



Optimizing Gas Exchange through Monitoring Functional Residual Capacity for a Ventilated Trauma Patient

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While most hospitals have emergency departments that are always open, Community Regional Medical Center's (CRMC) Table Mountain Rancheria Trauma Center is the only ACS verified Level 1 trauma center in the 15,000 square-mile service area between Sacramento and Los Angeles.

What sets CRMC's Level 1 trauma center apart from regular emergency departments is that they have the specialists and equipment required to treat serious life-threatening injuries 24 hours a day, seven days a week. Having the trauma team always ready, instead of "on their way," can be the difference between life and death for critically injured patients.

When CRMC selected the GE Ventilator for use in their Trauma, Burn, Neuro and Step-down ICU units, it was critical to include the respiratory gas module on all 75 ventilators purchased. The decision was driven by CRMC's desire to better monitor gas exchange for its most critical patients. The following case study demonstrates the value of monitoring functional residual capacity (FRC), even in patients that have no underlying pulmonary disease.

Case Study

Subject: The patient is a 27-year-old male with a head injury. His mental status was altered and combative at the scene and was taken to Community Regional Medical Center for further evaluation. The patient arrived in the ED with a Glasgow Coma Scale (GCS) of 7 and was intubated (Figure 1).



Figure 1 – Initial chest film in ED. The endotracheal tube and NG tube are in good position. The size of the cardiac silhouette is within normal limits. The pulmonary vasculature is not congested. The lungs are clear.



Overview

Measuring FRC using the GE Ventilator with Respiratory Gas Module is quick and efficient for the clinician.

- FRC assessment requires only ~20-40 breathes
- Minimal FiO₂ adjustments are required
- Real-time data allows clinician to see early changes, intervene, and guide therapy

About CRMC

Community Regional Medical Center is the flagship of Community Medical Centers' three acute-care facilities, with 641 licensed beds and an average of 604 inpatients a day.

This academic-affiliated medical center is located on a 58-acre campus in downtown Fresno. With a full-service, 56,000-square-foot emergency department – one of the largest in California – it's home to the Table Mountain Rancheria Trauma Center and Leon S. Peters Burn Center – the region's only comprehensive burn and Level 1 trauma centers.

Computerized Tomography (CT) images revealed a traumatic brain injury with multiple intracranial hemorrhages (see Figure 2). The patient was taken to the operating room emergently for a right craniotomy for evacuation of epidural hematoma and left craniotomy and craniectomy for acute subdural hematoma with malignant brain swelling.

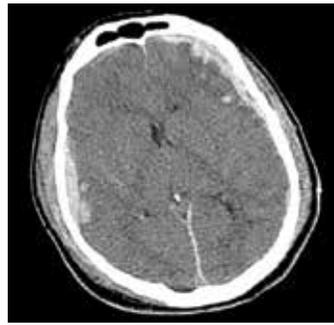


Figure 2 – CT image showing extensive bilateral hemorrhage noted which is compatible with subdural and epidural hemorrhages.

After surgery, an intracranial pressure (ICP) monitor (bolt) was placed and transported to the Surgery Intensive Care Unit (SICU). The patient was placed on the following ventilator settings: Pressure Control Ventilation-Volume Guarantee (PCV-VG), tidal volume (VT) 500 mL, rate 14/min, positive end-expiratory pressure (PEEP) 5 cmH₂O, fraction of inspired oxygen (FiO₂) 1.0.

Chest films were ordered each day and routine ventilator measurements were recorded every four hours. FRC was measured approximately every eight hours. We indexed FRC to the relative predicted FRC formula. Men: $[0.0472 \times \text{height (cm)}] + (0.0090 \times \text{age}) - 5.290$. We calculated this patient's FRC at 2.7 Liters (L).

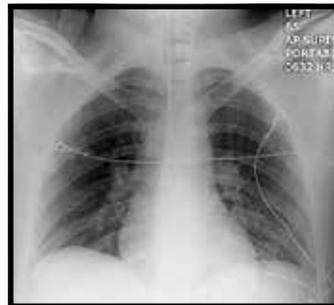


Figure 3 – Day 2. The lungs are clear.

Initial baseline FRC was 1.7 L (63% of predicted). Tidal volume was increased to 550 mL due to PaCO₂ of 44 mmHg above prescribed range (35-40 mmHg). FRC increased to 1.8 L. FRC around 0300 decreased to 1.6 L reducing to 59% of predicted (Table 1).

Table 1 – Ventilator settings and measurements.

