Respiratory system pressure-volume curve: Validation of a new, automatic, pressure ramp method of acquirement

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Introduction

The pressure-volume curve (PV curve) plots lung pressure against lung volume. It offers information that can help optimize the setup of a ventilator for the most severely compromised patients[1]. However, until now, the PV curve could only be obtained using complex, time-consuming and even harmful techniques[2].

Objective

The objective of this study was to validate an easy and fully-automatic Linear Pressure Ramp (LPR) method of obtaining a PV curve.

Materials and methods

The recently-marketed method here studied is based on a linear, pressure-controlled ramp, adjustable for ramp speed and maximum pressure. It is produced automatically by HAMILTON MEDICAL's GALILEO Gold ventilator (HAMILTON MEDICAL AG, Rhäzüns, Switzerland).

Based on a preliminary investigation, the current validation was performed using a pressure ramp of 2.5 cmH_2O/s.

At the start of the maneuver, the ventilator performs a prolonged exhalation that lasts for 5 expiratory time constants and empties the lung to the level of functional residual capacity (FRC). The extra volume of gas discharged from the lungs during this prolonged exhalation indicates the lung volume above FRC associated with PEEP (VPEEP).

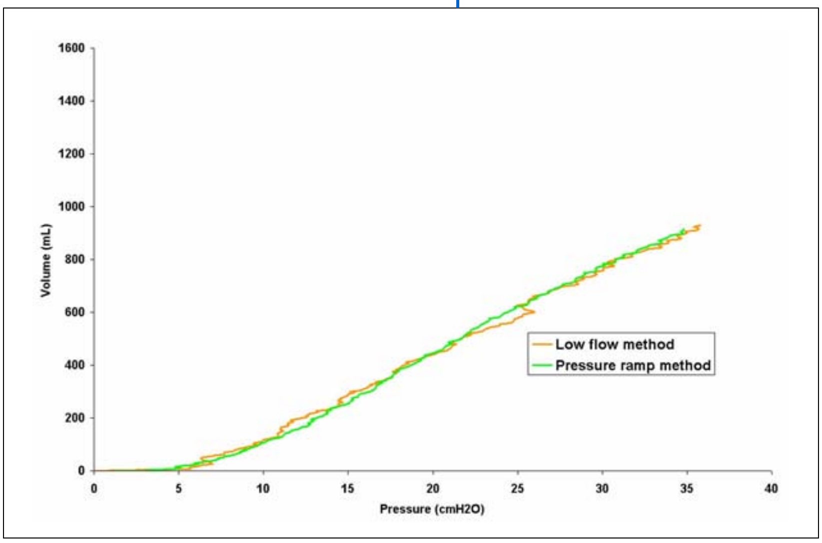

Figure 1: Typical pressure/volume curves obtained with the Low Constant Flow (orange) and the Linear Pressure Ramp (green) methods in a patient with restrictive lung disease.

The PV curves obtained using the automated LPR method were compared with quasi-simultaneous PV curves obtained using the Low Constant Flow method (LCF)[3]. The reference technique was as follows:

1. The patient was disconnected from the ventilator. (The Flow Sensor remained connected to the endotracheal tube and the patient remained intubated.)
2. A complete exhalation (6 to 10 seconds) was allowed, to reach the FRC.

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3. Low, constant-flow insufflations of 3 l/min (generated with the help of an O_2 flow meter attached to the endotracheal tube) were performed until a maximal airway pressure, similar to the top pressure set with the automated LPR method, was achieved.
4. Airway flow and pressure were recorded from the Flow Sensor, mounted between the O_2 flow meter connection and the endotracheal tube.
5. Following ethical approval, 12 ventilated patients with different lung diseases were studied.

Analysis

The lower inflection point (LIP) and the upper inflection point (UIP) of the curves were determined visually as being the minimum point (LIP) and the maximum point (UIP) of the intermediate, linear portion of the curve defining the linear Compliance (Clin). The start Compliance (Cstart) — the compliance at 100 ml of volume — was also determined.

Statistical analysis

Results were given in mean ± standard deviation, and compared using a paired t-test. Linear regression analysis, and bias and precision analysis were used to compare the LIP, UIP, Clin, and Cstart values obtained with the two methods.

