# AUTOMATION IN MECHANICAL VENTILATION

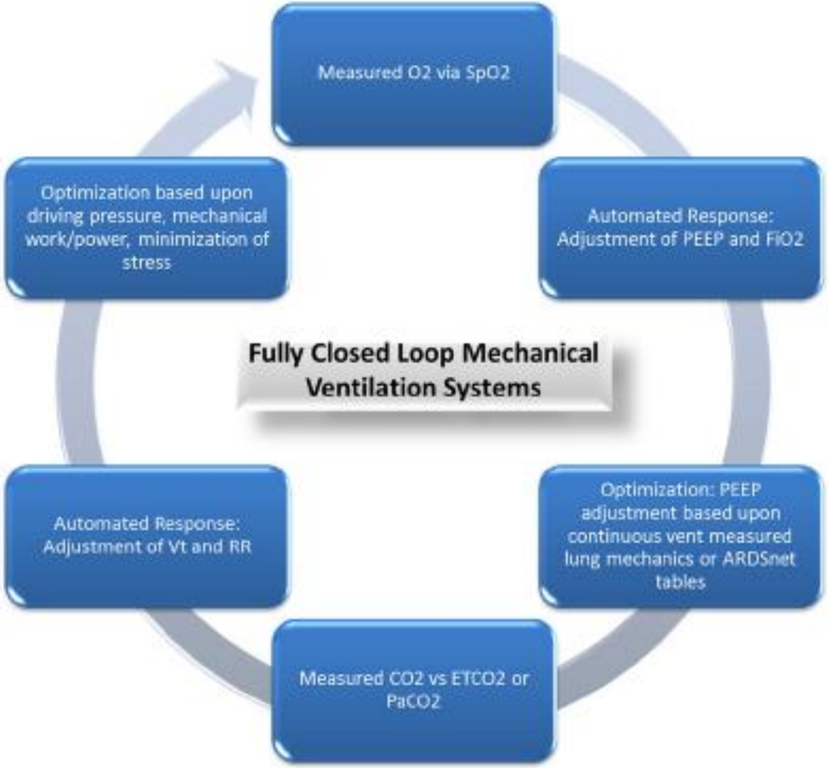
ELIAS BAEDORF KASSIS, MD

Beth Israel Deaconess Medical Center

A teaching hospital of Harvard Medical School

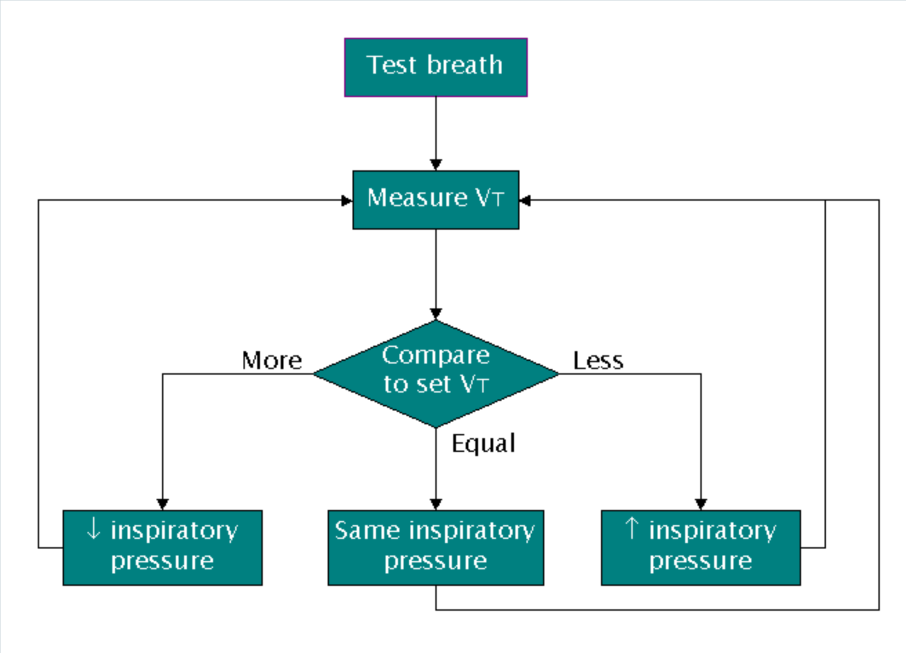
# Closed Loop Ventilation

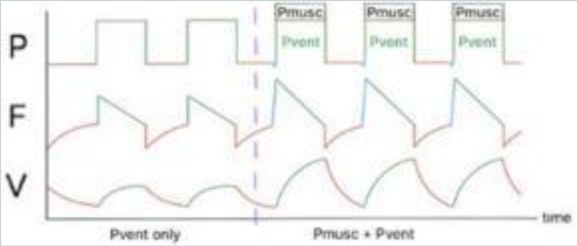
- Most "advanced" vent modes use some degree of closed loop adjustment
- Feedback from patient to automatically adjust vent parameters

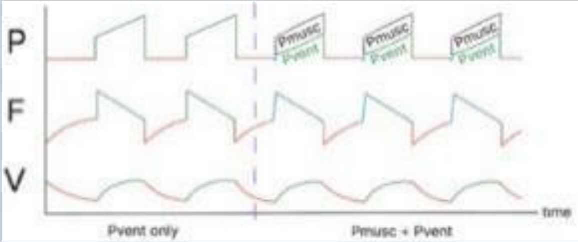


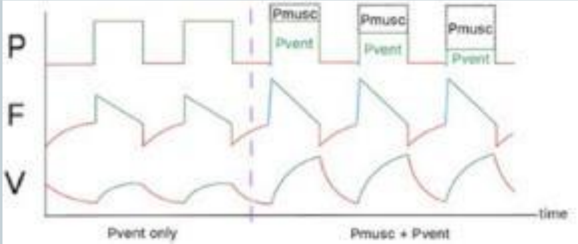

Baedorf Kassis and Talmor. 2021. Encyclopedia of Respiratory Medicine, 2nd Edition https://doi.org/10.1016/B978-0-08-102723-3.00214-6

# (sort of advanced)Pressure Regulated Volume Control



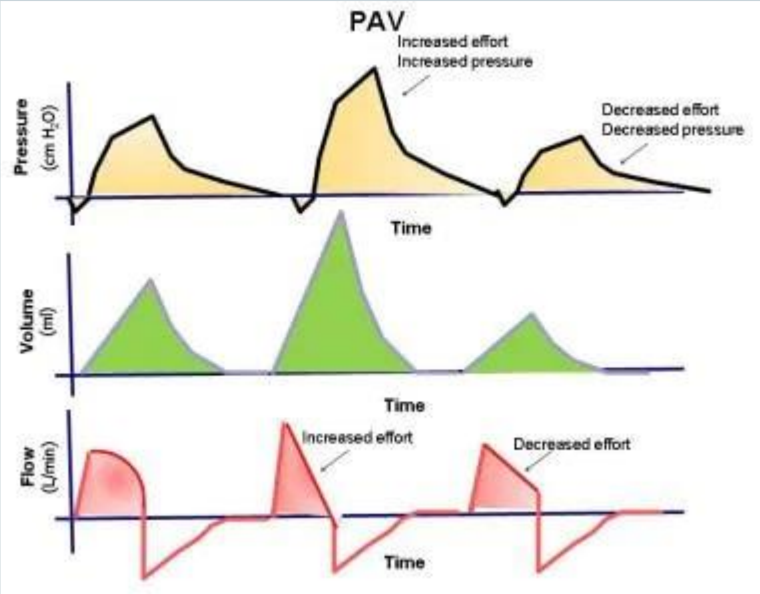
# PRVC – who cares?

| Pros | Cons |
| --- | --- |
| • Potential balance of the good aspects of PC and VC<br>• No fixed flow pattern<br>• Potentially more comfortable<br>• Less “flow asynchrony” | • Allows higher Vt than set with active breathing<br>• Potential worsening of some types of dyssynchrony<br>• Many clinicians don’t understand how it works |

# Proportional Assist Ventilation

- Alternate mode for spontaneous breathing during mechanical ventilation
- Continuous measurement of compliance and resistance
- Measurement of patient effort based upon deviations in flow/pressure

- Support then increases or decreases relative to effort (Partial Closed Loop)
  - High effort indicates more support needed
  - Lower effort indicated less support needed
- Potentially improves ventilator synchrony
- Potentially limited with auto-PEEP
- Do all patients with large efforts need MORE support?