Day/Time	VT	PEEP	Lung Comp.	P _{AW}	P:F	FRC Meas.	FRC%/Pred.
2/0700	500	5	50	8	307	1.7	0.63
2/1500	550	5	62	8	433	1.8	0.67
2/1900	550	5	50	8	N/A	1.8	0.67
3/0300	550	5	44	9	517	1.6	0.59

The patient remained stable with good oxygenation, respiratory system compliance and clear chest films (figure 4).

However, on day 3, FRC had declined to 1.2 L (44%) from 1.6 L on the same ventilator settings. Later that day, around



Figure 4 – Day 3. The lungs remain clear.

1400 hrs, the Respiratory Care Practitioner (RCP) was called to the bedside for a decline in patient's SpO₂ (87%) on 0.3 FiO₂. The RCP increased the PEEP from 5 to 8 cmH₂O and FiO₂ from 0.3 to 0.4. SpO₂ increased to 95%. Two hours later, FRC was measured and increased from 1.2 L to 1.4 L after the PEEP change.

During the same shift, the RCP was called again (0100 hrs) to the bedside for desaturation (86%) and FiO₂ was increased to 0.5. An arterial blood gas (ABG) was drawn with the following results: pH 7.36, PaCO₂ 41, PaO₂ 64, BE -1, SaO₂ 89%, PaO₂/FiO₂ = 128 mmHg. PEEP was raised to 10 cmH₂O. FRC at 0300 measured at 0.93L (Table 2).

Table 2 – Ventilator settings and measurements (Day 3).

Day/Time	VT	PEEP	Lung Comp.	P _{AW}	P:F	FRC Meas.	FRC%/Pred.
3/0700	550	5	46	8	N/A	1.2	0.44
3/1600	550	8	58	10	433	1.4	0.52
4/0300	550	10	52	12	128	0.93	0.34

The desaturation events were discussed with the surgery team and were likely caused by ventilation to perfusion mismatch in the right lung base (see Figure 5). Interestingly, the FRC showed declination approximately 24 hours before the first desaturation event.

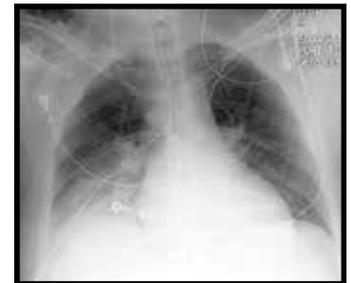


Figure 5 – Day 4. There is atelectasis in the right lung base. The left lung is clear.

Due to the low PaO₂/FiO₂, the surgery attending ordered Airway Pressure Release Ventilation (APRV).

Initial APRV settings were as follows: Mode: Bilevel, P-High 26, P-Low 0, T-High 6.0, T-Low 0.6 (65% of Peak Expiratory Flow Rate [PEFR]) and FiO₂ 0.6. Two hours later, FRC was measured at 2.8 L (1.04% of predicted) and nine hours later, FRC increased to 2.9 L (see Table 3).

Table 3 – FRC measurements after airway pressure release ventilation.

Day/Time	P-High	Lung Comp.	P:F	FRC Meas.	FRC%/Pred.
4/1000	26	45	N/A	2.8	1.04
4/1900	28	29	202	2.9	1.07
5/0800	28	33	353	3.01	1.11

FRC increased to over 100% of predicted as expected, however, this may not be optimal due to the indexed FRC for the upright position (see Figure 6). Most ventilated patients are in the supine or semi-recumbent position which reduces FRC.



Figure 6 – Day 5. Bilateral mid and lower lung parenchymal opacities. The upper lung zones remain clear. No new focal infiltrates identified.

As FRC continued to exceed the predicted value and gas exchange showed improvement, P-High and T-High were weaned by the “drop and stretch method”¹ and PaO₂/FiO₂ ratio increased to 353 mmHg from 202 mmHg. A chest film was taken approximately 7 hours later on APRV (see Figure 7).



Figure 7 – Day 5. Seven hours later on APRV, no evidence of acute cardiopulmonary disease. The lungs are clear.

Over the next 6 days, APRV continued to be weaned gradually until P-High reached 14 cm H₂O and T-High 10 seconds. Lungs remained clear (Figure 8) and a spontaneous awakening trial (SAT) and spontaneous breathing trial (SBT) were conducted. However, with an unstable GCS, the team anticipated the patient would not tolerate extubation at this time.



Figure 8 – Day 12, prior to extubation. Lungs are clear.