Results

General characteristics of the patients are shown in Table 1.

Pt	Age	Diseases	Cqs (ml/cm H_2O)	PaO_2/FiO_2 (mmHg)	PEEP (cmH_2O)
1	49	Pulmonary hypertension	23	400	9
2	60	ARDS	25	146	6
3	44	ALI	32	231	9
4	70	ALI	31	257	11
5	63	Pneumonia	61	198	10
6	62	Meningitis	56	267	10
7	48	Tetanus	76	295	9
8	80	Trauma	22	138	2
9	77	Post operative	49	400	5
10	58	Post operative	45	398	7
11	58	ARDS	13	68	12
12	37	ARDS	23	132	12

Table 1: General patient characteristics.
Abbreviation: Cqs: quasi-static compliance.

In 6 of the 12 patients, the curves obtained with the two methods were perfectly superimposed. In the remaining 6 patients, the curves showed small and non-clinically-relevant differences (Figure 1). Pair t-test comparisons of the PV curve characteristics (LIP, UIP, Cstart and Clin) obtained using the two methods failed to find any significant differences. The linear regression analysis showed good correlation of all PV curve characteristics between the two methods (Figure 2).

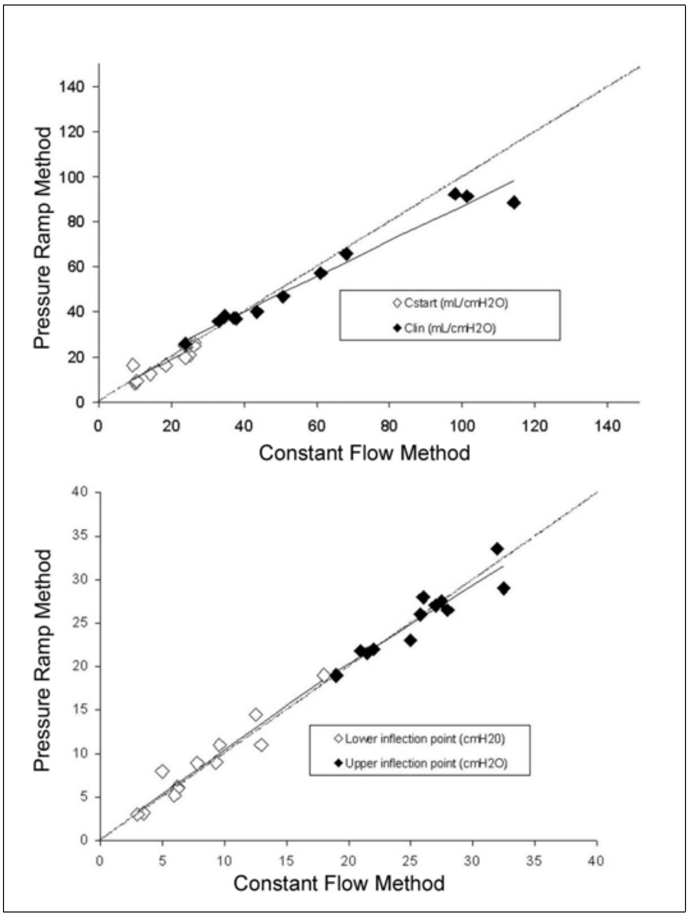

Figure 2: Linear regression analysis between the Low Constant Flow method, and the Linear Pressure Ramp method in 12 ventilated patients. (Dotted line is line of identity.)
Clin: linear compliance; Cstart: compliance at 100 ml of volume. All regressions are statistically significant.

The bias between the two methods was acceptable but displayed only moderate precision (Figure 3).

Discussion

The main result of the present study is the finding that in a mixed group of patients, information obtained from the PV curve using the LPR method was well correlated with information obtained using the LCF method.

In contrast with the LCF method (and by design) gas flow with the automated LPR method is not constant, as flow variations during the maneuver depend on the respiratory mechanics of the patient (resistance and compliance).

