; **Rongqing Chen:** Conceptualization, Methodology, Software, Data curation; **Jennifer L. Knopp:** Conceptualization, Methodology, Supervision; **Knut Möller:** Conceptualization, Methodology, Resources, Supervision, Funding acquisition; **J. Geoffrey Chase:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Funding acquisition.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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