Case Report

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Non-invasive respiratory volume monitoring in patients with traumatic thoracic injuries

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Abstract

Background: Respiratory decompensation is common after traumatic thoracic injuries such as multiple rib fractures and pulmonary contusions. A continuous, non-invasive, impedance-based respiratory volume monitor generates right and left tidal volume measurements, reflecting air exchange in the lungs and derives an instantaneous respiratory rate. The feasibility of using unilateral respiratory volume monitor–based tidal impedance measurements to monitor respiratory status in trauma patients is evaluated.

Methods: Three intensive care unit patients with three or more rib fractures following blunt trauma had continuous respiratory volume monitor measurements with a novel non-invasive impedance-based device (ExSpiron, Respiratory Motion Inc., Waltham, MA) and corresponding clinical data to permit analysis. Tidal impedance measurements were collected from both the injured and non-injured sides and converted into bilateral respiratory volume monitor measurements using advanced algorithms.

Results: In Patient 1, following evacuation of a pneumothorax, the respiratory volume monitor showed a significant increase in tidal measurements coupled with a compensatory decrease in tidal measurements on the uninjured side and a decrease in respiratory rate. In Patient 2, tidal measurements were only slightly decreased on both the injured side and uninjured side; respiratory rate remained unchanged. This patient remained stable and required no intervention. Patient 3 demonstrated a sustained decrease in tidal measurements on the injured side that corresponded with radiograph findings and clinical deterioration leading to the need for endotracheal intubation.

Conclusions: The results from these cases demonstrate that respiratory volume monitor can generate unilateral respiratory tidal measurements and respiratory rate in patients with traumatic thoracic injuries. Continuous respiratory volume monitor in patients with thoracic trauma has strong potential for application in the military, aeromedical, and other austere environments where respiratory monitoring is problematic. Future studies to investigate the utility of this technology are warranted.

Keywords

Respiratory monitoring, thoracic trauma, rib fractures, impedance monitoring, non-invasive pulmonary monitoring

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Background

Traumatic thoracic injuries are common in both civilian and military trauma and have a high associated morbidity and mortality.[1] Providers in austere locations have limited options for the early detection and management of thoracic trauma and its consequences. During combat operations and in environments with limited resources, the physical examination is frequently limited and access to radiological studies is often infeasible. Intermittent, manual measurements of respiratory rate and auscultation of lung sounds are the current standard for monitoring respiratory status, but these techniques are inconsistent and difficult to perform accurately in the forward-deployed and *en route* military setting.[2] Closer monitoring of respiratory parameters that quantify the adequacy of breathing may help identify patients at risk for adverse outcomes in a variety of military and civilian settings. Advanced respiratory monitoring in patients with traumatic thoracic injuries such as rib fractures, pulmonary contusions and pneumothoraces could improve outcomes through the early detection of deterioration in respiratory function in a situation where clinical and radiological evaluation is restricted. Furthermore, thoracic injuries are frequently associated with asymmetry of lung function, and few technologies exist to accurately and rapidly identify unilateral thoracic pathology.

Currently, there are no lightweight, durable, noninvasive point-of-care monitors with the capability to conveniently and accurately measure respiratory parameters.[2] With the advent of improved computing and refinement of complex waveform analyses, impedance methods have recently been reintroduced as a non-invasive modality for the monitoring of respiratory parameters in a variety of critical care settings.[2,3] Previous techniques were limited by the assumption of symmetric pulmonary physiology in reference to the calculation of overall tidal volume and minute ventilation measurements. A non-invasive impedance-based respiratory volume monitor (RVM) has been developed to provide continuous measurements and graphical trends of minute ventilation (MV), tidal volume (TV), and respiratory rate (RR).[2] This device has been shown to have clinical accuracy, acceptable bias, and a high level of precision in a study of voluntary subjects with a wide range of RRs.[2] Such a monitor has the potential to improve patient care, assist in the diagnosis of evolving pulmonary pathology, and provide an objective measure of therapeutic efficacy.

The feasibility of using bi-lateral RVM-based tidal impedance measurements to monitor respiratory status in trauma patients is evaluated in these cases. It was hypothesized that the RVM can detect subtle trends in diminished respiratory function in patients with thoracic injuries, and identify those at high risk for respiratory decompensation.