Despite acceptable correlation and bias, we found only moderate precision, with the LPR method resulting in a lower Clin estimate in patients with high compliance (Figure 3). With neither method did we quantify resistive pressure. Whether one method is superior to the other in the presence of high resistance, and which of the two gave the most

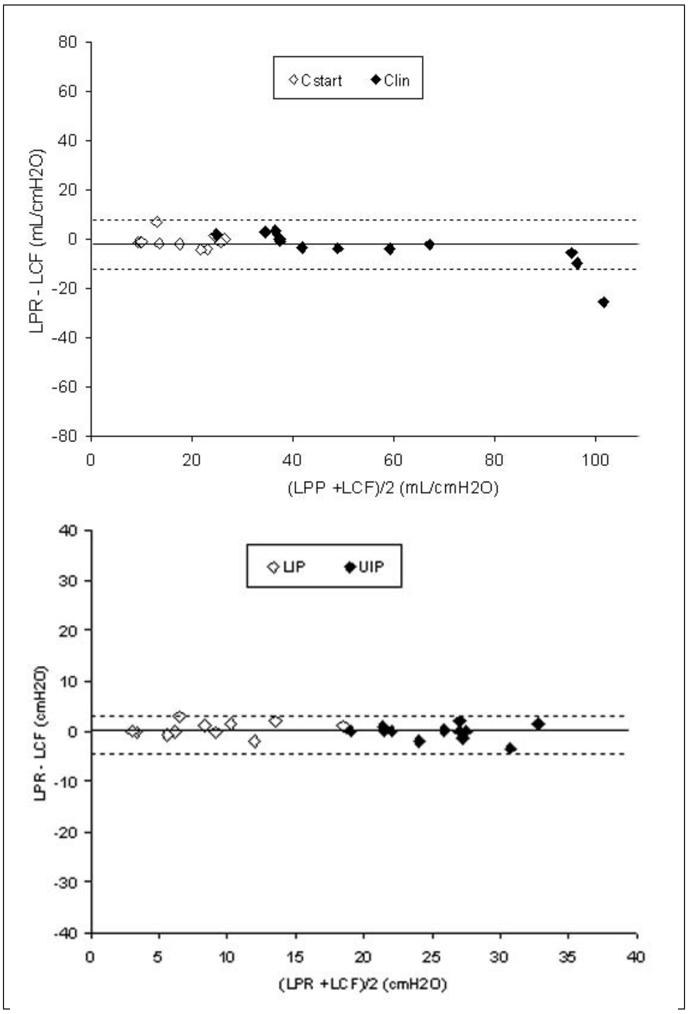

Figure 3: Bland & Altman plots for the data from the Linear Pressure Ramp method and the Low Constant Flow method in 12 ventilated patients.
Abbreviations: LIP: lower inflection point; UIP: upper inflection point; Clin: linear compliance; Cstart: compliance at 100 ml of volume.

accurate information could not be ascertained in the current study.

Other considerations that could explain the merely moderate precision are the differences between the two methods with respect to air trapping and intrinsic PEEP before starting the PV maneuver. In the LPR method, the pre-maneuver exhalation time depends on the expiratory time constant (5 times RCexp); in the LCF method, this time was not precisely controlled, and did not depend on the mechanical respiratory characteristics of the patient.

Finally, the visual identification of LIP and UIP by only one observer could introduce an observational bias. There are evidences of substantial inter-observer and intra-observer variability in the determination of the inflection points, although this variability can be reduced by managing the data with a sigmoid equation[4]. Conversely, a recent paper found fairly good agreement among different observers analyzing different PV curves obtained using a manual method[5]. Finally, observational bias usually tends to reduce, rather than increase, the difference between two methods.

The automatic LPR method may have several advantages over manual methods. First, it gives the volume above the FRC related to PEEP (VPEEP), after prolonged exhalation based on the respiratory time constant. Although there are still some debates about the significance of the PV curve inflection points, the meaning of VPEEP is no longer questioned. Second, by controlling the pressure instead of the volume increase, this method offers an easy opportunity to also obtain the deflation part of the PV curve that might give information to prevent end-expiratory derecruitment[6]. Finally, such an automatic option avoids disconnection from the ventilator or changes to ventilator settings, and may therefore greatly improve the safety of the maneuver.

Conclusions

The two methods compared offer almost identical results. Only in few patients was the precision between the two methods modest, without definitive arguments to suggest that one method would be preferable to the other. However, the LPR method gives the volume above the FRC that is related to PEEP, and also offers the ability to easily and safely obtain the deflation part of the PV curve.

References

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