# Neurally adjusted ventilator assist (NAVA)

- Basically PAV, but uses diaphragm electrical signals
- Synchronizes initiation of patient effort and degree of effort.
  - Rapid detection of diaphragm electrical activity to trigger
  - Assessment of neural effort and subsequent adjustment of assistance with each breath
- Possible decreases in dyssynchrony
- Unclear if much additional benefit over traditional pressure support
- Potential value in COPD
  - Patients with auto-PEEP -> masks airway pressure and flow changes which delay triggering and the vent sensing efforts

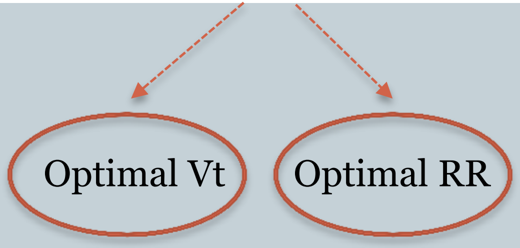
# Other Automated Modes

- Smartcare/PS
- Mandatory Rate Ventilation (MRV)
- Automode

# Breathing Power (Initial ASV algorithm)

- "Optimal breathing frequency" in unassisted breathing
- Equation of motion derivation
- Solved to minimize breathing effort (called breathing power - or the rate of muscular work)

$$f_{BP} = \frac{-1 + \sqrt{1 + \frac{4 \cdot \pi^2 \cdot RC \cdot MV_A}{V_D}}}{2 \cdot \pi^2 \cdot RC}$$




Otis. (1950) J Appl Physiol 2(11):592–607
Mead J (1960) J Appl Physiol 15(3):325–336

# ASV Time Constant

$RC_{exp}$ = Compliance(ΔVolume/ ΔPressure) x resistance(ΔPressure/ΔFlow)

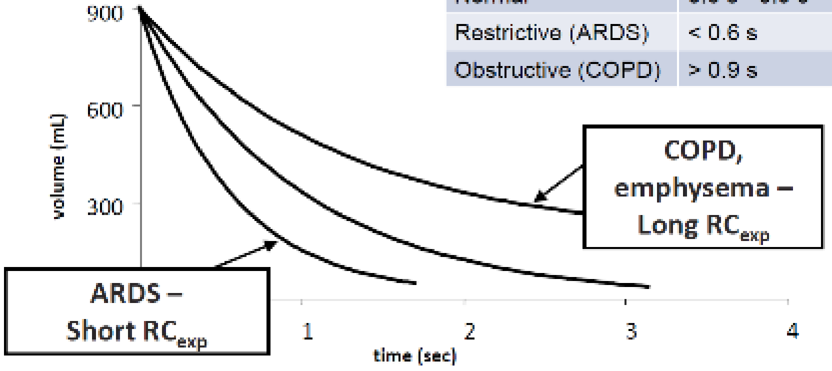
**$RC_{exp}$ = ΔVolume / ΔFlow - assumes equal resistance throughout breath**

## Expiratory time constant ($RC_{exp}$)

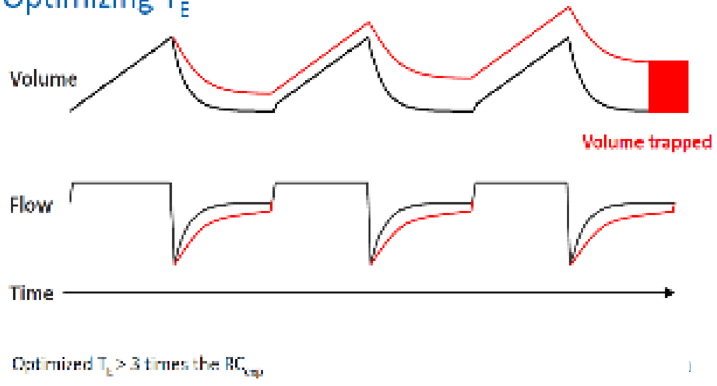
- 1 x $RC_{exp}$ 63% of VT
- 2 x $RC_{exp}$ 86.5% of VT
- 3 x $RC_{exp}$ 95% of VT

## Expiratory time constant

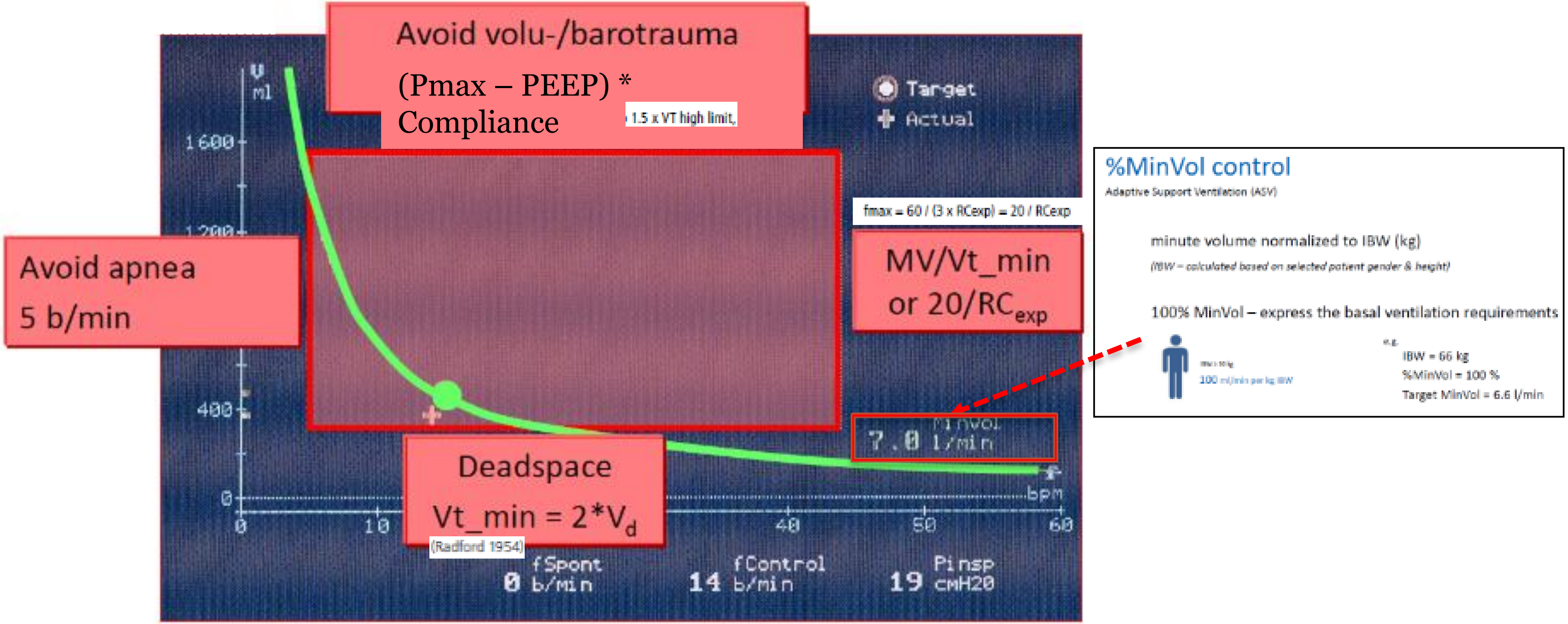
| Lung condition | $RC_{exp}$ |
|---|---|
| Normal | 0.6 s - 0.9 s |
| Restrictive (ARDS) | < 0.6 s |
| Obstructive (COPD) | > 0.9 s |




## Optimizing $T_E$



# ASV Safety Graph



# ASV Evidence - Weaning

A randomized controlled trial comparing the ventilation duration between Adaptive Support Ventilation and Pressure Assist/Control Ventilation in medical patients in the ICU

Kirak

Ches

PMID

Adaptive support ventilation for faster weaning in COPD: a randomised controlled trial

Kiral

Eur I

PMII

Adaptive support ventilation for fast tracheal extubation after cardiac surgery: a randomized controlled study

Sulze

Anest

PMID

A randomized controlled trial of 2 protocols for weaning cardiac surgical patients receiving adaptive support ventilation

Tam N

J Crit

PMID

A randomized controlled trial of adaptive support ventilation mode to wean patients after fast-track cardiac valvular surgery

Zhu F, C

Anesthe

PMID 2!

Adaptive Support Ventilation versus Synchronized Intermittent Mandatory Ventilation with Pressure Support in weaning patients after orthotopic liver transplantation

Celli P,

Ruberti

Transpl

PMID 2

Randomized controlled trial comparing adaptive-support ventilation with pressure-regulated volume-controlled ventilation with automode in weaning patients after cardiac

Gruber P

Anesthe:

PMID 18

Automatic "respirator/weaning" with adaptive support ventilation: the effect on duration of endotracheal intubation and patient management

Petter /

Anesth

PMID 1

Effects of implementing adaptive support ventilation in a medical intensive care unit

Chen

Respi

PMID

Clinical experience with adaptive support ventilation for fast-track cardiac surgery

Cassina

J Cardio

PMID 14

Automatic weaning from mechanical ventilation using an adaptive lung ventilation controller

Linton DM, Potgieter PD, Davis S, Fourie AT, Brunner JX, Laubscher TP

Chest. 1994 Dec;106(6):1843-50

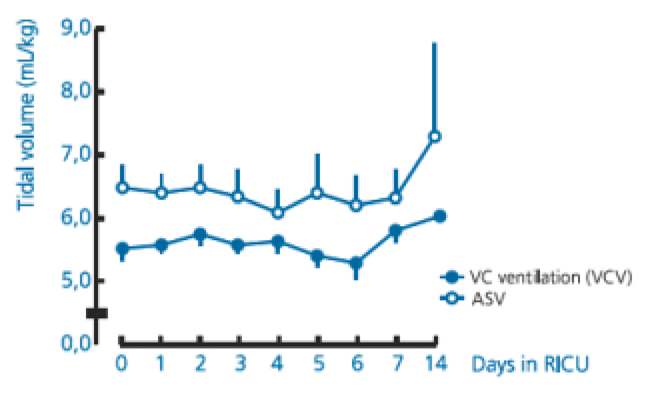
PMID 7988211, **http://www.ncbi.nlm.nih.gov/pubmed/7988211**

# ASV Use In All Ventilated Patients

- 243 ICU patients enrolled in prospective observational study
  - 1327 days monitored on ASV
- Vt-RR combinations varied with mechanics phenotypes
  - Higher VT and lower RR in COPD than in ALI/ARDS
    - 9.3ml/kg (8.2-10.8) predicted body weight (PBW) and 13 breaths/min (11-16) vs. 7.6ml/kg (6.7-8.8) PBW and 18 breaths/min (16-22).