Figure 1. Example of BiRVM lead placement. Two electrodes are placed at the sternal notch, and two electrodes on the left and right sides in the mid-axillary line at the level of the xiphoid.

Methods

The Facility Institutional Review Board (IRB) approved this study. All subjects provided written informed consent. Non-intubated adults (age >18) admitted to an intensive care unit (ICU) with three or more rib fractures from blunt trauma were included. Standard electrode placement (Figure 1) consisted of two electrodes at the sternal notch, two electrodes on the right side at the level of the xiphoid and two electrodes on the left side at the level of the xiphoid. Deviations from the standard placement to accommodate chest tubes and dressing were noted and documented. Tidal impedance measurements were collected from the injured side as well as the non-injured side and converted into bilateral RVM measurements (TM_L and TM_R) using advanced algorithms. The RVM displays a real-time respiratory volume curve and provides trends of the measurements. The RVM calculates mean TV measurements, calculated by dividing MV by RR ($TV = MV/RR$). With the recommended electrode placement and calibration algorithms in a unilateral configuration, strong correlations (0.96 ± 0.16, mean $\pm$ 95% confidence intervals [CI] for regular and erratic breathing) between RVM and spirometric measurements have been demonstrated.[2,4] Continuous respiratory data were collected over 10–12 hours.

Case reports

Three ICU patients with three or more rib fractures following blunt trauma were enrolled within 48 hours of admission. Rib fractures were diagnosed by plain chest radiographs and confirmed by computed tomography. All three patients had left-sided thoracic injuries. Clinical features of the included patients are summarized in Table 1.

Patient 1

A 48-year-old male smoker sustained fractures of the left 3rd–6th ribs after a motor vehicle crash. Shortly after arrival in the emergency department, vital signs showed: heart rate 75, blood pressure 80/60, RR 14, O_2 saturations of 93% on room air, and temperature of 98.8°F. A chest thoracostomy tube was placed for a left-sided pneumothorax. Following evacuation of the pneumothorax, the RVM showed a significant increase in TM_L on the side of the injury ($p < 0.05$, Figure 2(a)) coupled with a compensatory decrease in TM_R of the uninjured right lung and a significant decrease in RR ($p < 0.01$, Figure 2b). This patient did not require endotracheal intubation.

Table 1. Clinical features of patients monitored with the respiratory volume monitor (RVM) system.

Variables	Patient 1	Patient 2	Patient 3
Age	48	41	50
Gender	Male	Male	Male
Height (cm)	177.8	163	152
Weight (kg)	63.5	65	99
Injury location	Left 3–6	Left 6, 9, 10	Left 8, 10, 11
Glasgow Coma Scale (GCS)	14	15	15
History of cardiac or pulmonary disease	No	No	No
Vital signs			
Blood pressure (mmHg)	80/60	120/40	176/108
Heart rate (beats per minute)	75	89	87
Respiratory rate (breaths per minute)	14	20	20
Temperature (°F)	98.8	98.2	98.1
Chest tube	Yes	No	Yes
Concomitant medications	Yes	Yes	Yes
Intubation	No	No	Yes
Arterial blood gas results			
FiO_2	0.35	0.28	0.40
pH	7.41	[a]	7.32
PaO_2 (mmHg)	65	[a]	63
$PaCO_2$ (mmHg)	37	[a]	59
HCO_3-	26.9	[a]	30.4
Base excess	+3	[a]	+3
SpO_2 (%)	94	100	89

[a]Blood gas data not available for this patient.

Patient 2

A 41-year-old male sustained fractures to the left 6th, 9th, and 10th ribs in a motor vehicle crash. Vital signs on arrival in the ER were: heart rate 89, blood pressure 120/40, O_2 saturation was 100% on a non-rebreather mask, RR 18, and temperature 98.2°F. Initial RVM monitoring showed decreased tidal measurements in both the injured (TM_L, Figure 2c, blue) and uninjured side (TM_R, Figure 2d) with a slightly greater decrease on the left. Neither decrease was significant (both, $p > 0.06$). Respiratory rate was stable throughout. This patient remained stable and required no intervention.

