Multiplex Ventilation:
Solutions for Four Main Safety Problems: A Simulation-Based Study

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Background

The topic of ventilating two patients with one machine during a ventilator shortage has become prevalent during the COVID-19 pandemic. A previous multiplex ventilation study by Chatburn et al. indicated failure in 67% of simulations using an unmodified multiplex circuit to ventilate patients with different lung mechanics (PMID: 32345741). The four safety problems that must be solved to provide practical multiplex ventilation: 1) individual adjustment of tidal volume (V_T), 2) individual measurement of V_T, 3) individual adjustment of positive end expiratory pressure (PEEP), 4) individual PEEP measurement.

The purpose of this study was to evaluate potential solutions developed at our institution in their ability to ventilate two simulated patients with different lung mechanics.

Methods

Two IngMar ASL 5000 breathing simulators were ventilated with a modified multiplex circuit using pressure control continuous mandatory ventilation with set-point targeting. Parameters used for the simulated lung models (resistance and compliance) were created from evidence-based values.

A modified multiplex circuit was designed to solve the main safety problems. The modifications included: an adjustable flow diverter valve (AFDV), prototype dual volume display (AVD-19), PEEP valve, and disposable PEEP display.
The devices that were used for the in-circuit modifications were first evaluated individually for accuracy and functionality.

The modified multiplex circuit was assessed by ventilating six pairs of simulated patients with different lung mechanics (all with a passive effort: Pmus=0). The AFDV , PEEP valves, and ventilator inspiratory pressure were adjusted until both lung simulators received equal ventilation. Ventilation was considered equalized when V_T and end expiratory lung volume (EELV) were within 10% for each simulation

Results

In this study the failure modes observed in the original study were corrected. Adjustments to the AFDV, PEEP valves, and inspiratory pressure allowed for individualized ventilation and the ability to equalize ventilation so that all outcome variables were within 10% of each patient.

Experiment	A			B			C		
Use Case	Balanced Resistance-Compliance			Unequal Compliance			Unequal Compliance (Extreme)		
Patient	A	B	Δ	A	B	Δ	A	B	Δ
Diagnosis	ARDS-Mild	ARDS-Mild		ARDS-Mild	ARDS-Severe		Normal	ARDS-Severe	
Valve Setting	0			B7			B8		
P_I (cm H_2O)	15			29			38		
PEEP Display (cm H_2O)	7.5*	7.5*		10.0	20.0		10.0	20.0	
ΔP (cm H_2O)	15.0	15		24.0	14.0		33.0	23.0	
Dual Display VT (L)	0.456	0.455	0.2%	0.458	0.456	0.4%	0.428	0.456	-6.3%
V_E (L/min)	9.1	9.1	0.2%	9.2	9.1	0.4%	8.6	9.1	-6.3%
$PaCO_2$ mmHg	38	38	-0.2%	38	38	-0.4%	40	38	6.3%
V_T (mL/kg)	6.5	6.5	0.2%	6.5	6.5	0.4%	6.1	6.5	-6.3%
EELV (L)	0.282	0.282	0.0%	0.291	0.291	0.0%	0.329	0.319	3.1%
pH	7.43	7.42	0%	7.43	7.43	0.0%	7.40	7.43	-0.4%

