Title

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Journal

CHEST Journal, 148(4)

ISSN

0012-3692

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Publication Date

2015-10-01

DOI

10.1378/chest.2281731

Peer reviewed

AUTOMATED MECHANICAL VENTILATOR WAVEFORM ANALYSIS OF PATIENT-VENTILATOR ASYNCHRONY

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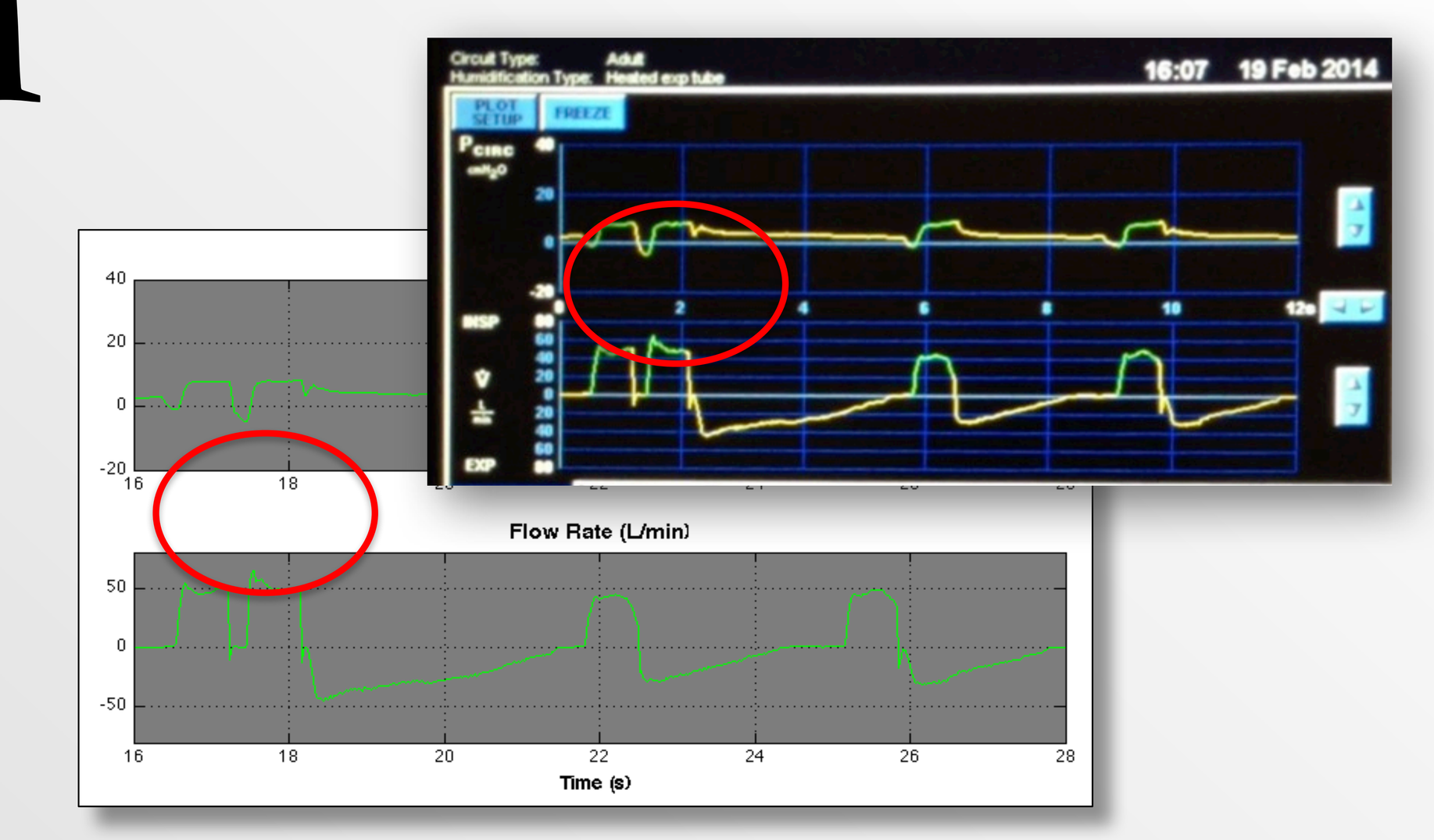


Purpose

Mechanical ventilation is a life-saving intervention but is also associated with adverse effects including ventilator-induced lung injury (VILI). Patient-ventilator asynchrony (PVA) is thought to contribute to VILI, but the study of PVA has been hampered by limited access to the high frequency, large volume data streams produced by modern ventilators and a lack of robust PVA analytics. To address these limitations, we developed an automated pipeline for breath-by-breath analysis of mechanical ventilator waveform data.

