Mechanical Power

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1

CONCEPTS

Ventilation induced lung injury (VILI)

was defined as the lesions derived from

the application of mechanical ventilation

Vasquez et al (2018)

2

Mechanisms of VILI

- Barotrauma
- Volutrauma
- Atelectrauma
- Biotrauma
- Ergotrauma

(Brochard; Bersten, 2019)

3

NEW AIM

Understanding the biophysical causes of VILI changed the focus of concern from the inflation pattern related to tidal volume and pressures, to consider harmful exposures of energy.

Marini & Gattinoni (2020)

4

UNIFICATION

Comprised of plateau pressure, driving pressure,

PEEP, tidal volume, flow, resistance,

elastance and respiratory rate

Serpa Neto *et al* (2018)

5

ESSENSE

Mechanical power depicts the

energy transferred to the respiratory system by the

ventilator during a certain period

in joule per minute

Van der Meijden et al (2019)

6

But

Where did it come from?

7

It came from the phisics

Newton's work formula:

Work (J) = Force (N) . Displacement (m)

In the respiratory sistem,

Pressures produce volume changes (*MARINI,* 2018)

Work of breathing = Stress . Strain

8

STRESS

The airway pressure reflects the *stress*

applied to the lungs and chest wall

Marini, Gattinoni & Rocco (2020)

9

STRAIN

It corresponds to change in lung volume,

that is,

the alveolar deformation

Marini, Gattinoni & Rocco (2020)

10

WORK OF BREATHING

Work of breathing = Stress . Strain

or

Work of breathing ($cmH_2O.L$) = Pressure (cmH_2O) . Tidal volume (L)

11

MECHANICAL POWER

Power (cmH2O.L/minute) = RR (1/minute) . Pressure (cmH2O) . Vt (L)

Constant 0.098 to convert to joule per minute

Mechanical Power (J/minute) = 0.098 . RR (1/minute) . Pressure (cmH2O) . Vt (L)

12

BUT

HOW CAN IT BE MEASURED?

13

GEOMETRIC METHOD

Power can be calculated using the geometric method,

measuring the dynamic inspiratory area of airway pressure

and volume curve during the respiratory cycle

Chiumello et al., (2020)

14

It’s necessary to know

a little about

hysteresis…

15

Hysteresis is defined as

the different trajectories of the *volume* in the application

and removal of a certain *pressure*

and reflect an imperfect elastic response to deformation…

Chiumello *et al*., (2020)

16

Hysteresis corresponds to the energy required during inflation

and complete pulmonary deflation,

that is,

the effort to overcome parenchymal viscoelasticity

Marini (2019)

17

On ventilator display,

hysteresis is represented

by the P-V Loop

18

GEOMETRIC METHOD

Mechanical Power =

0.098 . RR (1/minute) . P_{Total} (cmH_2O) . Vt (L)

19

GEOMETRIC METHOD

0.098 . RR . (P_{Peak} . Vt)

0.098 . 28. 27. 0,34

Mechanical Power = 25.1 J/minute

20

…In order to make it easier to use mechanical power,

formulas were created for its calculation…

$$0,098.\ RR.\ (\Delta Vt^2\ .\ [0,5xEL_{rs} + RR\ (1 + I{:}E)/(60\ .\ I{:}E)\ x\ R_{wa}\ ] + \Delta Vt\ .\ PEEP)$$

Gattinonni *et al* (2016)

$$Vt\ x\ (Flow\ R + \int Flow\ DT/2C + PEEPI$$

Marini (2019)

21

But

it still remained complex

and they created the surrogate formulas

22

Surrugate formulas use variables available

on the ventilator to calculate the

mechanical power in VCV and PCV

Despite the small differences in relation to the geometric method

Chiumello et al (2020)

23

Surrugate formulas

VCV

0.098.RR.Vt .[Ppico – 0,5 (PPlateau – PEEP)]

Gattinonni et al (2016)

$$\frac{\text{Ve . (PPeak + PEEP + Flow Inspiratory /6)}}{20}$$

Giosa et al (2019)

PCV

0.098 . RR . Vt . (PEEP + ΔPInsp)

Becher et al (2019)

24

…What is it for?

25

It is the physiological concept

that simplifies the assessment

of mechanical ventilation portraying it

with for the unification of the set of its components

Vasquez *et al* (2018)

26

There is a tendency to replace the concepts based on

tidal volume and pressures for understanding

mechanical power as a VILI generator,

but its predictive accuracy is still unclear

Marini, Rocco & Gattinoni (2020)

However, lower levels of mechanical power are desired…

Coppola *et al* (2020)

27

The quantitative fragmentation of the energy

required to inflate the lungs may point to protective ventilation strategies

effective to the reduction of the risk of VILI

Marini, Rocco & Gattinoni (2020) Vassali *et al* (2020)

and may clarify the contribution of each component

of the power to the generation of such injury

Vassali *et al* (2020)

28

The total elastic power is subdivided into two parts:

- Dynamic power corresponds to the energy necessary to inflate the lungs.
- Static power corresponds to the potential energy stored in the respiratory system by the PEEP.

