Maximizing Oxygen Delivery During Mechanical Ventilation with a Portable Oxygen Concentrator

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The Center for Sustainment of Trauma and Readiness Skills/Institute of Military Medicine University of Cincinnati

SMSgt Dario Rodriquez Jr. BS RRT
Thomas C. Blakeman BA RRT
Col Warren Dorlac MD
Col Jay A. Johannigman MD
Richard D. Branson MSc RRT

Overview

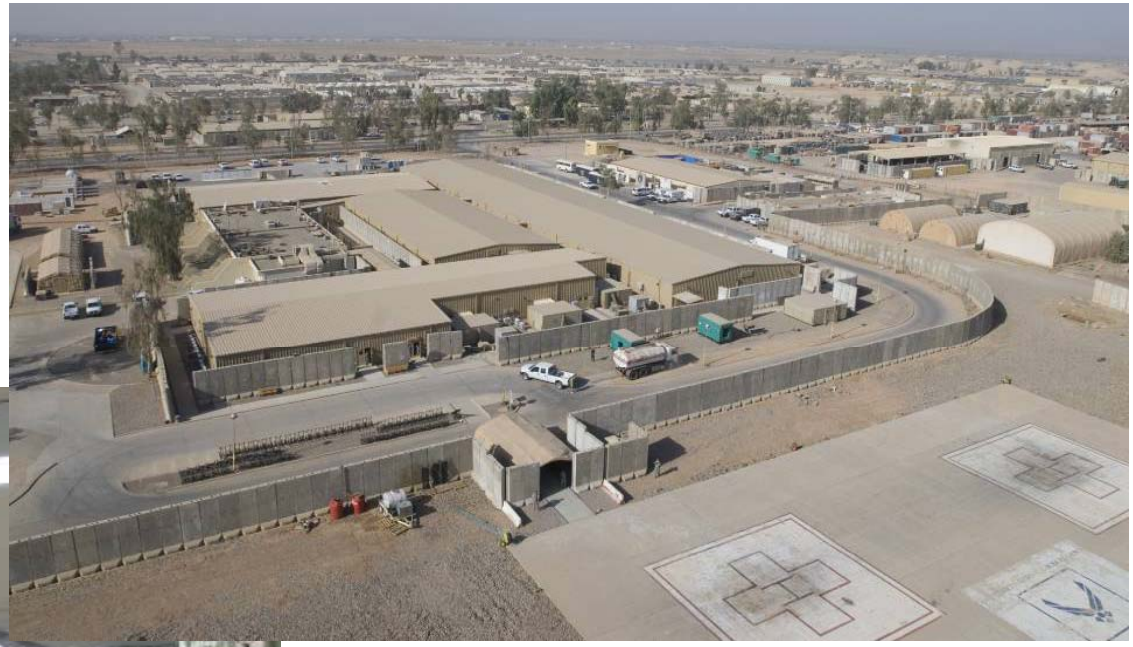
- Importance of Oxygen in Austere Environment
  - Oxygen in prehospital setting: Do Trauma patients need O_2?
  - Oxygen requirement in transport
- Challenges of Transporting Oxygen
  - Compressed gas containers are cumbersome
  - Large amounts required for shipment
  - Potential increased hazard
- Alternative Solution
  - Electrically generated oxygen source
  - Portable/lightweight
- Potential developments