Methods

Simulated pressure and flow time series data representing normal breaths and common forms of PVA were generated on mechanical ventilators, collected unobtrusively using wireless peripheral devices, and transmitted to a networked server for storage and analysis. Two critical care physicians reviewed waveforms to generate gold standard data sets of PVA events. Rule-based algorithms were developed to quantify inspiratory and expiratory tidal volumes (TV) and identify common PVA subtypes including double trigger and delayed termination asynchrony. Data were split randomly into derivation and validation sets. Algorithm performance was compared with ventilator reported values and clinician annotation.

Common Patient-Ventilator Asynchronies and "Artifacts"

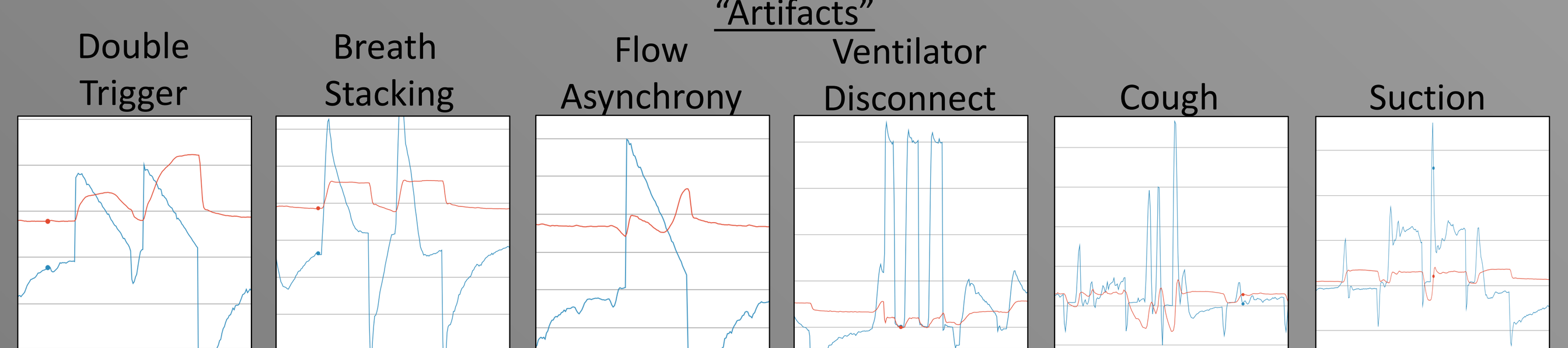


Figure 2: Derivation and validation of double trigger algorithm

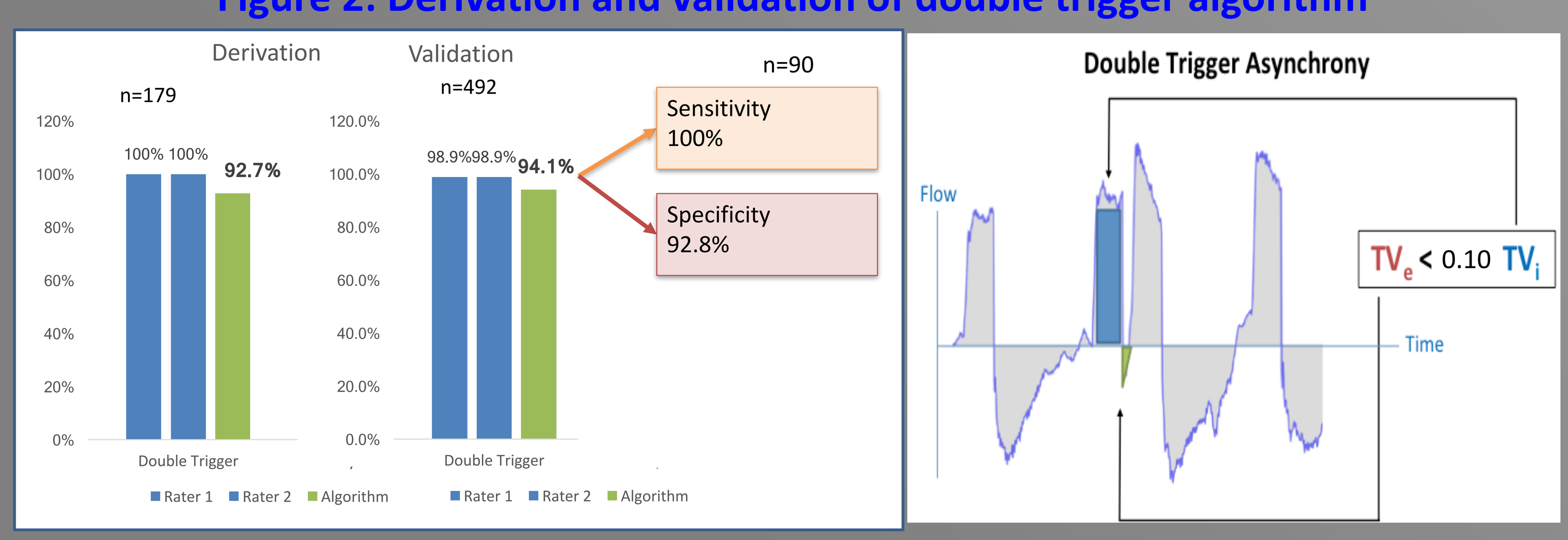


Figure 1: Bedside to Cloud mechanical ventilator waveform pipeline

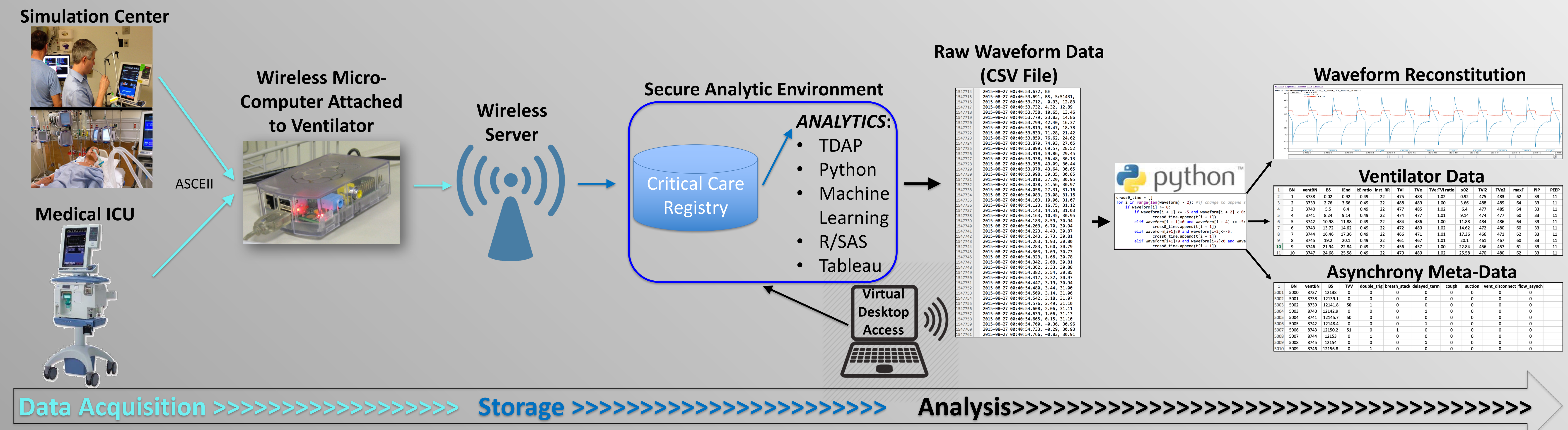


Figure 3: Charted tidal volumes compared to continuously recorded tidal volumes of a subject with ARDS, subsequently treated with neuromuscular blockade