# ASV vs Conventional

- 48 patients with ARDS randomized to ASV (n=23) or volume control (n=25)
- Similar duration of mechanical ventilation, mortality, ICU stay and other parameters




- 88 patients in 3 groups (22 normal lung, 36 restrictive disease, 30 with obstructive)
- Conventional ventilation → ASV.
- ASV resulted in lower inspiratory work
- Slightly lower RR and higher Vt in ASV
- Lower Vt in restrictive disease
- 3 patients with obstruction had unacceptably high Vt

Respirology. 2013 Oct;18(7):1108-15.

Intensive Care Med **36**, 1371–1379 (2010).

# ASV Algorithm Adjustment

- An alternate derivation of equation of motion
- Solve for the breathing frequency that minimizes the average force per breath
- By minimizing the force per breath this essentially results in reduction of driving pressure with each breath
- Added to help support improved lung protection

$$f_{BF} = \left(\frac{MV_A}{V_D}\right)^{1/3} \cdot (2\pi RC)^{-2/3}$$

Mead J (1960) J Appl Physiol 15(3):325–336

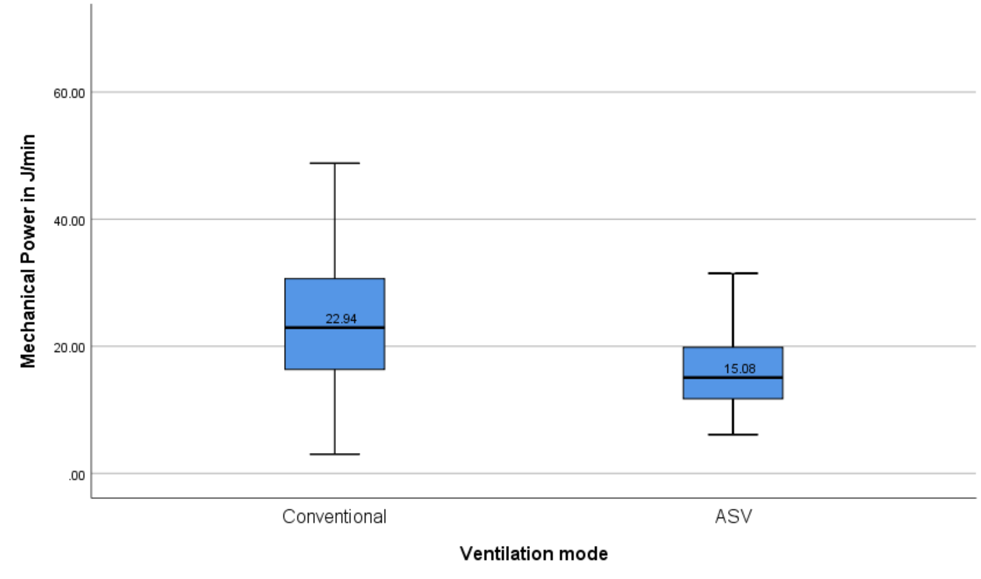
# ASV – Application During Lung Injury

- 26 Pediatric Cases requiring Mechanical Ventilation
- ASV 1.1 vs control mode compared with crossover
- Driving pressure primary endpoint
  - 10.4 (8.5-12.1) cmH2O in ASV vs 12.4 (10.5-15.3) cmH2O in Control
- Lower Vt in ASV
  - 6.4 (5.1-7.3) cc/kg IBW in ASV vs 7.9 (6.8-8.3) cc/kg IBW in control

Pediatr Pulmonol 2021 Jul 22

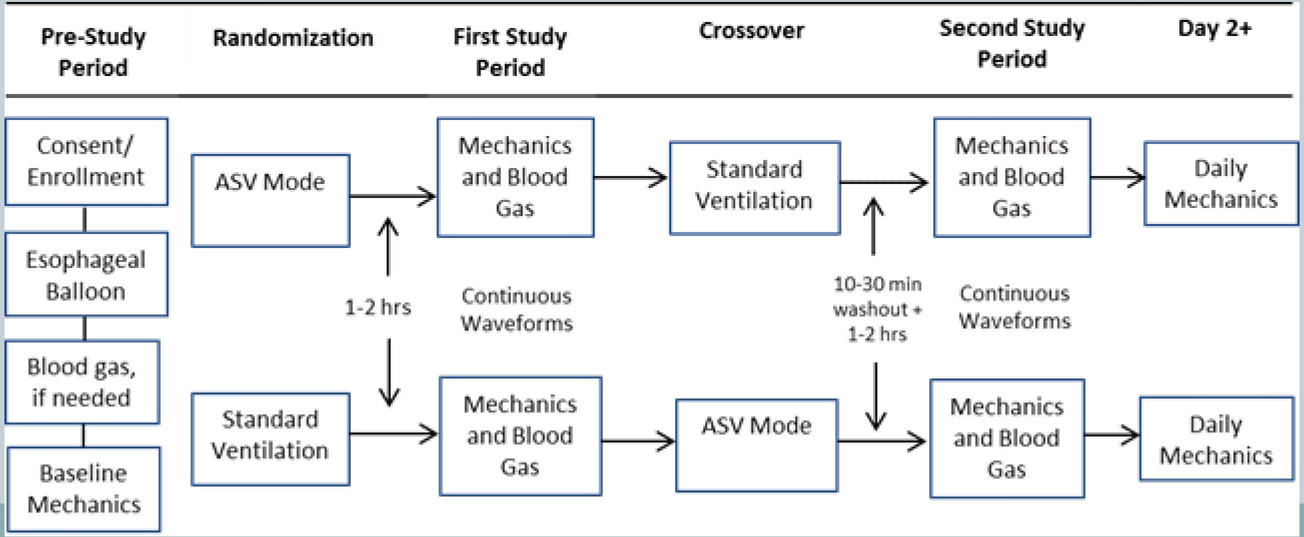
# ASV Mechanical Power

- 24 patients – 12 consecutive patients in ASV vs 12 consecutive patients in PCV
- Mechanical Power = 0.098 * VT * RR * (Ppeak – ½ * ΔP)
- Attempt to adjust variables between groups based upon gender, time and APACHE score
- Mechanical power significantly lower in the ASV group
- Small and lacks internal control



# ASV in ARDS

- 20 person randomized crossover study
- Confirmed ARDS per Berlin Criteria
- Patients randomized to ASV or control mode with Vt set to 6cc/kg IBW



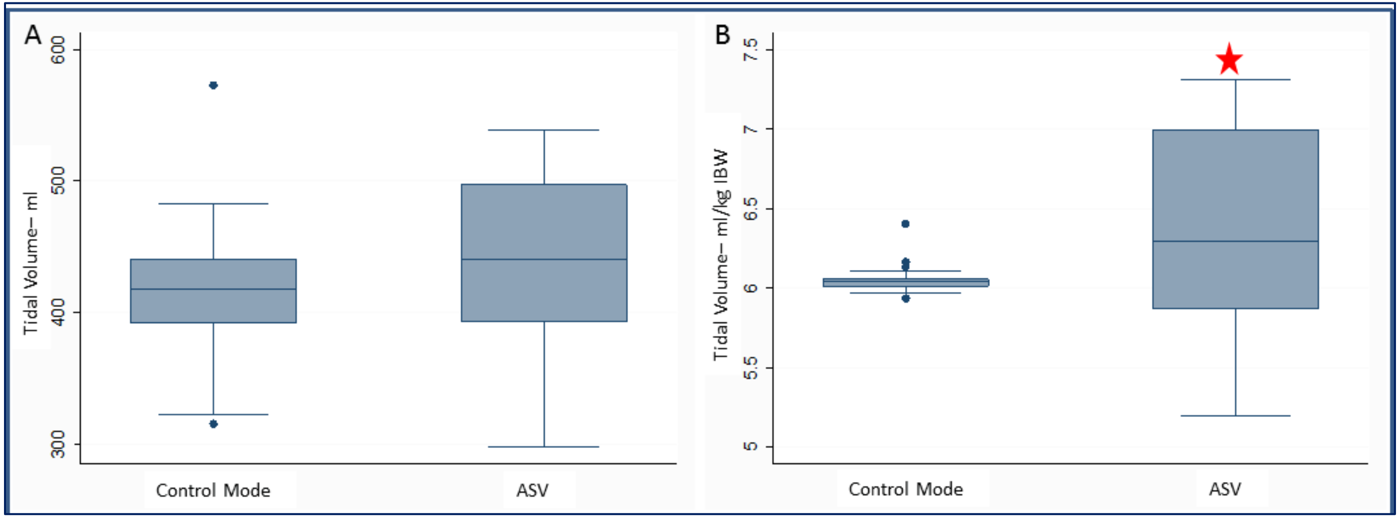
# Comparison at Before and After Crossover