Working Environment

- Current Theatre
  - Iraq
  - Afghanistan
- Facility
  - Early on

Working Environment

- Current Facility



Ambulance Bus Transport

Air Transport

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Role of Oxygen

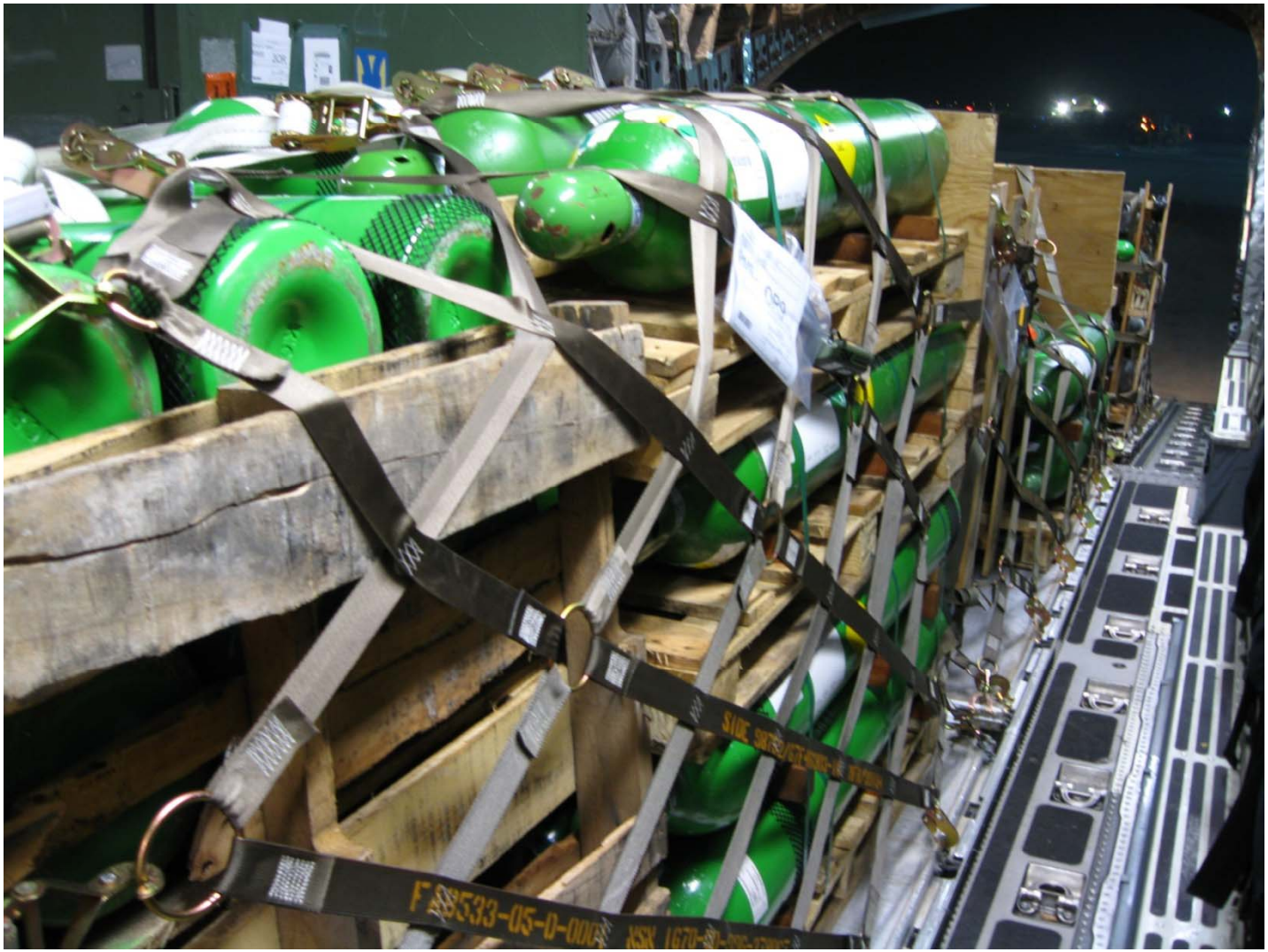
- Oxygen use in CCATT Transport
  - Barnes et al suggests approx. 70 percent of patients require $\leq$ 3 lpm of oxygen
- Prehospital oxygen use
  - Research suggests all trauma patients do not need oxygen
  - C-STARS/UC research project evaluating need/use of oxygen in prehospital setting

Barnes SA et al.En-route care in the air: A snapshot of mechanical ventilation at 37,000 feet. J Trauma 2008;64:S129-S135.

Logistical Constraints

- Compressed oxygen tanks require separate transport
- Weight and cube of cylinders/LOX are cumbersome
- Oxygen supports combustion/poses potential hazards
- Tanks must be swapped out for PTLOX for fixed wing flight

Oxygen Re-supply



Oxygen Re-supply

Study Objective

- Assess interoperability of mechanical ventilators with an oxygen concentrator
  - Capitalize on power efficiency of pulse dose delivery of oxygen from a POC
  - Modify concentrator to trigger on positive pressure signal
  - Maximize pulse dose volume to maximize FIO_2
  - Accurately deliver consistent volume of oxygen