Colino el al (2019)

29

The total inflation energy, that is, the mechanical power is equal to the total elastic power plus the total kinetic power,

Marini, Gattinoni & Rocco (2020)

which is the energy spent on overcoming the airway and tissue resistance to the flow

Colino el al (2019)

30

Some evidence about ?

31

Mechanical power evidences

An elevated Mechanical Power regardless of the combination of its components can lead to VILI
Serpa Neto et al (2018)

Especially when it exceeds 12J/minute, whereas over 17J/min it is associated with a higher mortality rate
Coppola el al (2020)

and between 19 to 24J/minute denotes the severity of ARDS
Maiolo et al (2018)

32

PCV

Mechanical power in burn patients were elevated and that, regardless of mechanical ventilation time, these values are related to mortality

	Number of days	Outcome	N	Mean	SD ±	P value
Mechanical power (J/min)	1-5	Survival Death	5 9	17.60 24.42	5.54 7.76	0.029*†
	6-9	Survival Death	3 4	17.42 30.01	2.92 10.81	
	10+	Survival Death	2 3	22.31 25.20	0.82 5.86	

Simonete, Alberti da Silva & Franck, 2023

33

PCV

There is interference in the outcome in the univariate analysis of mechanical power and its components, but the multivariate analysis showed that only mechanical power correlates with the outcome in SARS-CoV-2

Variables	P value		Risk Ranking	Odds Ratio	95% Confidence Interval
	Univariate	Multivariate			
V_T (L)	< 0.001	0.236	---	0.911	(0.780 - 1.064)
Elastance(cmH_20/L)	< 0.001	0.580	---	1.060	(0.862 - 1.303)
ΔP (cmH_20)	< 0.001	0.450	---	1.239	(0.708 - 2.166)
$P_{Plateau}$(cmH_20)	< 0.001	0.586	---	0.953	(0.802 - 1.133)
Mechanical power (J/minute)	0.009	0.040	Higher values	1.062	(1.003 - 1.124)

Franck, Franck & Daoud (2022)

34

VCV

The univariate analysis did not show differences in outcome, whereas the multivariate analysis suggests interference in the outcome, further estimating that for every additional unit in mechanical power there is an increase of 13.4% on the mortality risk.

Variable	P value		Risk Ranking	Odds Ratio	95% Confidence Interval
	Univariate	Multivariate			
Age (Years)	< 0.001	< 0.001	Older ages	1.063	(1.029 - 1.099)
Driving pressure (cmH_2O)	< 0.001	0.245	---	1.245	(0.859 - 1.806)
PEEP (cmH_2O)	< 0.001	0.044	Lower values	1.217	(1.006 - 1.473)
Elastance (cmH_2O/L)	< 0.001	0.029	Higher values	1.118	(1.012 - 1.237)
Mechanical Power (J/min)	0.864	0.023	Higher values	1.134	(1.018 - 1.263)

Franck, Franck & Feronato (2022)

35

Some doubts about ?

36

IS THE EVALUATION OF MECHANICAL POWER AND ITS COMPONENTS SIMILAR IN PRESSURE OR VOLUME VENTILATION?

37

IS THE EVALUATION OF TIDAL VOLUME AND COMPLIANCE IS SIMILAR IN PRESSURE OR VOLUME VENTILATION?

38

VCV

SARS-CoV-2

TIDAL VOLUME & COMPLIANCE

Variable	Outcome	N	Mean	Median	Min.	Max.	Standard Deviation	P value
F_{Insp} (L/min)	Survival	53	53.3	54.0	35	74	8.9	0.903
	Death	94	53.1	53.5	24	82	8.9	
Compliance (L/cmH_2O)	Survival	53	0.034	0.034	0.016	0.060	0.010	< 0.001
	Death	94	0.027	0.023	0.009	0.077	0.013	
Vt (L)	Survival	53	0.35	0.36	0.25	0.50	0.06	0.367
	Death	94	0.34	0.34	0.23	0.54	0.06	

Franck, Franck & Feronato (2022)