| Table 3. Comparison between ventilator modes before and after crossover on day 1 (n=17) | | | |
|---|---|---|---|
| **Vent Mode** | **CMV** | **ASV** | **p value** |
| **Vt – ml** | 417.7 (392.7-440.8) | 440.5 (393.4-497.4) | 0.06 |
| **Vt/IBW – ml/kg** | 6.04 (6.01-6.06) | 6.29 (5.87-6.99) | 0.03* |
| **Resp Rate – bpm** | 27 (22-30) | 25 (22-26) | 0.01 |
| **Minute Ventilation – L/min** | 10.4 (8.6-12.1) | 10.5 (9.1-12.2) | 0.33 |
| **Plateau Pressure - $cmH_2O$** | 24.7 (22.6-27.6) | 25.3 (23.5-26.8) | 0.14 |
| **Total PEEP – $cmH_2O$** | 12.8 (10.4-15.1) | 12.8 (10.6-15.5) | 0.44 |
| **End Expiratory Transpulmonary Pressure – $cmH_2O$** | 0.0 (-1.7-1.8) | 0.2 (-1.1-1.3) | 0.62 |
| **End Inspiratory Transpulmonary Pressure – $cmH_2O$** | 8.7 (6.6-11.8) | 8.6 (7.2-11.9) | 0.46 |
| **End Expiratory Esophageal Pressure – $cmH_2O$** | 13.2 (12.1-15.3) | 12.4 (11-16.3) | 0.72 |
| **End Inspiratory Esophageal Pressure – $cmH_2O$** | 15.5 (13.8-18.3) | 15.2 (11.9-19.6) | 0.89 |
| **Respiratory System Driving Pressure – $cmH_2O$** | 12.8 (9-15.8) | 11.7 (10.7-15.1) | 0.29 |
| **Transpulmonary Driving Pressure - $cmH_2O$** | 7.8 (7-10.7) | 8.3 (7.3-12.8) | 0.68 |
| **Chest Wall Driving Pressure – $cmH_2O$** | 3 (1.6-3.9) | 2.6 (2.3-4.3) | 0.95 |
| **Respiratory System Elastance - $L/cmH_2O$** | 30.1 (24.4-40.5) | 28.3 (22.8-39.5) | 0.62 |
| **Lung Elastance - $L/cmH_2O$** | 22.4 (17.2-29.4) | 20.2 (14.7-28.5) | 0.84 |
| **Check Wall Elastance – $L/cmH_2O$** | 7.2 (3.7-8.8) | 6.2 (4.8-8.8) | 0.57 |
| **Respiratory System Compliance – ml/cmH2O** | 33.2 (24.7-40.9) | 35.3 (25.3-43.8) | 0.74 |
| **Transpulmonary Compliance – ml/cmH2O** | 44.6 (34-58) | 49.5 (35-67) | 0.36 |
| **Chest Wall Compliance – ml/cmH2O** | 139 (113-268.3) | 119.3 (90.4-178.6) | 0.06 |
| **Expiratory Time Constant - s** | 0.42 (0.39-0.53) | 0.47 (0.41-0.55) | 0.13 |
| **pH** | 7.4 (7.31-7.45) | 7.4 (7.31-7.44) | 0.10 |
| **pCO2** | 42 (37-45) | 39 (36-49) | 0.10 |
| **PaO2/FiO2** | 200 (150-235) | 168 (146-207.5) | 0.22 |
| **Mechanical Power – J/min** | 26.9 (23.8-37.9) | 28.2 (22.2-36.4) | 0.84 |

Vt indicates tidal volume, IBW indicates ideal body weight, PEEP indicates positive end expiratory pressure, CMV indicates control mode ventilation, ASV indicates adaptive support ventilation

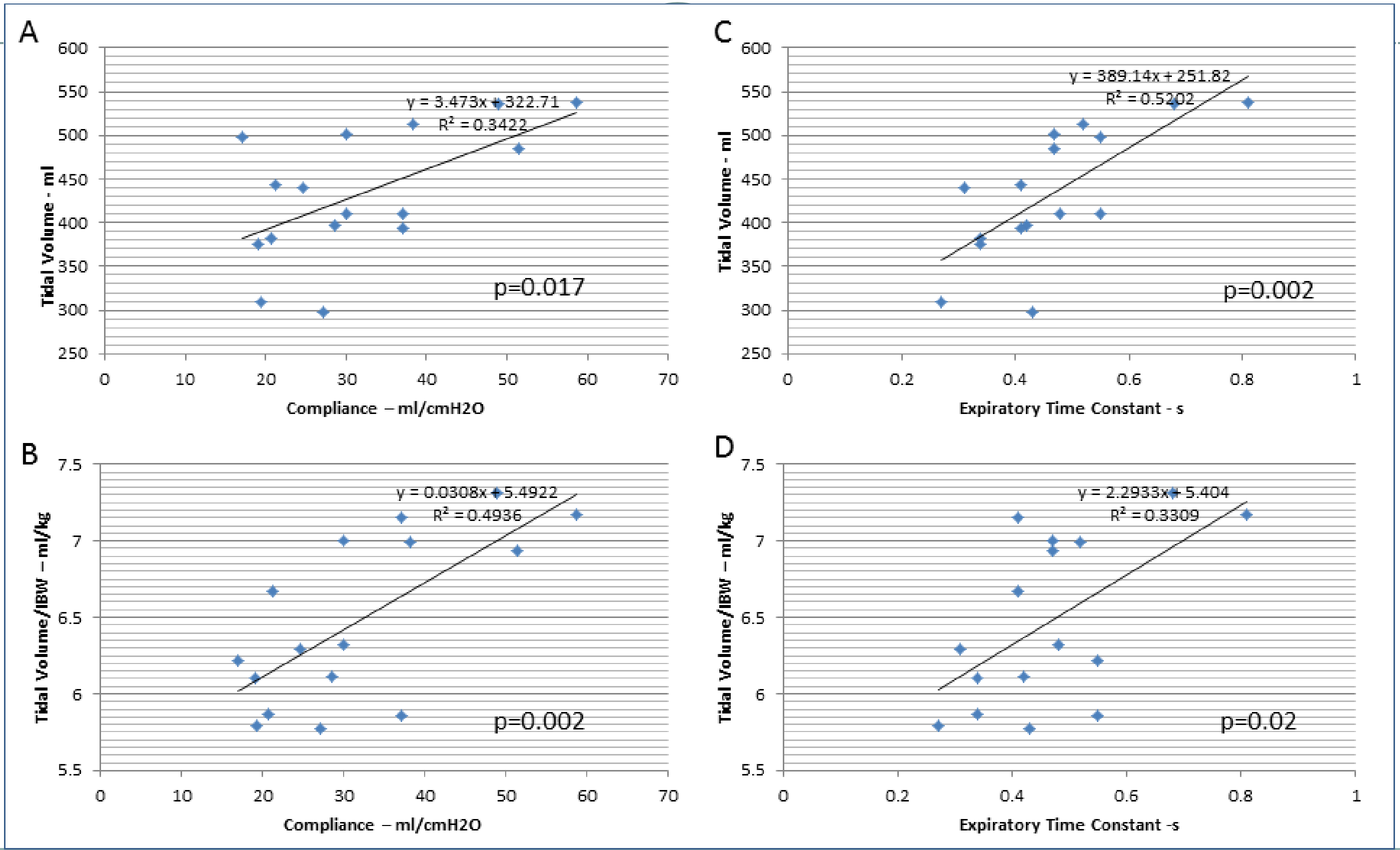
All comparisons made with paired t test except where indicated by the * which is indicative of non-parametric distribution and the use of the Wilcoxon signed paired signed rank test

# Comparison Before and After Crossover




Baedorf Kassis et al. Respir Care. 2022 Aug 16:respcare.10159. doi: 10.4187/respcare.10159. Epub ahead of print. PMID: 35973716

# Tidal Volume Variability in ASV




Baedorf Kassis et al. Respir Care. 2022 Aug 16:respcare.10159. doi: 10.4187/respcare.10159. Epub ahead of print. PMID: 35973716