Integration of Ventilator and Concentrator

- Vents chosen for study
  - Impact 754
    - 90% of transports
    - Compressor driven
    - Volume control
    - Correct tidal volume maximizes FIO_2
    - Entrainment positions/reservoir most efficient
  - LTV 1000/1200
    - 10% of transports
    - Turbine driven
    - Volume/Pressure control
    - Bias flow on/off
    - Entrainment positions/limited reservoir capability

Current Military Assets

	Impact 754	LTV-1200
Weight (kg)	5.8	6.1
Dimensions (W x L x D) cm	22.5 x 29.2 x 4.75	25 x 8 x 30
Breath types	Volume	Volume and Pressure
Modes	Assist control SIMV CPAP	Assist Control SIMV Pressure support CPAP
Tidal volume range (ml)	0 -3000	50 -2000
Inspiratory flow range (L/min)	10-60	10 – 100
PEEP range (cm H_2O)	0-20	0-20
Breath rate (breaths/min)	1-150	0-80
Volume monitoring	Volume exiting ventilator	Inspired and expired volume at the airway
Internal Air Source	Compressor	Turbine
Blender	Mechanical 0.21-1.0	Electronic 0.21-1.0
Bias Flow	None	0 or 10 lpm
Low pressure oxygen inlet	Reservoir at compressor inlet	Direct connection via DISS fitting

Alternative to Compressed Gas

- Concentrator characteristics
  - Home care stationary devices
    - Capable of continuous flow in excess of 10 lpm
    - Larger/non-portable
  - Portable Sequal Eclipse II
    - 3 lpm
    - Pulse dose capability modified to double volume
    - Modified version synchronizing delivery with vent trigger compared to standard operation
    - Capable of accurate delivery of pulse dose volume

Oxygen Concentrator

- SeQual Eclipse
- 3 L/min at 94% oxygen
- Pulse dose oxygen – 32-192 ml

SeQual Eclipse

Characteristic	Specification
Dimensions H x W x D (cm)	49 x 31 x 18
Weight (kg)	8.1
Continuous flow (liter per minute)	0.5 – 3.0
Pulse dose (ml)	16 – 96*
Power consumption continuous flow	145 watts at 3 lpm
Power consumption pulse flow	95 watts at maximum pulse dose
Battery life (minutes)	80 at 3 lpm continuous flow 210 maximum pulse dose

*We used a modified device for this study capable of a pulse dose of 192 ml

How Does it Work?

- Oxygen Concentrator uses ambient gas
- O_2 and N_2 are separated by using zeolite granules to selectively absorb nitrogen from ambient air
- Internal compressor raises the air pressure to about 20-lbs per square inch (P.S.I)
- Compressed air is introduced to a zeolite canister scrubbing N_2 and leaving O_2 for use
- Compressed air is redirected to second canister approximately 20 seconds later repeating the cycle
- Pressure in the first canister is reduced to zero allowing N_2 to be released into the atmosphere
- Alternating pressure in two canisters between 0 and 20 P.S.I. permits a constant supply of oxygen while zeolite is continuously being regenerated