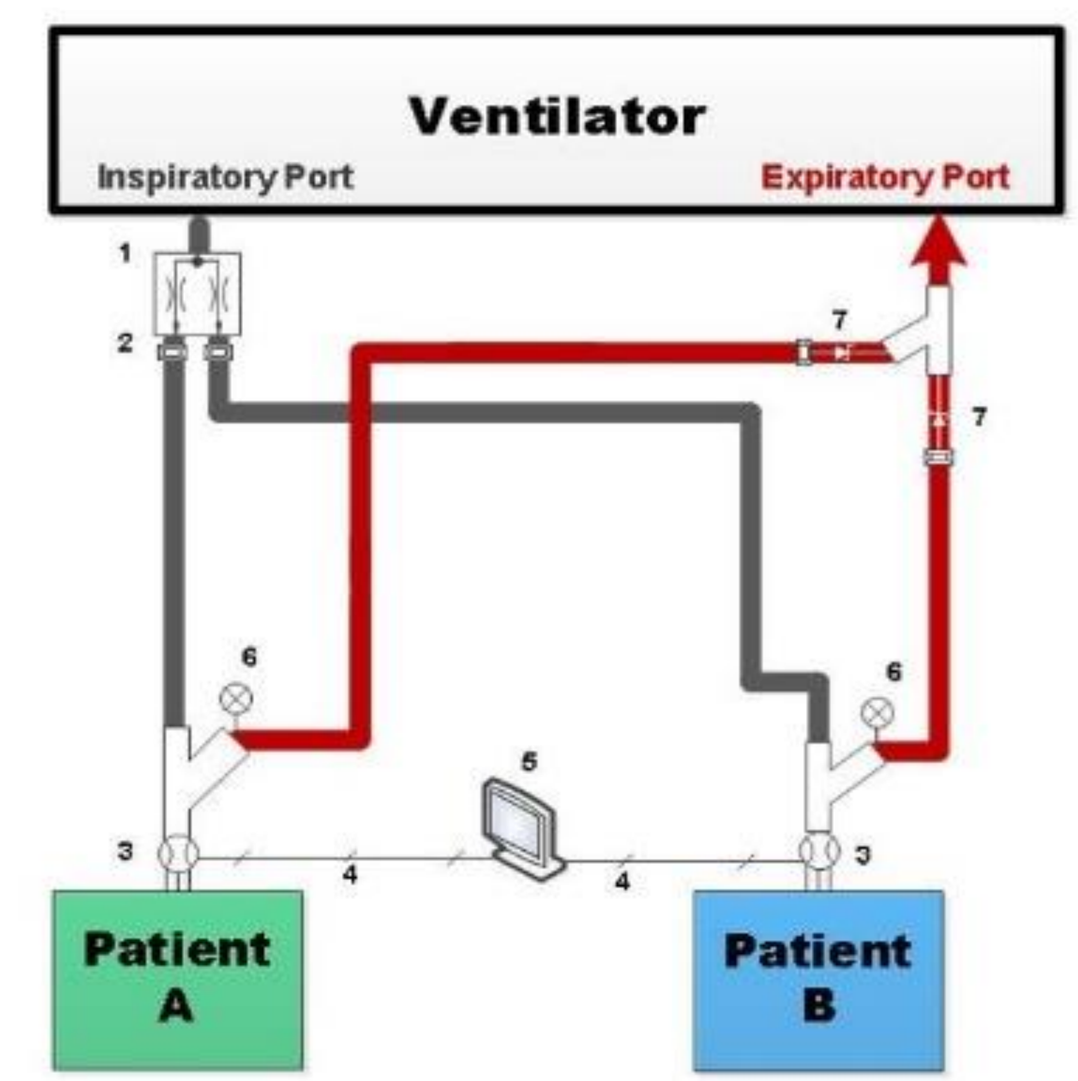
Experiment	D			E			F		
Use Case	Unequal Resistance			Unequal Resistance (Extreme)			Unequal T (Extreme)		
Patient	A	B	Δ	A	B	Δ	A	B	Δ
Diagnosis	ARDS-Mild	ARDS-Mild		ARDS-Mild	Asthma-ARDS		ARDS-Severe	COPD	
Valve Setting	B5			B6.5			A6.5		
P_I (cm H_2O)	18			28			34		
PEEP Display (cm H_2O)	7.5*	7.5*		10.0	7.5		30.0	7.5	
ΔP (cm H_2O)	18	18		23.0	25.5		9.0	31.5	
Dual Display V_T (L)	0.443	0.450	-2%	0.442	0.441	0%	0.464	0.437	6%
V_E (L/min)	8.9	9.0	-2%	8.8	8.8	0%	9.3	8.7	6%
$PaCO_2$ mmHg	39	38	2%	39	39	0%	37.2	39.5	-6%
V_T (mL/kg)	6.3	6.4	-2%	6.3	6.3	0%	6.6	6.2	6%
EELV (L)	0.270	0.282	-4%	0.338	0.314	7%	0.488	0.505	-3%
pH	7.41	7.42	0%	7.41	7.41	0%	7.43	7.41	0%

Values in blue are considered the most important clinical outcomes
Gray values are the adjusted settings to equalize ventilation
V_T = tidal volume
V_E = minute ventilation
EELV = end expiratory lung volume
P_I = Inspiratpry pressure above set PEEP on the ventilator
ΔP = driving pressure for inspiratory flow = (P_I + vent PEEP) - measured PEEP
*PEEP valve was not adjusted (producing zero PEEP above the ventilator setting)

Conclusions

This study solves the main safety problems presented in the original multiplex study: (1) the ability to individualize V_T, (2) the ability to individualize PEEP, and (3) a means of measuring delivered tidal volume and (4) a means of measuring set PEEP to each patient. This study confirms that despite large differences in respiratory mechanics, it is possible to individualize ventilation to each patient during multiplex ventilation.

Going forward, the application of multiplex ventilation is still recommended to be a last resort option when ventilating patients and should only be used if there are absolutely no ventilators available for single patient ventilation.



Modified Multiplex Ventilation Circuit, (1) adjustable flow diverter valve (AFDV), (2) one-way valve, (3) flow sensor, (4) flow signal from flow sensor, (5) dual volume display, (6) disposable PEEP display, (7) PEEP valve with internal one-way valve

Disclosures

Conflicts of Interest: Morgan Sorg : none; Richard Branson: Consultant Mallinckrodt, Pfizer, Vyaire, Ventec Life Systems, Zoll ; Umur Hatipoğlu: none; Robert L. Chatburn: Consultant for IngMar Medical, Vyaire Medical, Inovytec, Temple, Aires, Ventis Medical, and Promedic Consulting.