# Comparison at Before and After Crossover

| Table 3. Comparison between ventilator modes before and after crossover on day 1 (n=17) | | | |
|---|---|---|---|
| **Vent Mode** | **CMV** | **ASV** | **p value** |
| **Vt – ml** | 417.7 (392.7-440.8) | 440.5 (393.4-497.4) | 0.06 |
| **Vt/IBW – ml/kg** | 6.04 (6.01-6.06) | 6.29 (5.87-6.99) | 0.03* |
| **Resp Rate – bpm** | 27 (22-30) | 25 (22-26) | 0.01 |
| **Minute Ventilation – L/min** | 10.4 (8.6-12.1) | 10.5 (9.1-12.2) | 0.33 |
| **Plateau Pressure - $cmH_2O$** | 24.7 (22.6-27.6) | 25.3 (23.5-26.8) | 0.14 |
| **Total PEEP – $cmH_2O$** | 12.8 (10.4-15.1) | 12.8 (10.6-15.5) | 0.44 |
| **End Expiratory Transpulmonary Pressure – $cmH_2O$** | 0.0 (-1.7-1.8) | 0.2 (-1.1-1.3) | 0.62 |
| **End Inspiratory Transpulmonary Pressure – $cmH_2O$** | 8.7 (6.6-11.8) | 8.6 (7.2-11.9) | 0.46 |
| **End Expiratory Esophageal Pressure – $cmH_2O$** | 13.2 (12.1-15.3) | 12.4 (11-16.3) | 0.72 |
| **End Inspiratory Esophageal Pressure – $cmH_2O$** | 15.5 (13.8-18.3) | 15.2 (11.9-19.6) | 0.89 |
| **Respiratory System Driving Pressure – $cmH_2O$** | 12.8 (9-15.8) | 11.7 (10.7-15.1) | 0.29 |
| **Transpulmonary Driving Pressure - $cmH_2O$** | 7.8 (7-10.7) | 8.3 (7.3-12.8) | 0.68 |
| **Chest Wall Driving Pressure – $cmH_2O$** | 3 (1.6-3.9) | 2.6 (2.3-4.3) | 0.95 |
| **Respiratory System Elastance - L/$cmH_2O$** | 30.1 (24.4-40.5) | 28.3 (22.8-39.5) | 0.62 |
| **Lung Elastance - L/$cmH_2O$** | 22.4 (17.2-29.4) | 20.2 (14.7-28.5) | 0.84 |
| **Check Wall Elastance – L/$cmH_2O$** | 7.2 (3.7-8.8) | 6.2 (4.8-8.8) | 0.57 |
| **Respiratory System Compliance – ml/cmH2O** | 33.2 (24.7-40.9) | 35.3 (25.3-43.8) | 0.74 |
| **Transpulmonary Compliance – ml/cmH2O** | 44.6 (34-58) | 49.5 (35-67) | 0.36 |
| **Chest Wall Compliance – ml/cmH2O** | 139 (113-268.3) | 119.3 (90.4-178.6) | 0.06 |
| **Expiratory Time Constant - s** | 0.42 (0.39-0.53) | 0.47 (0.41-0.55) | 0.13 |
| **pH** | 7.4 (7.31-7.45) | 7.4 (7.31-7.44) | 0.10 |
| **pCO2** | 42 (37-45) | 39 (36-49) | 0.10 |
| **PaO2/FiO2** | 200 (150-235) | 168 (146-207.5) | 0.22 |
| **Mechanical Power – J/s** | 26.9 (23.8-37.9) | 28.2 (22.2-36.4) | 0.84 |

Vt indicates tidal volume, IBW indicates ideal body weight, PEEP indicates positive end expiratory pressure, CMV indicates control mode ventilation, ASV indicates adaptive support ventilation

All comparisons made with paired t test except where indicated by the * which is indicative of non-parametric distribution and the use of the Wilcoxon signed paired signed rank test

# Comparison at Before and After Crossover

Table 3. Comparison between ventilator modes before and after crossover on day 1 (n=17)

| Vent Mode | CMV | ASV | p value |
|---|---|---|---|
| Vt – ml | 417.7 (392.7-440.8) | 440.5 (393.4-497.4) | 0.06 |
| Vt/IBW – ml/kg | 6.04 (6.01-6.06) | 6.29 (5.87-6.99) | 0.03* |
| Resp Rate – bpm | 27 (22-30) | 25 (22-26) | 0.01 |
| Minute Ventilation – L/min | 10.4 (8.6-12.1) | 10.5 (9.1-12.2) | 0.33 |
| Plateau Pressure - $cmH_2O$ | 24.7 (22.6-27.6) | 25.3 (23.5-26.8) | 0.14 |
| Total PEEP – $cmH_2O$ | 12.8 (10.4-15.1) | 12.8 (10.6-15.5) | 0.44 |
| End Expiratory Transpulmonary Pressure – $cmH_2O$ | 0.0 (-1.7-1.8) | 0.2 (-1.1-1.3) | 0.62 |
| End Inspiratory Transpulmonary Pressure – $cmH_2O$ | 8.7 (6.6-11.8) | 8.6 (7.2-11.9) | 0.46 |
| End Expiratory Esophageal Pressure – $cmH_2O$ | 13.2 (12.1-15.3) | 12.4 (11-16.3) | 0.72 |
| End Inspiratory Esophageal Pressure – $cmH_2O$ | 15.5 (13.8-18.3) | 15.2 (11.9-19.6) | 0.89 |
| Respiratory System Driving Pressure – $cmH_2O$ | 12.8 (9-15.8) | 11.7 (10.7-15.1) | 0.29 |
| Transpulmonary Driving Pressure - $cmH_2O$ | 7.8 (7-10.7) | 8.3 (7.3-12.8) | 0.68 |
| Chest Wall Driving Pressure – $cmH_2O$ | 3 (1.6-3.9) | 2.6 (2.3-4.3) | 0.95 |
| Respiratory System Elastance - L/$cmH_2O$ | 30.1 (24.4-40.5) | 28.3 (22.8-39.5) | 0.62 |
| Lung Elastance - L/$cmH_2O$ | 22.4 (17.2-29.4) | 20.2 (14.7-28.5) | 0.84 |
| Check Wall Elastance – L/$cmH_2O$ | 7.2 (3.7-8.8) | 6.2 (4.8-8.8) | 0.57 |
| Respiratory System Compliance – ml/cmH2O | 33.2 (24.7-40.9) | 35.3 (25.3-43.8) | 0.74 |
| Transpulmonary Compliance – ml/cmH2O | 44.6 (34-58) | 49.5 (35-67) | 0.36 |
| Chest Wall Compliance – ml/cmH2O | 139 (113-268.3) | 119.3 (90.4-178.6) | 0.06 |
| Expiratory Time Constant - s | 0.42 (0.39-0.53) | 0.47 (0.41-0.55) | 0.13 |
| pH | 7.4 (7.31-7.45) | 7.4 (7.31-7.44) | 0.10 |
| pCO2 | 42 (37-45) | 39 (36-49) | 0.10 |
| PaO2/FiO2 | 200 (150-235) | 168 (146-207.5) | 0.22 |
| Mechanical Power – J/s | 26.9 (23.8-37.9) | 28.2 (22.2-36.4) | 0.84 |

Vt indicates tidal volume, IBW indicates ideal body weight, PEEP indicates positive end expiratory pressure, CMV indicates control mode ventilation, ASV indicates adaptive support ventilation

All comparisons made with paired t test except where indicated by the * which is indicative of non-parametric distribution and the use of the Wilcoxon signed paired signed rank test

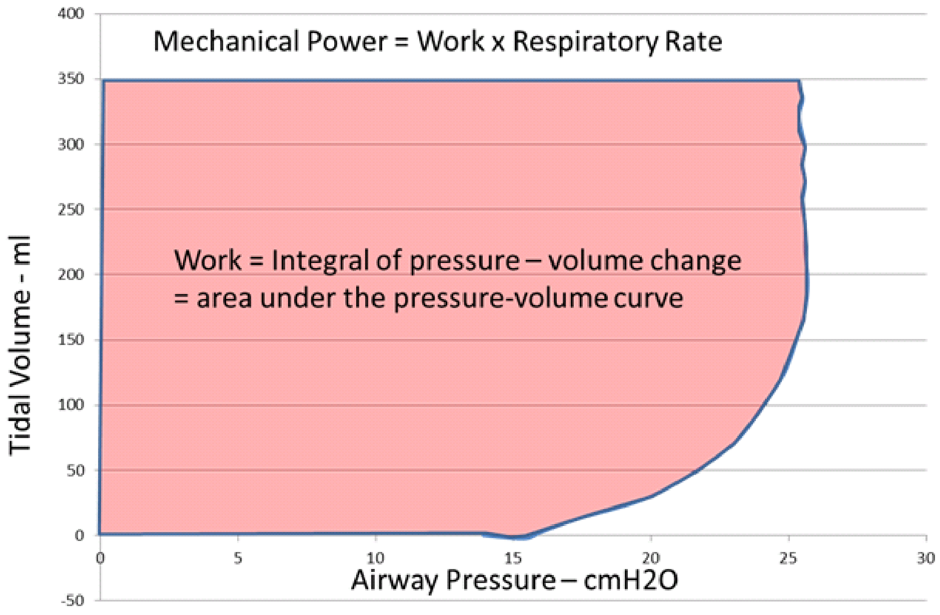
# Comparison at Before and After Crossover