Test Configuration

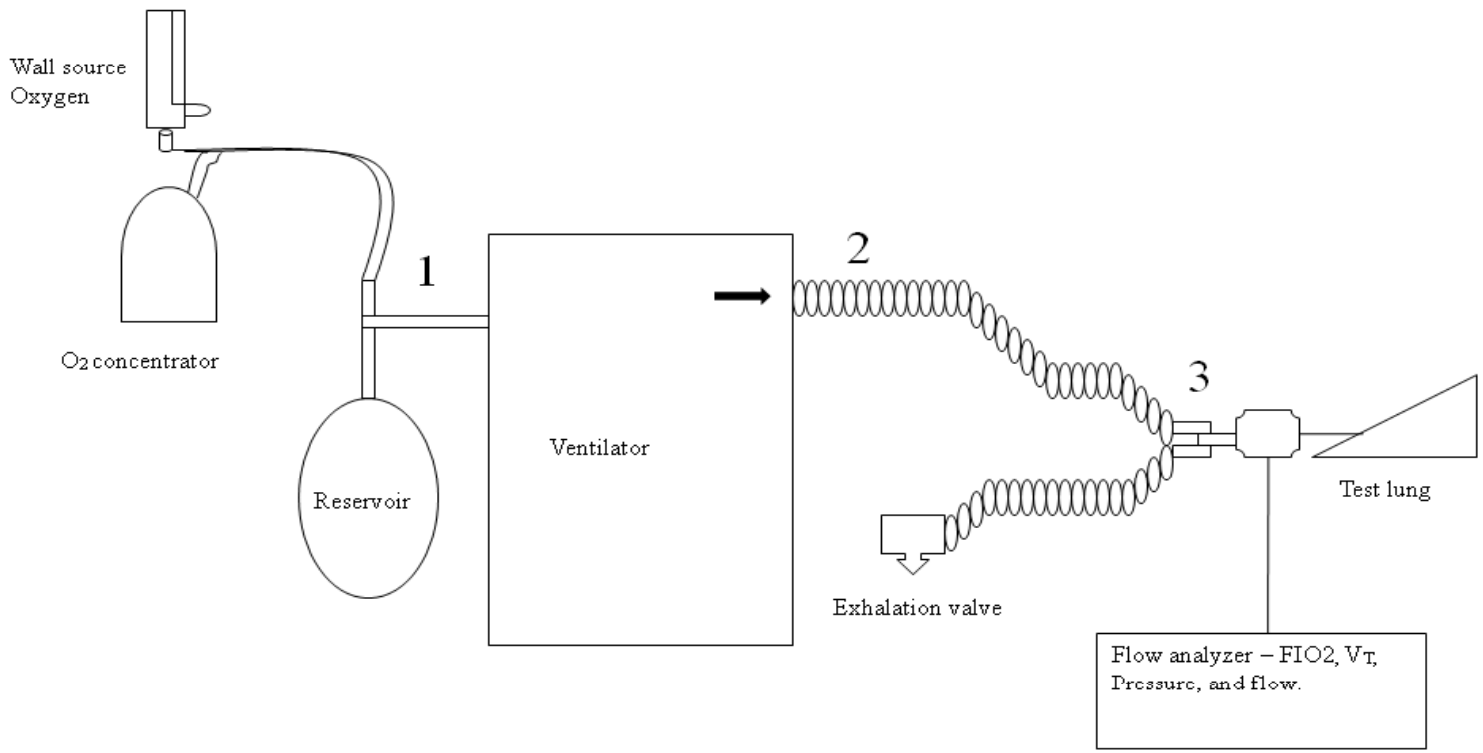