Patient 3

A 50-year-old male sustained left-sided posterior 8th, 10th, and 11th rib fractures after a fall. Vital signs on arrival in the ER were: heart rate 87, blood pressure 176/108, O_2 saturation 100% on room air, RR 20, and temperature 98.1°F. An arterial blood gas indicated hypercarbia and hypoxemia (Table 1). As the patient was being prepared for endotracheal intubation, RVM data were collected, revealing a significant decrease in TM_L on the injured side ($p < 0.01$, Figure 2e, blue). Figure 3 shows representative 1-minute TM plots of continuous RVM data. TM_L decreased by 53% and TM_R decreased by 33% over the course of monitoring (Figure 3). RR did not increase significantly throughout the patient's period of clinical deterioration. RR did not increase to compensate for a falling MV.

Discussion

This series of three cases with multiple rib fractures demonstrates the feasibility of an impedance-based RVM for the monitoring of unilateral respiratory MV, TM, and RR. Continuous RVM monitoring provides a non-invasive, quantitative evaluation of unilateral lung function in real time. This technology can assist in the identification and management of respiratory compromise and the assessment of interventions for patients with thoracic trauma.

Just as the CT scanner[5] and other forward deployed point-of-care technologies have revolutionized the care of combat wounded patients,[6] future technologies such as RVM will be essential for diagnostic evaluations in

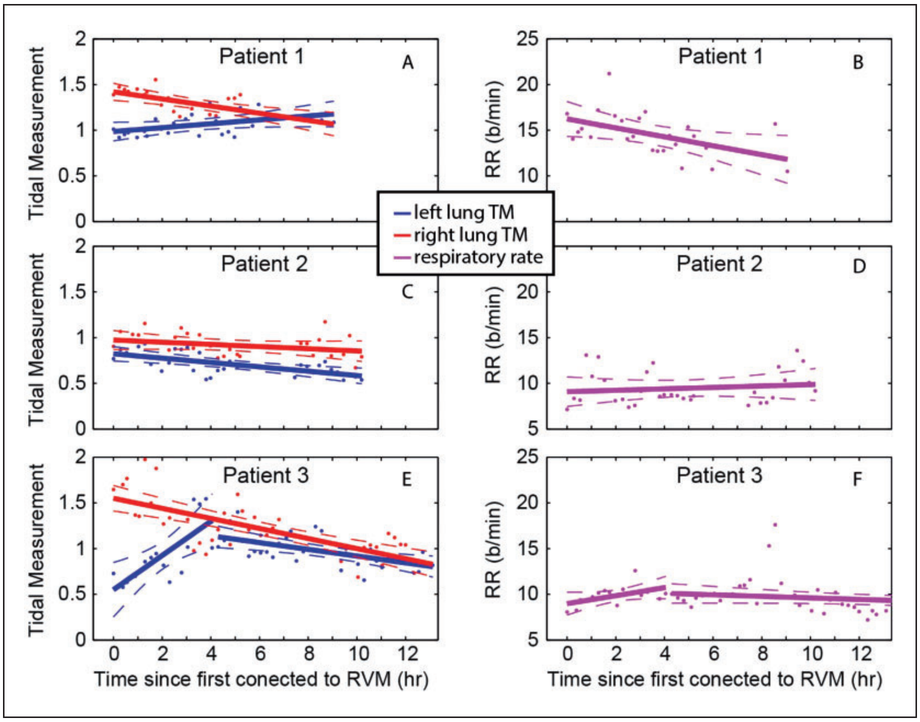

Figure 2. Continuous RVM unilateral tidal measurements (TML and TMR, arbitrary units) from left, injured (blue) and right, uninjured (red) lungs over 10–12 hours (a, c, e). Respiratory Rate (RR) over the same time period (b, d, f). *Patient 1* shows increase in TML of the injured left lung and compensatory decrease in TMR of uninjured right lung and decrease in RR associated with resolution of pneumothorax. *Patient 2* shows significant decrease in of both the injured left lung (TML) and the uninjured right lung (TMR) associated with worsening chest X-ray. *Patient 3* shows initial increase in (TML) in the injured lung followed by significant decrease in TI of both injured and uninjured lungs associated with generalized respiratory failure prior to intubation.