| Table 3. Comparison between ventilator modes before and after crossover on day 1 (n=17) | | | |
|---|---|---|---|
| **Vent Mode** | **CMV** | **ASV** | **p value** |
| **Vt – ml** | 417.7 (392.7-440.8) | 440.5 (393.4-497.4) | 0.06 |
| **Vt/IBW – ml/kg** | 6.04 (6.01-6.06) | 6.29 (5.87-6.99) | 0.03* |
| **Resp Rate – bpm** | 27 (22-30) | 25 (22-26) | 0.01 |
| **Minute Ventilation – L/min** | 10.4 (8.6-12.1) | 10.5 (9.1-12.2) | 0.33 |
| **Plateau Pressure - $cmH_2O$** | 24.7 (22.6-27.6) | 25.3 (23.5-26.8) | 0.14 |
| **Total PEEP – $cmH_2O$** | 12.8 (10.4-15.1) | 12.8 (10.6-15.5) | 0.44 |
| **End Expiratory Transpulmonary Pressure – $cmH_2O$** | 0.0 (-1.7-1.8) | 0.2 (-1.1-1.3) | 0.62 |
| **End Inspiratory Transpulmonary Pressure – $cmH_2O$** | 8.7 (6.6-11.8) | 8.6 (7.2-11.9) | 0.46 |
| **End Expiratory Esophageal Pressure – $cmH_2O$** | 13.2 (12.1-15.3) | 12.4 (11-16.3) | 0.72 |
| **End Inspiratory Esophageal Pressure – $cmH_2O$** | 15.5 (13.8-18.3) | 15.2 (11.9-19.6) | 0.89 |
| **Respiratory System Driving Pressure – $cmH_2O$** | 12.8 (9-15.8) | 11.7 (10.7-15.1) | 0.29 |
| **Transpulmonary Driving Pressure - $cmH_2O$** | 7.8 (7-10.7) | 8.3 (7.3-12.8) | 0.68 |
| **Chest Wall Driving Pressure – $cmH_2O$** | 3 (1.6-3.9) | 2.6 (2.3-4.3) | 0.95 |
| **Respiratory System Elastance - L/$cmH_2O$** | 30.1 (24.4-40.5) | 28.3 (22.8-39.5) | 0.62 |
| **Lung Elastance - L/$cmH_2O$** | 22.4 (17.2-29.4) | 20.2 (14.7-28.5) | 0.84 |
| **Check Wall Elastance – L/$cmH_2O$** | 7.2 (3.7-8.8) | 6.2 (4.8-8.8) | 0.57 |
| **Respiratory System Compliance – ml/cmH2O** | 33.2 (24.7-40.9) | 35.3 (25.3-43.8) | 0.74 |
| **Transpulmonary Compliance – ml/cmH2O** | 44.6 (34-58) | 49.5 (35-67) | 0.36 |
| **Chest Wall Compliance – ml/cmH2O** | 139 (113-268.3) | 119.3 (90.4-178.6) | 0.06 |
| **Expiratory Time Constant - s** | 0.42 (0.39-0.53) | 0.47 (0.41-0.55) | 0.13 |
| **pH** | 7.4 (7.31-7.45) | 7.4 (7.31-7.44) | 0.10 |
| **pCO2** | 42 (37-45) | 39 (36-49) | 0.10 |
| **PaO2/FiO2** | 200 (150-235) | 168 (146-207.5) | 0.22 |
| **Mechanical Power – J/min** | 26.9 (23.8-37.9) | 28.2 (22.2-36.4) | 0.84 |

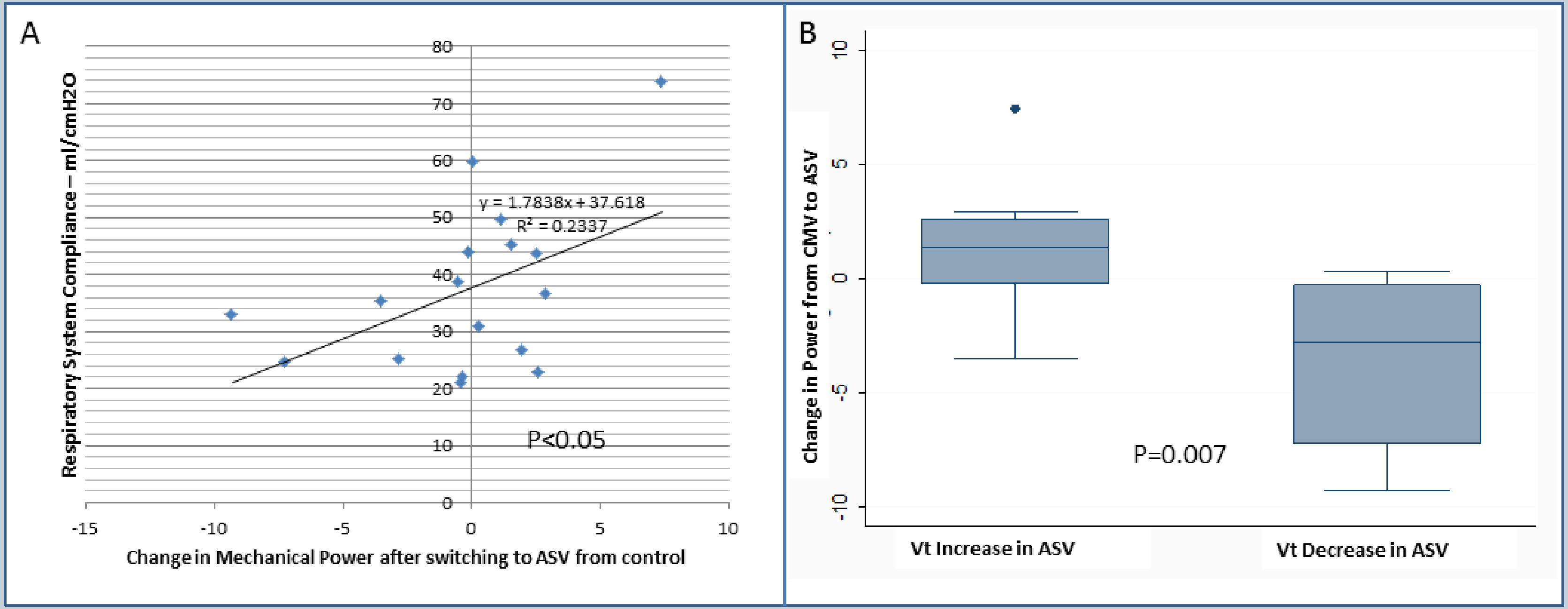
Vt indicates tidal volume, IBW indicates ideal body weight, PEEP indicates positive end expiratory pressure, CMV indicates control mode ventilation, ASV indicates adaptive support ventilation

All comparisons made with paired t test except where indicated by the ***** which is indicative of non-parametric distribution and the use of the Wilcoxon signed paired signed rank test

# Mechanical Power



# Mechanical Power Change Between ASV and Control



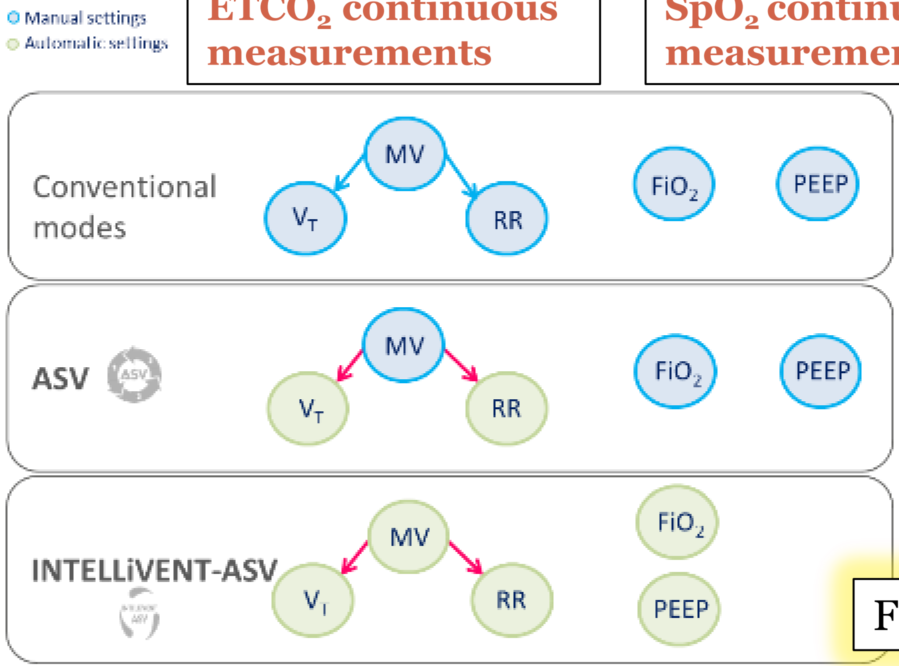
# Study Conclusions

- Vt and Vt/IBW similar between standard of care and ASV groups overall
  - Wider range in Vt distribution in ASV secondary to variable compliance and time constants
  - ASV lowered Vt in patients with stiffer lungs
- Mechanical power similar overall
  - Decreased power in patients with stiffer lungs
- Other markers of safety were similar between groups
  - Similar driving pressure, plateau, gas exchange
- Physiological rationale for potential benefit by providing individual titration