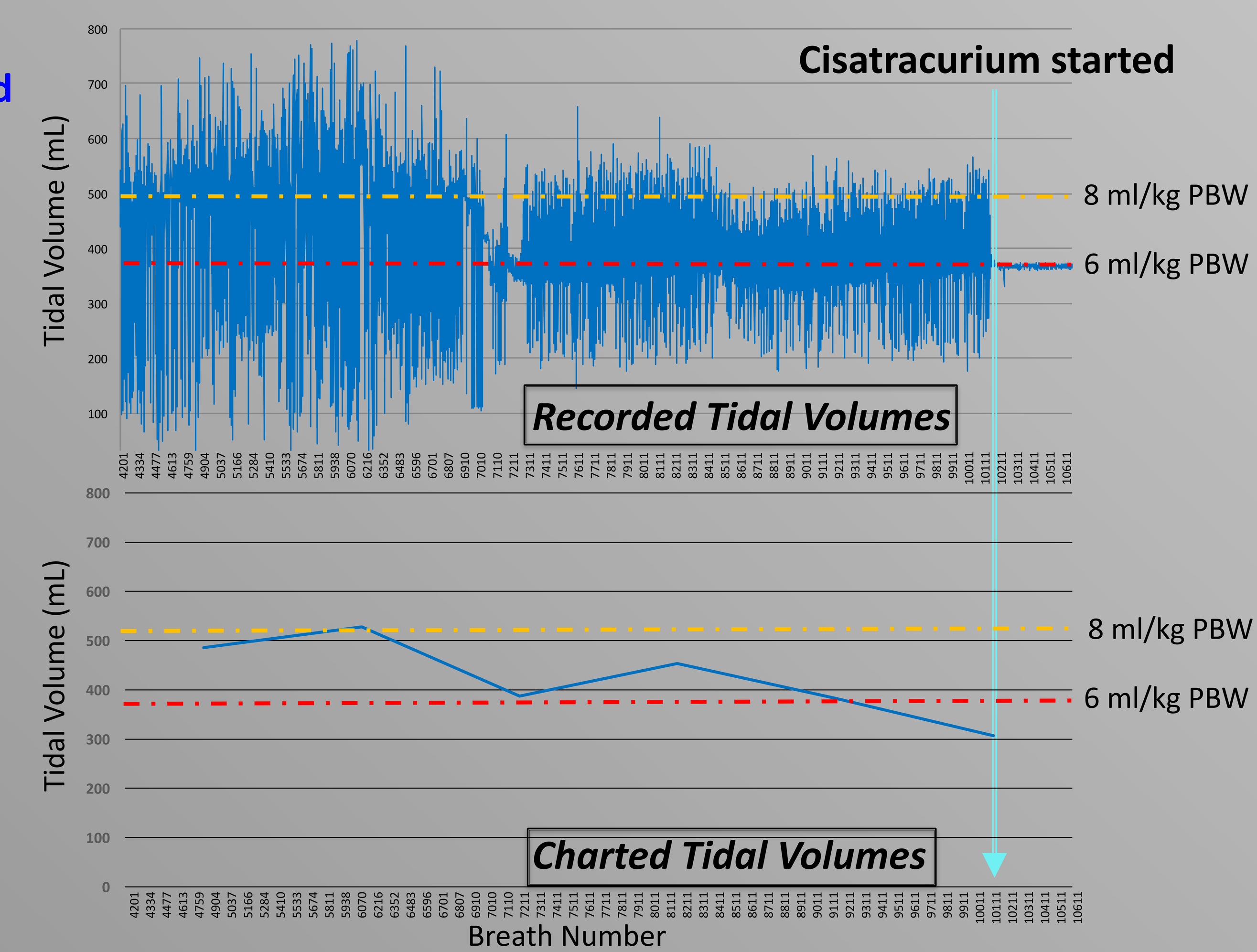
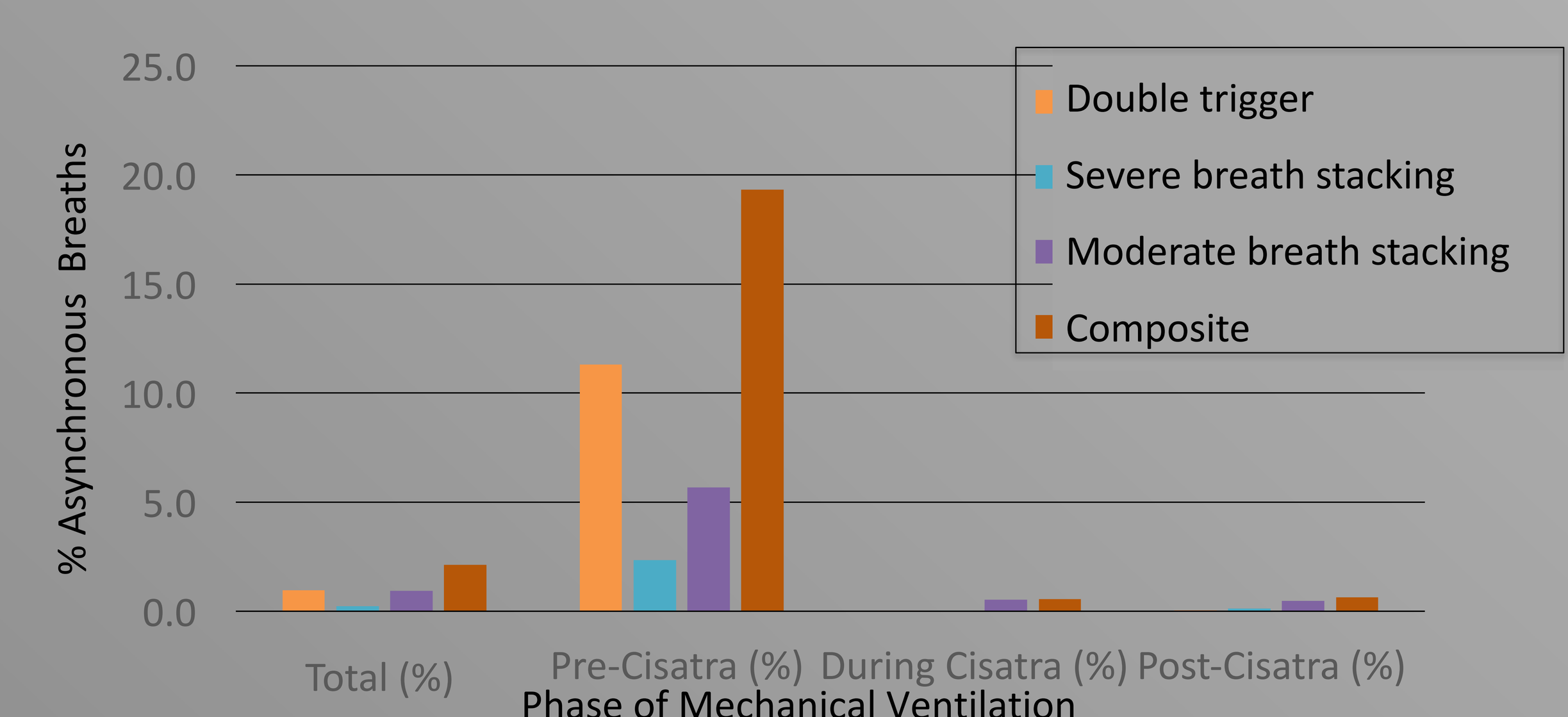