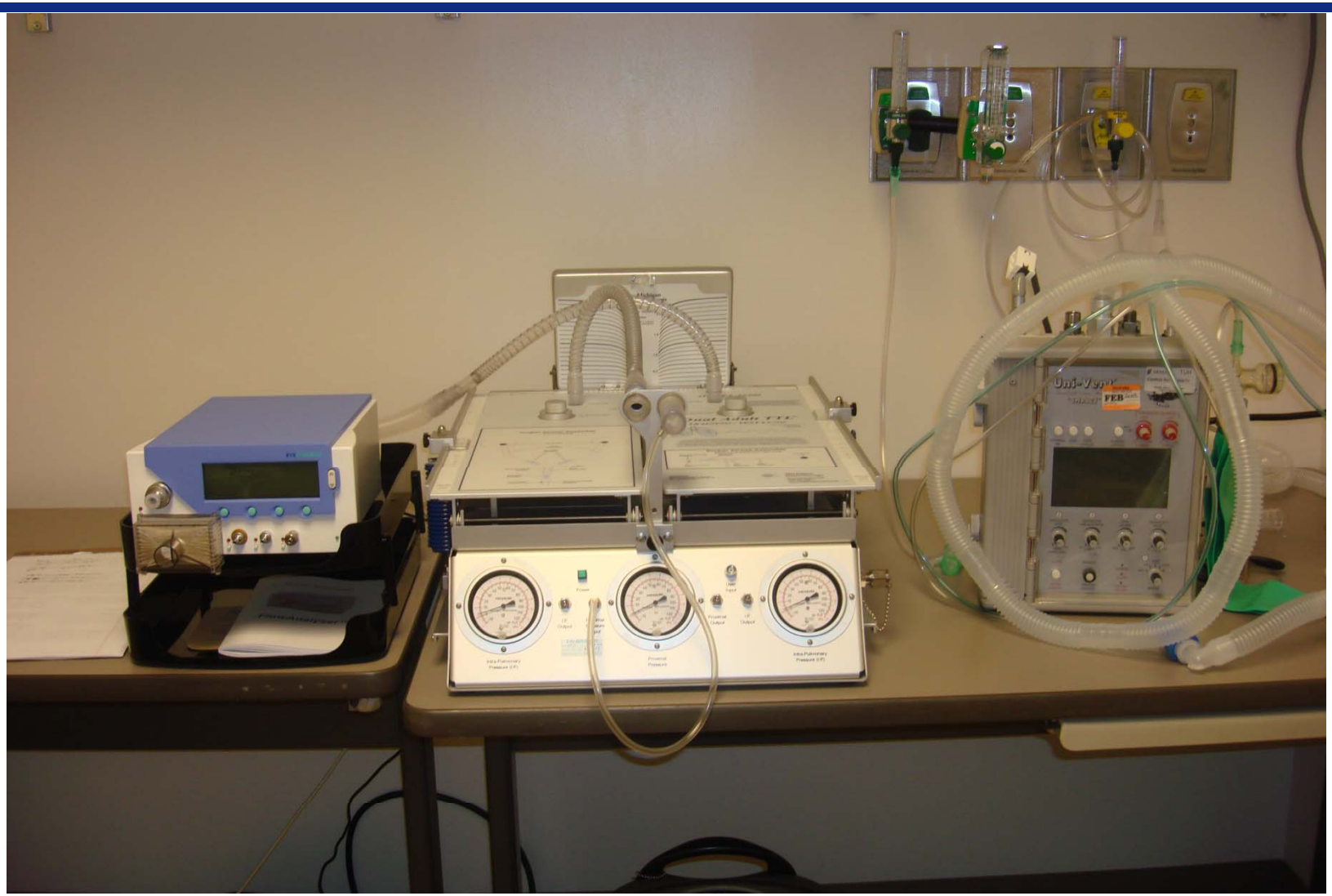