# Fully Closed Loop Mechanical Ventilation

**$ETCO_2$ continuous measurements**

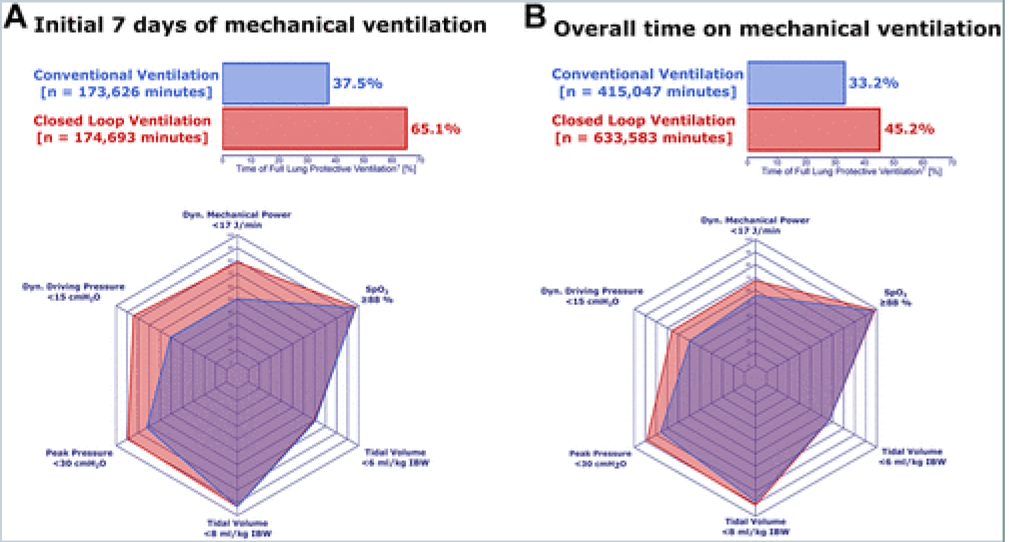
**$SpO_2$ continuous measurements**




Fully Automated

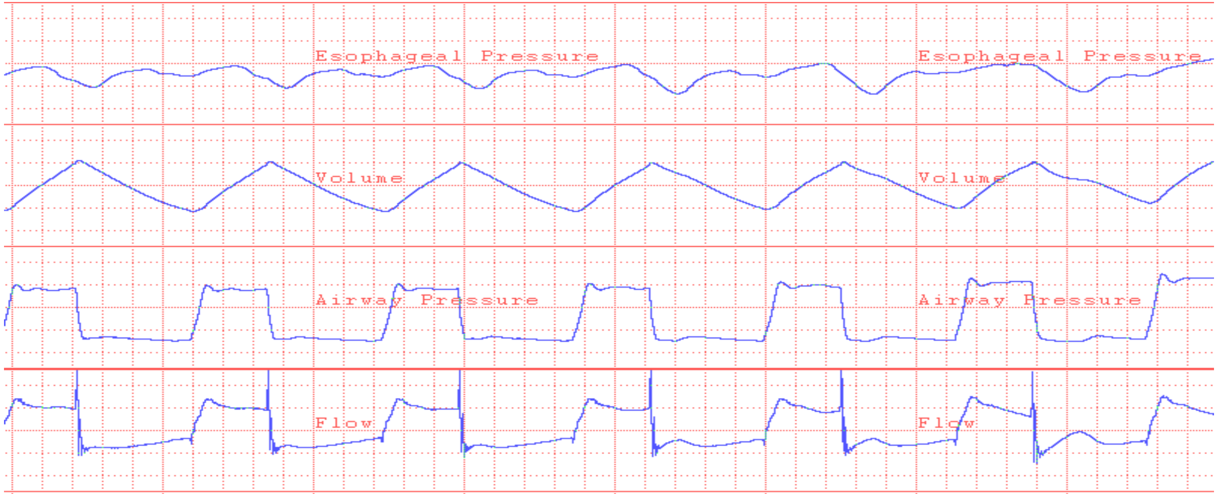
# Closed Loop Ventilation During COVID

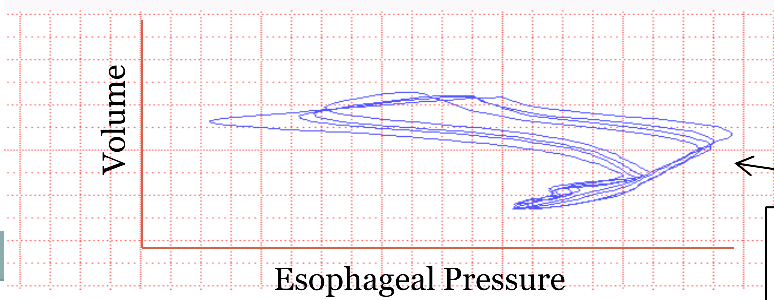
- Enrollment of patients with COVID-19 ARDS
- 40 total patients enrolled
- Allocated to closed loop (23 patients) or conventional (17 patients) based upon ventilator availability
- "Lung protection" defined as Vt < 8cc/kg, ΔP < 15 cmH2O, peak pressure , 30 cmH2O, peripheral O2 saturation >88% and dynamic mechanical power < 17 J/min
- Lung protection achieved 65% of the time in ASV vs 38% of the time in conventional over first 7 days

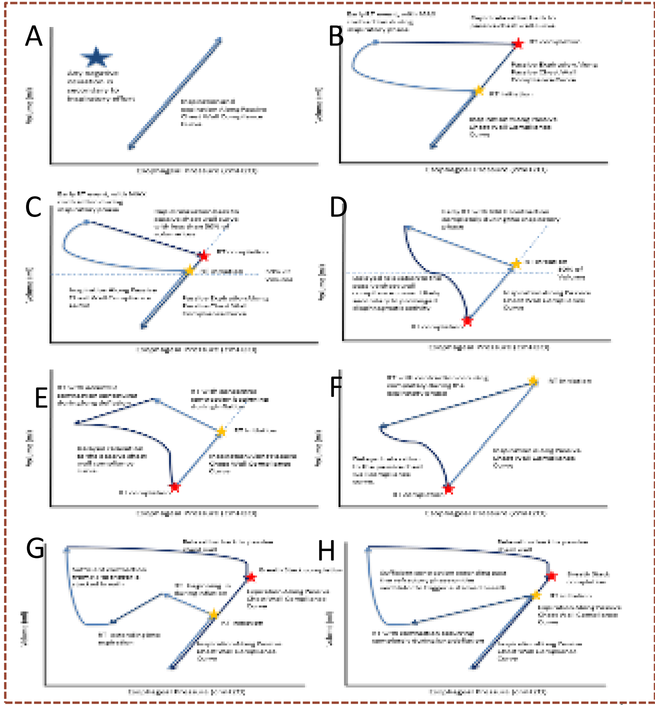



J Intensive Care Med. 2021 Jun 8:8850666211024139.