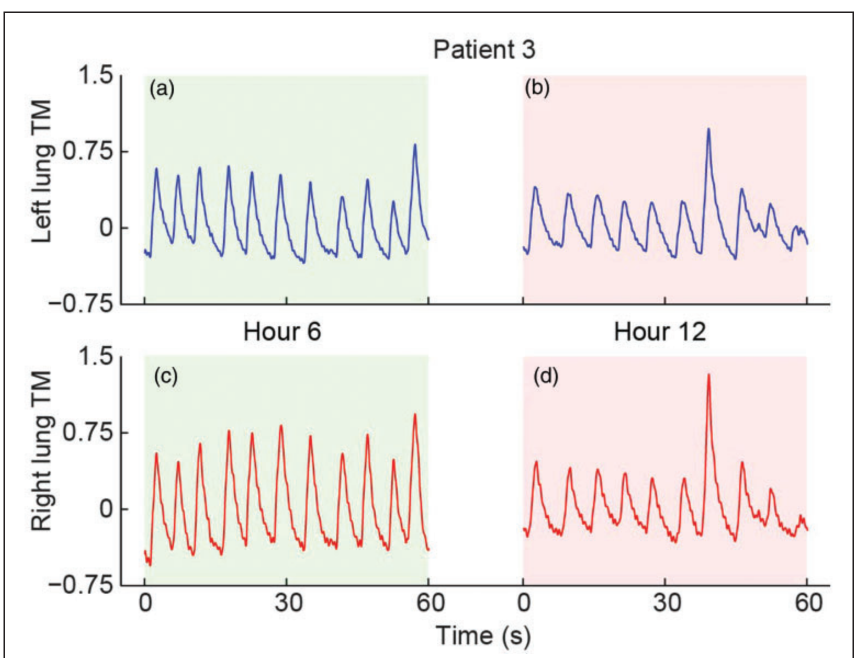

Figure 3. One-minute excerpts of RVM unilateral tidal measurements. Average unilateral RVM, TM_L of 0.85 and TM_R of 0.9 from hour 6 decreased to 0.4 and 0.6 at hour 12 in association with clinical deterioration. Note the occasional larger "sigh" breaths observed prior to intubation (b, d).

seriously injured trauma patients with thoracic trauma. Of the potentially survivable injuries observed during Operation Iraqi Freedom and Operation Enduring Freedom, airway compromise was the second most common etiology followed by tension pneumothorax.[7] Hence, prompt diagnosis and treatment of potentially survivable injuries remains a top priority for providers caring for patients in austere environments.

In this case series, each of the three patients demonstrated TM changes, but not necessarily RR changes, consistent with formally diagnosed thoracic injuries. RVM data for Patient 1 revealed an initially low TM_L of the injured lung with a compensatory increase in TM_R. After treatment of the pneumothorax, TM_L improved considerably, RR declined, and the patient did not require any further interventions. Hence, use of RVM in an austere setting could potentially be used to monitor responses to treatment such as tube thoracostomy placement; such monitoring might obviate the need for additional radiologic tests and closer clinical monitoring in an environment where fewer providers are available to monitor multiple casualties. In Patient 2, RVM data showed decreased TM_L on the injured side with a decrease in the uninjured right side. Importantly, RR did not change significantly in this patient, even though the patients bilateral tidal measurements were decreased. In similar patients, RVM might serve as an early warning point-of-care test that could be used when standard vital signs are potentially misleading and confounded by other clinical factors such as the effects of sedatives and analgesics. In Patient 3, initial RVM data showed an initial improvement in TM_L on the injured side, although over time, the patient deteriorated clinically, without a significant associated rise in RR. In patients at risk for generalized respiratory failure as a result of thoracic injuries, RVM holds promise for trending of critical TM data that would otherwise be undetectable without bulky, invasive equipment.

As a case series, this study has obvious limitations. Arterial blood gas results were not collected as part of this case series and spirometry was not employed. The correlation of TM changes with additional physiological parameters remaining the focus of ongoing work in this area.

As a diagnostic modality, RVM must be subject to the same methodological and analytical scrutiny required for all diagnostic tests. In a larger patient population, comparisons with spirometry and physiological variables must be analyzed for accuracy, level of agreement, bias, sensitivity, and specificity.

Conclusions

The results from this pilot study demonstrate that RVM can generate unilateral respiratory tidal measurements and respiratory rates in patients with traumatic thoracic injuries. Continuous RVM in patients with thoracic trauma may have potential for application in the military, aeromedical, and other critical care environments where respiratory monitoring is problematic. Larger studies to investigate the utility of this technology are warranted.

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Conflict of interest

Drs Brayanov, Ladd, and Freeman are employed by Respiratory Motion, Inc. Drs Galvagno, Corneille, Voscopoulos, and Sordo declare no conflict of interest.

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