39

PCV

SARS-CoV-2

TIDAL VOLUME & ELASTANCE

Variable	Outcome	N	Mean	Median	Min.	Max.	Standard Deviation	P value
Mechanical power (J/min)	Survival	84	28.06	25.39	11.92	83.85	11.14	0.009
	Death	79	33.34	28.79	14.49	92.88	13.92	
F_{Insp} (L/min)	Survival	84	33.16	31.20	21.82	73.60	8.70	0.011
	Death	79	29.78	29.60	12.60	56.25	7.95	
Compliance (L/cmH_20)	Survival	84	0.040	0.037	0.021	0.074	0.010	< 0.001
	Death	79	0.027	0.027	0.010	0.050	0.009	
Elastance (cmH_20/L)	Survival	84	26.72	26.93	13.51	48.72	6.64	< 0.001
	Death	79	42.41	37.50	20.00	100.00	16.21	
Resistence (cmH_2O/L/min)	Survival	84	0.09	0.08	0.02	0.23	0.05	0.071
	Death	79	0.11	0.09	0.06	0.41	0.07	
V_T (L)	Survival	84	0.49	0.48	0.30	0.92	0.10	< 0.001
	Death	79	0.41	0.40	0.21	0.75	0.10	

Franck, Franck & Daoud (2022)

40

PCV

BURNS

TIDAL VOLUME & ELASTANCE

	Outcome	N	Mean	Median	SD ±	Min	Max	P value
RR (Breath/min)	Survival Death	10 16	20.7 26.43	22.0 26.5	4.57 5.92	15 17	30 37	0.015*
T_{insp} (s)	Survival Death	10 16	0.94 0.87	0.95 0.8	0.15 0.14	0.65 0.7	1.2 1.3	0.233**
PEEP (cmH_2O)	Survival Death	10 16	7.6 12.0	7.5 11.0	1.5 3.1	5 8	11 19	<0.001*†
P_{peak} (cmH_2O)	Survival Death	10 16	23.1 31.87	23.0 32.0	4.81 5.41	21	42	<0.001*
P_{plat} (cmH_2O)	Survival Death	10 16	18.3 29.46	19.0 29.0	3.3 5.19	12.0 19.0	23.0 38.0	<0.001*
ΔP_{insp} (cmH_2O)	Survival Death	10 16	15.5 19.875	15.5 20.5	4.64 4.88	7 7	22 27	0.033*
ΔP (cmH_2O)	Survival Death	10 16	9.57 15.25	9.4 15.4	2.93 3.03	6 9.5	13.2 19.4	<0.001*
V_T (l)	Survival Death	10 16	0.57 0.41	0.56 0.39	0.18 0.08	0.33 0.27	0.97 0.57	0.005*

Simonete, Alberti da Silva & Franck (2023)

41

WE NEED TO FRAGMENT

MECHANICAL POWER ?

42

The increase in Mechanical Power with increased dynamic elastic power and decreased static elastic power influenced the mortality rate of patients with SARS-CoV-2

Variable (*J*/min)	Outcome	N	Media	Median	Min.	Max.	Standard Deviation	*P* value
Mechanical Power or Total Inspiratory Energy	Survival	53	26.80	25.24	15.83	44.98	7.59	0.864
	Death	94	26.58	24.96	13.72	50.01	50.01	
Elastic Energy Dynamic Inflation	Survival	53	6.17	5.93	2.21	13.89	2.25	< 0.001
	Death	94	8.41	7.76	1.96	24.11	3.51	
Inspiratory Flux Resistance Energy	Survival	53	4.56	3.81	0.83	11.66	2.73	0.562
	Death	94	4.81	4.51	1.51	11.11	2.18	
Static Elastic Energy	Survival	53	16.07	15.61	6.27	27.59	5.07	0.005
	Death	94	13.36	11.71	5.35	33.34	5.84	

(Franck, Franck & Feronato, 2022)

43

Is mechanical power accurate?

44

Global lung mechanics provide for a poor surrogate of alveolar dynamics and methods for the in-depth analysis of alveolar dynamics on the level of individual alveoli are sparse and afflicted by important limitations.

Grune, Tabuchi & Kuebler, 2019

45

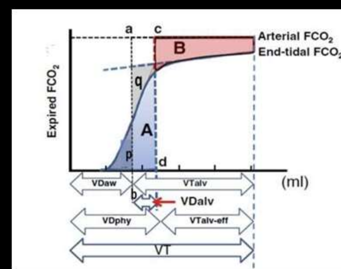
CAN WE MEASURE ALVEOLAR MECHANICS?

46

Alveolar mechanics: A new concept in respiratory monitoring

The concept of alveolar compliance depend on measuring the transalveolar pressure using esophageal balloon manometry and alveolar tidal volume using volumetric capnometry.

This may have multiple implications in the understanding of components of ventilator induced lung injury specifically alveolar stress, strain, and mechanical power.



Daoud & Franck, 2023.

47

DO WE NEED ANY INDEX?

48

49

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50

I hope to see them soon….

51