# More Complex Data for Improved Pattern Recognition

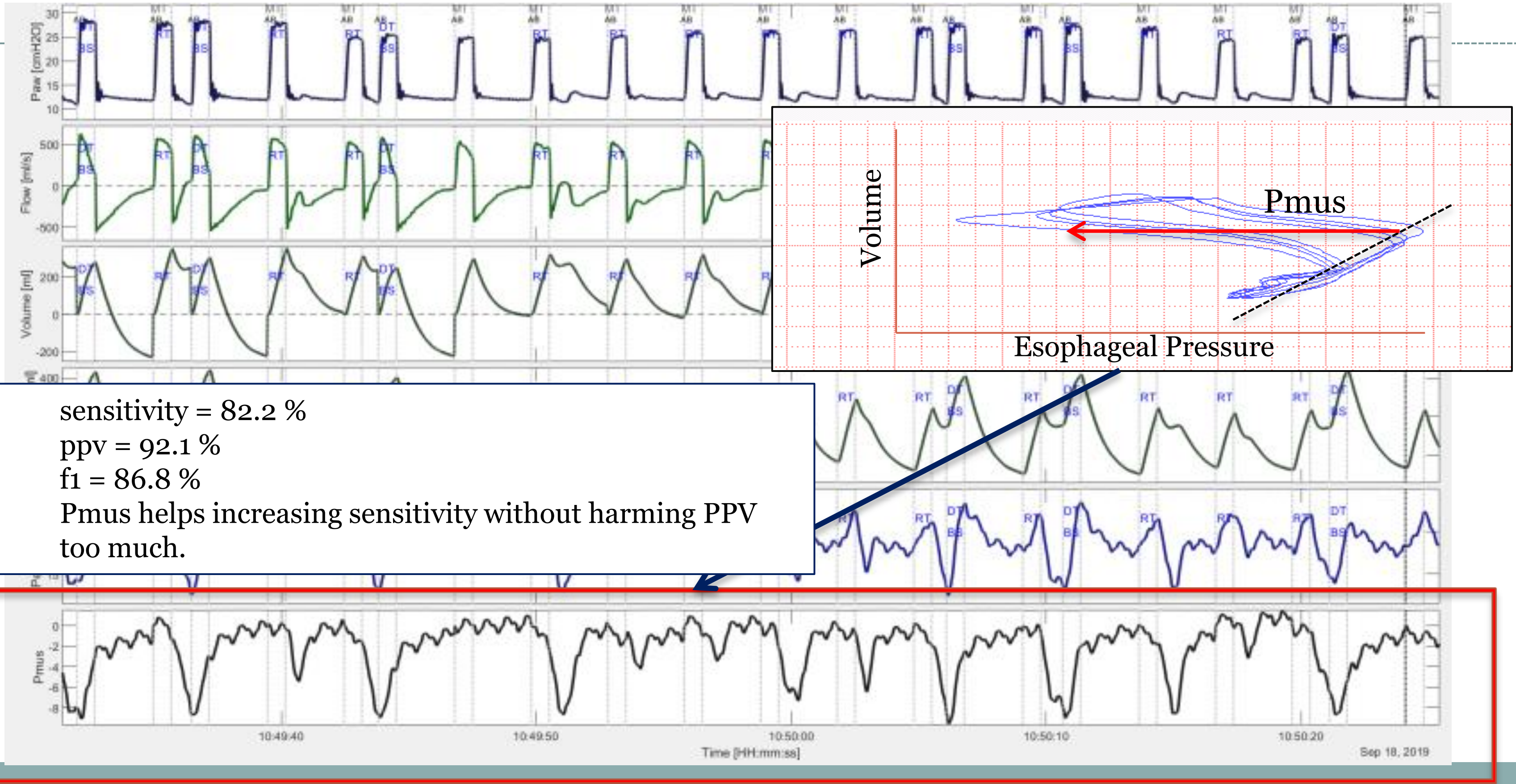


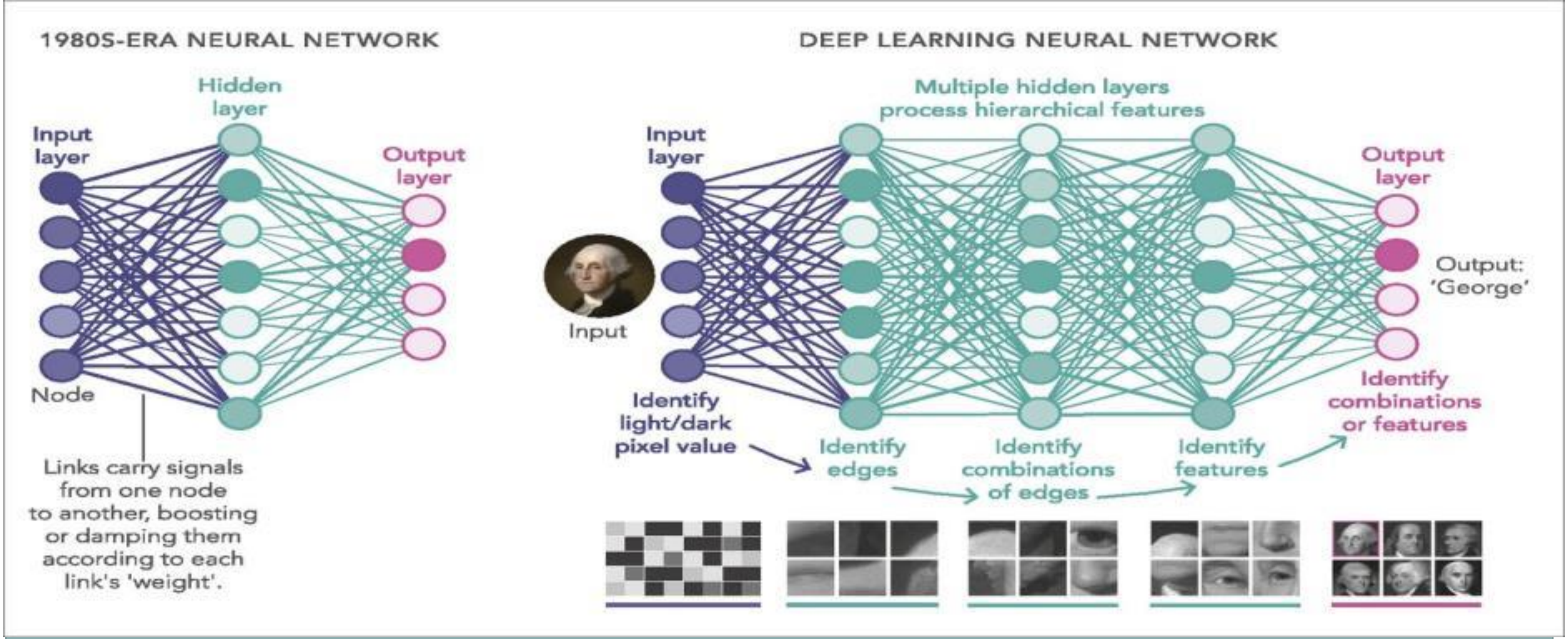

Multi-Dimensional Data For A Breathing Pattern Providing Improved Pattern Recognition to Detect Reverse Triggering

# Automation Software



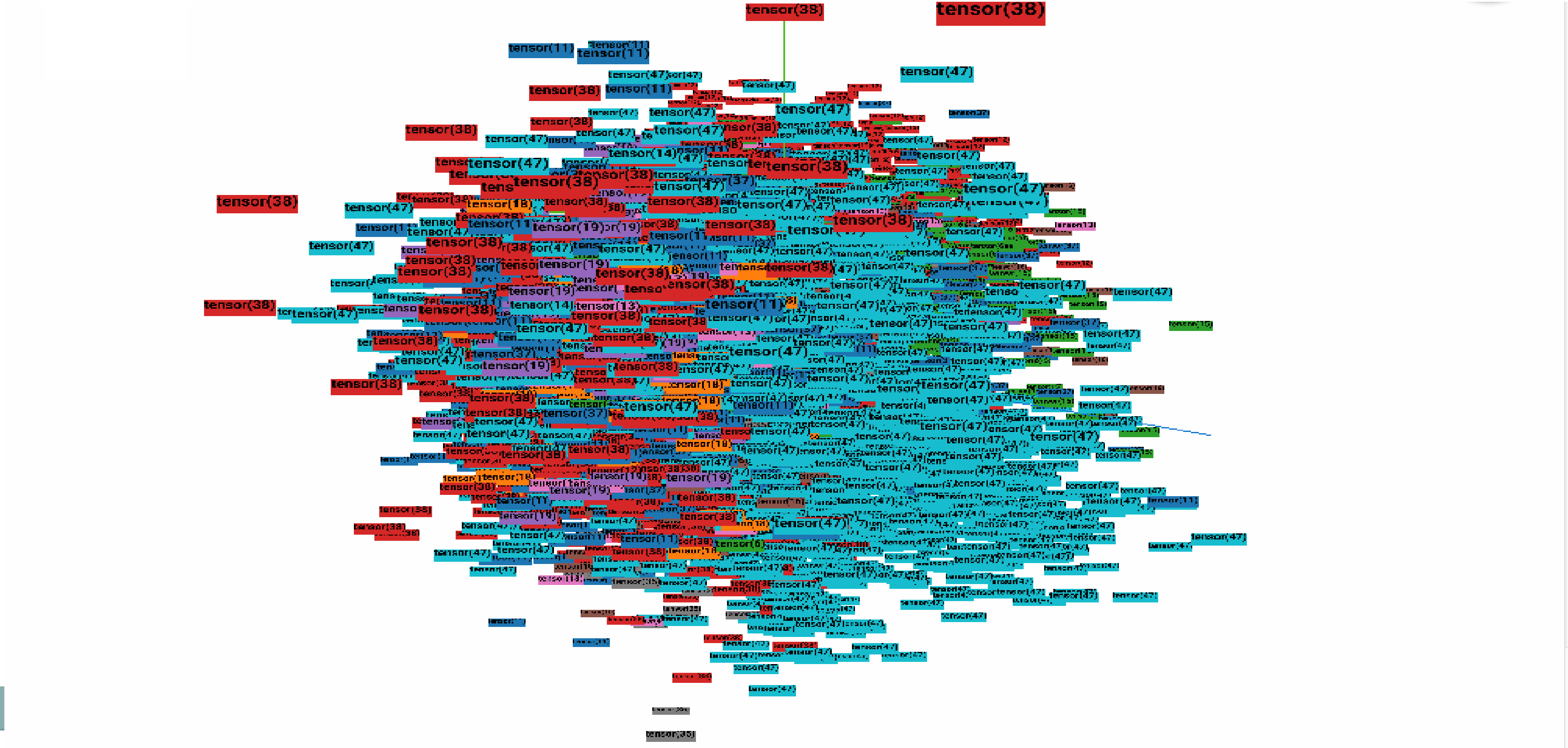

sensitivity = 82.2 %
ppv = 92.1 %
f1 = 86.8 %
Pmus helps increasing sensitivity without harming PPV too much.

# Automated Dyssynchrony Detection
# Machine Learning Approaches
# Deep Neural Network Pattern Recognition




PNAS | January 22, 2019 | vol. 116 | no. 4

# Principle Component Analysis Clusters By Phenotype




THANKS!!!!
Dr. Elias Baedorf Kassis
enbaedor@bidmc.harvard.edu