Outcome: On day 13, GCS had improved to 10T. A SBT was performed with success and the patient was extubated to nasal cannula. The patient’s mental status continued to improve and was weaned to room air the next day. A follow-up chest film was taken and the lungs remained clear (Figure 9). The patient was transferred to a rehabilitation unit two days later.

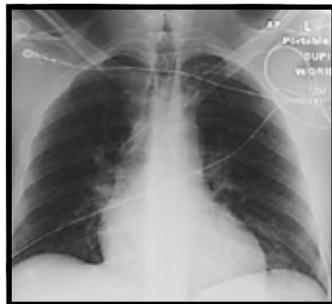


Figure 9 – Day 13, following extubation. Lungs are clear.

Discussion

FRC is the resting lung volume at end-expiration, however, when a patient is lying in the supine or semi-recumbent position, FRC is decreased up to 25%.² Positive end-expiratory pressure (PEEP) is generally used to stabilize alveolar volume, minimize dead space-to-tidal volume ratio (VD/VT) and, theoretically, increase FRC. Depending on the method chosen to set optimal PEEP, the challenge is to consistently monitor the PEEP level because patient illness severities are higher today and dynamically changing minute-to-minute. Preserving normal FRC is crucial for optimizing gas exchange during positive pressure ventilation due to its role as the body’s physiologic reserve. By optimizing FRC, alveolar ventilation continues through diffusion without disruptions, and dead space-to-tidal volume ratio (VD/VT) is minimized. However, during an acute change in pulmonary status, such as atelectasis, gas exchange is affected and VD/VT increases (Figure 10).

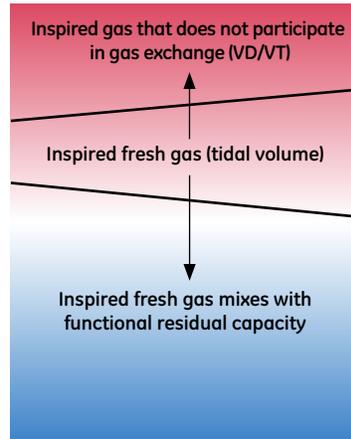


Figure 10 – Gas exchange is a continuous process, breathing just tops up the alveoli with a bit of fresh air from time to time. At the end of expiration the lungs still contain over 2 liters of air (this represents the functional residual capacity, or FRC), and inspiration during normal breathing at rest only adds 500 mL to the volume of air in the lungs. Approximately 150 mL of each breath is wasted in the conducting airways as dead space (VD), leaving 350 mL to contribute to the volume ventilating the alveoli (VA).

Computerized tomography (CT) is considered the gold standard to measure FRC in ventilated patients,^{3,4} but this practice is not available or impractical for routine application after every ventilator change. At CRMC, monitoring disease progression is made simpler with the GE Ventilator and respiratory gas module.

Conclusion

Measuring functional residual capacity (FRC) can be an essential tool to assess the pulmonary status in patients with acute respiratory failure requiring mechanical ventilation.⁵ FRC can assist in assessing if alveolar ventilation and pulmonary perfusion are optimally matched. Unfortunately, there is no current data establishing a ‘gold standard’ for indexing normal FRC values for ventilated patients. This case study highlights the usefulness of how measuring FRC can identify lung derecruitment as an early indicator and guide ventilator management to optimize gas exchange while indexing to FRC predicted values. Further randomized, controlled trials are needed to determine the optimal FRC with ventilated patients.

How GE measures FRC

Accurate measurement of FRC previously required that the patient be conscious and spontaneously breathing. This changed with the GE Ventilator and the Respiratory Gas Module. Now the FRC measurement is made based on monitoring the change of N₂ (nitrogen) concentration measured at the airway (Modified Nitrogen Dilution method). The concentration of inspired nitrogen is changed by the delivered FiO₂ concentration. A comparison study was conducted that demonstrated “excellent concordance between FRC-WI/WO and FRC-CT” using the GE Ventilator and Respiratory Gas Module.⁶



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Wade is the clinical educator for Respiratory Care Services at Community Regional Medical Center, Fresno, CA. Wade is an active member of the AARC and committed to clinical research in the use of FRC with mechanical ventilation to improve patient outcomes.



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Wil is the Director of Respiratory Care Services at Community Regional Medical Center, Fresno, CA. He manages 140 full-time equivalents, serving a Level 1 Trauma Center & Emergency Department, Level 1 Burn Unit, Level 3 NICU, NICU Transport Team, Surgical, Medical, Neuro, and Cardiovascular ICUs, Pulmonary Rehab, Asthma Education, and Step-Down Units.

Imagination at work

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