Figure 1. Experimental set up. Oxygen was added from either a wall oxygen source or a portable oxygen concentrator at the ventilator inlet (1), at the outlet of the inspiratory limb (2), or at the ventilator Y piece (3). Continuous flow was provided at positions 1, 2, and 3 from the concentrator and wall oxygen source. Pulse dose delivery of oxygen was provided at positions 2 and 3.

Test Equipment



Test Matrix

Oxygen Source	Flow or Dose	Ventilator	Breath type	Tidal Volume (ml)	Respiratory Rate (bpm)	PEEP (cm H_2O)	Tidal volume corrected?
Wall	1,2,3 lpm	754, LTV	Volume	500	10,20,30	0 and 10	No
POC	1,2,3 lpm	754, LTV	Volume	500	10,20,30	0 and 10	No
POC	192 ml	754, LTV	Volume	500	10,20,30	0 and 10	Y and No
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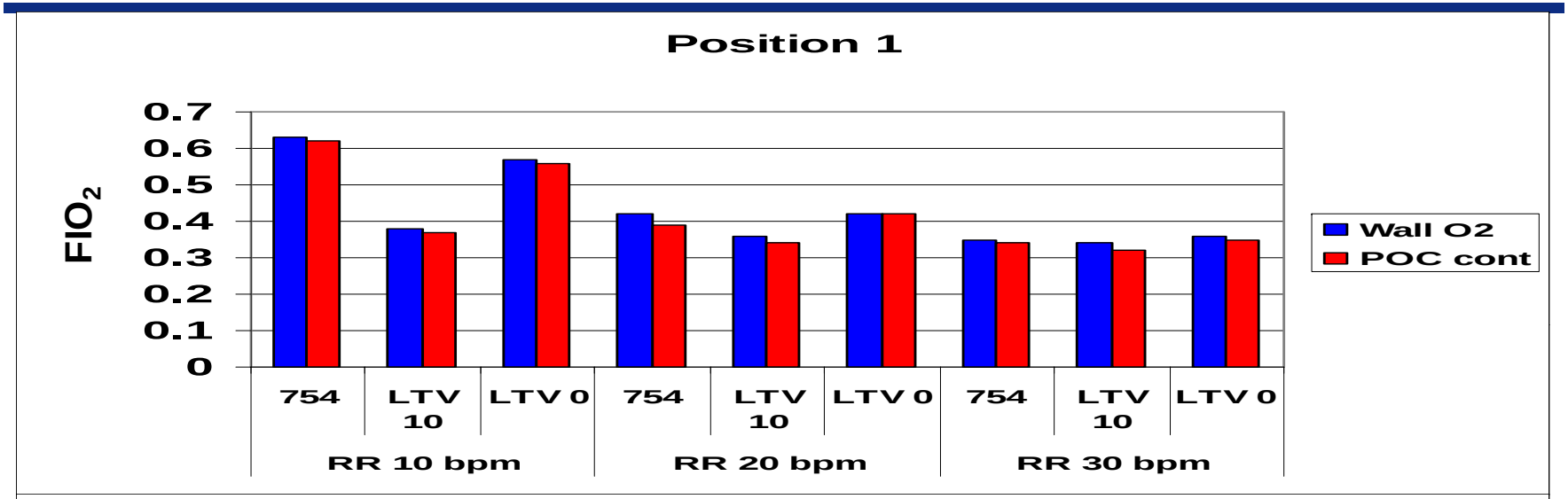
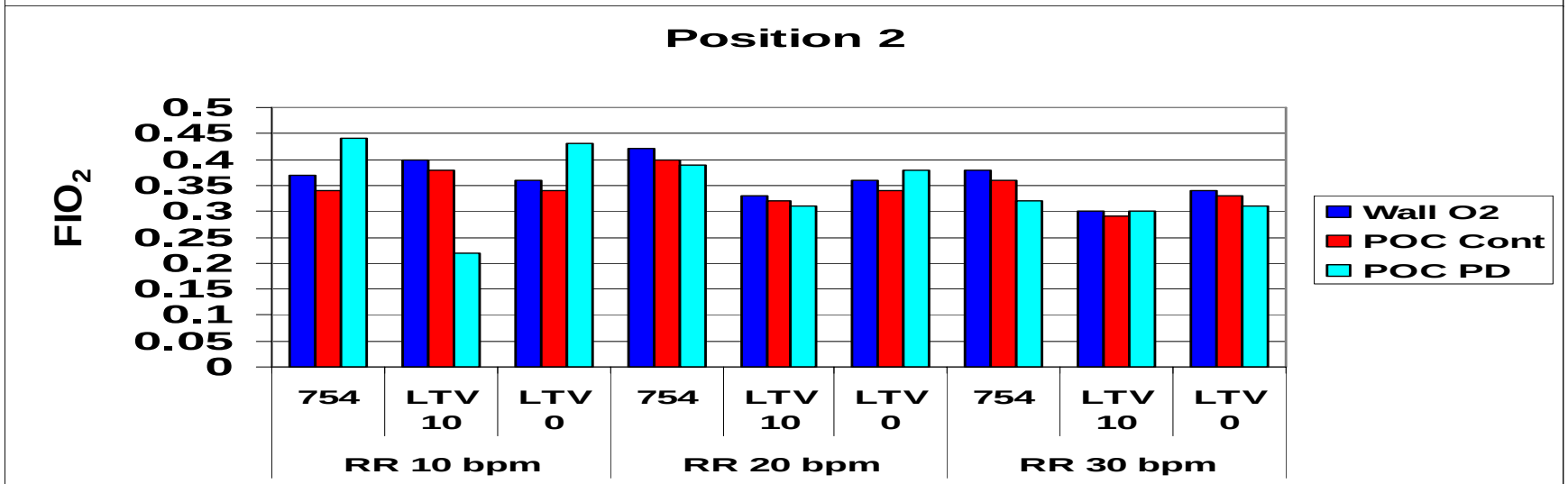
POC	192 ml	LTV	Pressure	500	10,20,30	0 and 10	No

Our Results

- FIO_2 up to 0.76 with pulse dose (VCV, V_E =5 L/min)
- Highest FIO_2 with 192 ml pulse dose closest to patient
- Correcting for pulse dose volume in VCV yielded highest FIO_2
- Pressure control automatically adjusted for added volume from POC
- MV effects FIO_2
- Vent performance effects FIO_2
  - LTV bias flow
  - Impact PEEP effect
  - Reservoir differences