Figure 4: PVA frequency pre and post cisatracurium. Severe breath stacking is defined as TVe:TVi 10 to 33%. Moderate breath stacking defined as as TVe:TVi 33 to 67%.



Results

The mean difference between algorithm-determined and ventilator-reported TVs was 3.1% (99% CI ± 1.36%). Algorithm agreement with clinician annotation was excellent for double trigger PVA and moderate for delayed termination PVA, with Kappa statistics of 0.85 and 0.58, respectively. In the validation data set (n = 492 breaths), double trigger asynchrony was detected with an overall accuracy of 94.1%, a sensitivity of 100%, and a specificity of 92.8%.

Conclusions

A pipeline combining wireless ventilator data acquisition and rule-based signal analysis algorithms informed by the principles of bedside ventilator waveform analysis allows for accurate, automated, quantitative breath-by-breath analysis of patient-ventilator interactions.

Clinical Impact

- Improved classification and automated identification of double triggers, tidal volume, and other common types of PVA allowing more robust analysis of injurious patient-ventilator interactions
- Future plans include:
  - Expansion to all mechanically ventilated patients at UCDMC, including the emergency department
  - Comparison of rules-based algorithms to machine based learning algorithms
  - Outcomes correlation to PVA/TV metadata

Scan QR code for access to references via Dropbox.com