3 lpm/Max Pulse Dose Results





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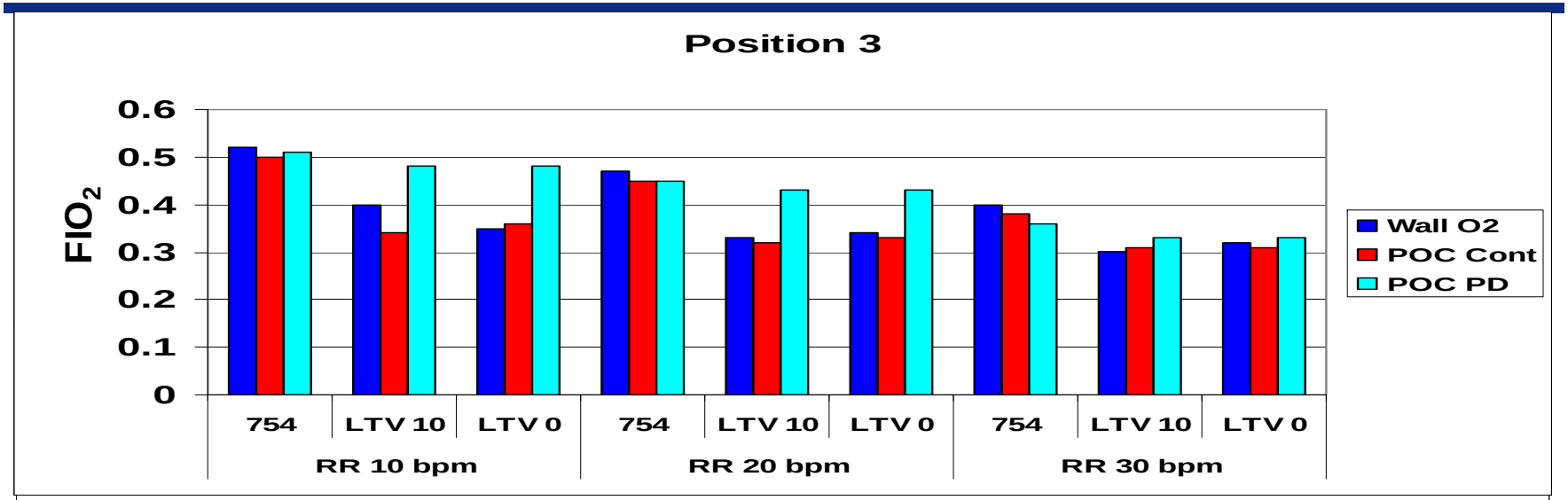
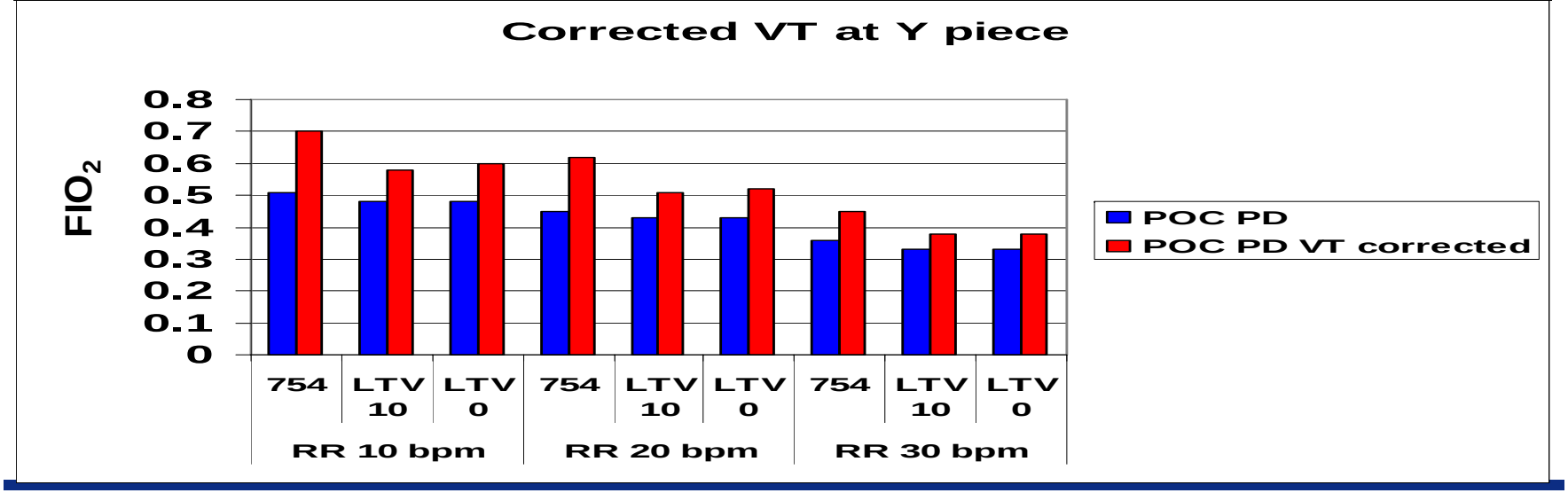
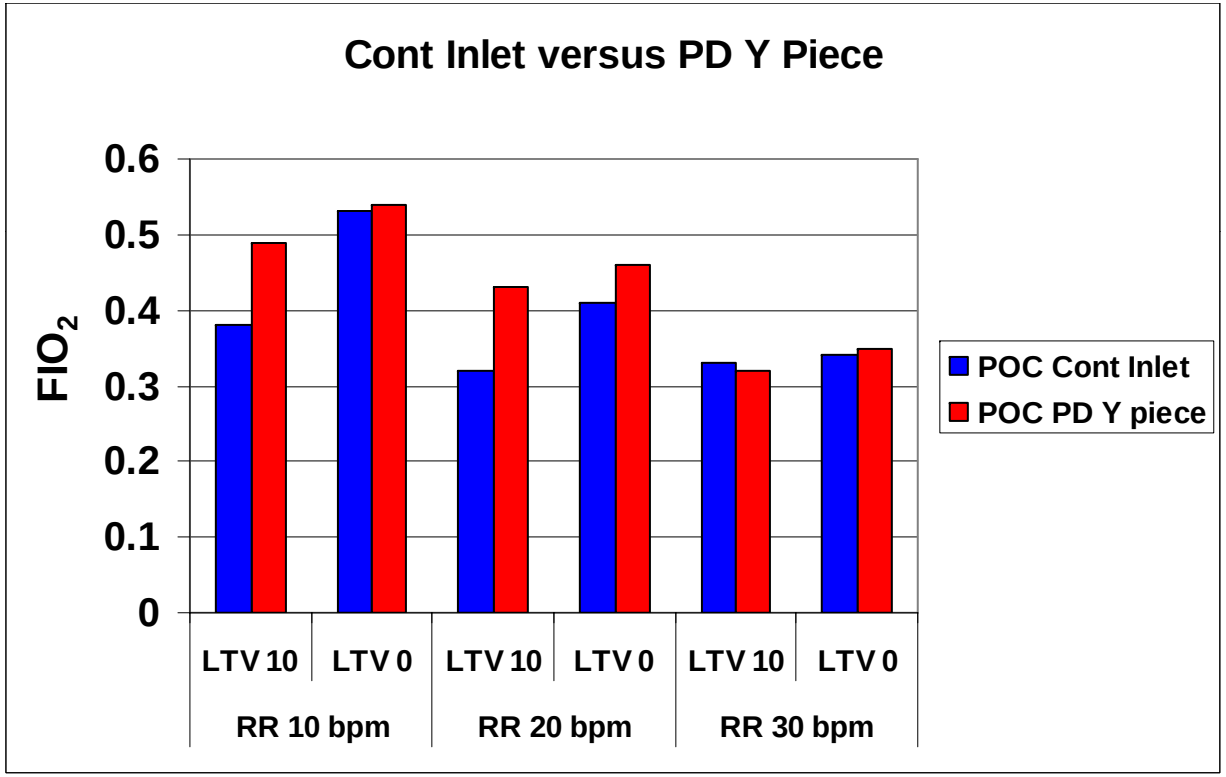




Pressure Control Ventilation 3 lpm vs. Max Pulse Dose Results



With and without bias flow

Perceived Benefits/Limitations

- Portable/lightweight
- Limitless oxygen use
- Current units capable of providing sufficient oxygen concentration for majority of combat casualties
- Potential for oxygen availability in any transport scenario
- Does not eliminate need for compressed gas
- 100% oxygen **is not** possible – may need small ‘back-up’ cylinder
- Alarm function limited

Where to Next?

- Potential methodology
  - Our current method (pneumatic)
    - Education paramount to appropriate delivery of tidal volume
    - Risk of inappropriate alarm capability
  - Communication link between units (electronic)
    - Vent would adjust function in case of concentrator malfunction
    - More accurate control of FIO_2
  - Ideal: Integrated design of oxygen concentrator within ventilator (composite)
    - Ventilator controls function of concentrator relative to vent settings

THANK YOU

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