HAMILTON MEDICAL

Mechanical power and ventilator-induced lung injury

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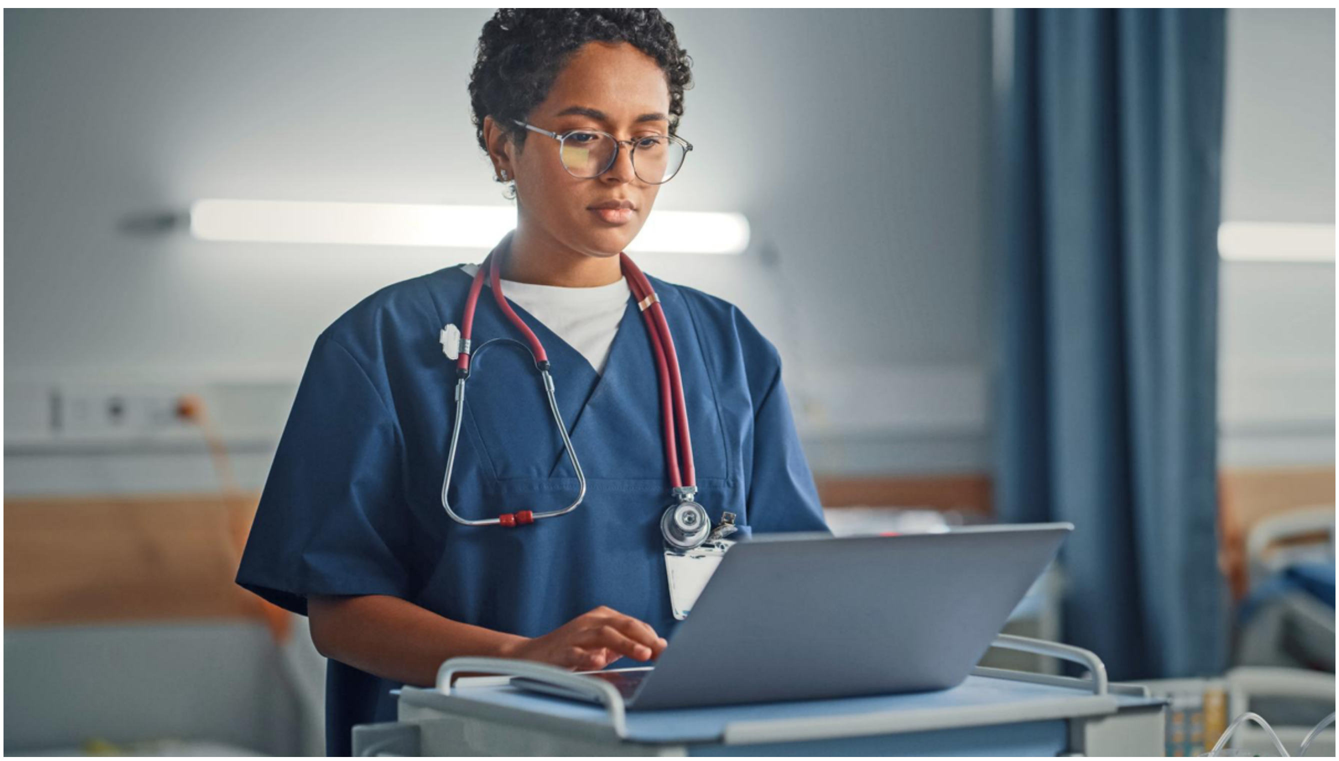
This article takes a closer look at the different components of mechanical power, its relevance in a clinical setting, and its use as a monitoring parameter.



The scope of this discussion is limited to mechanical power (MP) during the inspiratory phase of controlled ventilation, assuming there is no patient effort.

In physics:

- Mechanical work is the energy transferred to (or from) an object via the application of force along a movement from one position to another.

- Power is the amount of energy transferred per unit of time.

In mechanical ventilation, the power transferred from the ventilator to the respiratory system during inspiration is a unifying variable that combines the elements that may cause ventilator-induced lung injury (VILI) (1).

Mechanical power during CMV

During Controlled Mandatory Ventilation (CMV) with constant flow, MP can be described as work per breath (W) times the respiratory rate (RR) (Figure 1) (2):

Where:

- Wel,PEEP represents the Elastic Static component, i.e., the component of MP related to PEEP.
- Wel,DP represents the (tidal) Elastic Dynamic component, i.e., the component of MP related to tidal inflation. It has the shape of a right-angled triangle, whereby the vertical side corresponds to the tidal volume (Vt) and the horizontal side corresponds to the driving pressure (DP). The slope of the third side corresponds to compliance.
- Wres is the Resistive component, i.e., the energy dissipated during each inspiration to overcome the resistive and viscous properties of the respiratory system. Wres is represented by a parallelogram whose base corresponds to the difference between peak pressure (Ppeak) and plateau pressure (Pplat), while the height corresponds to Vt.

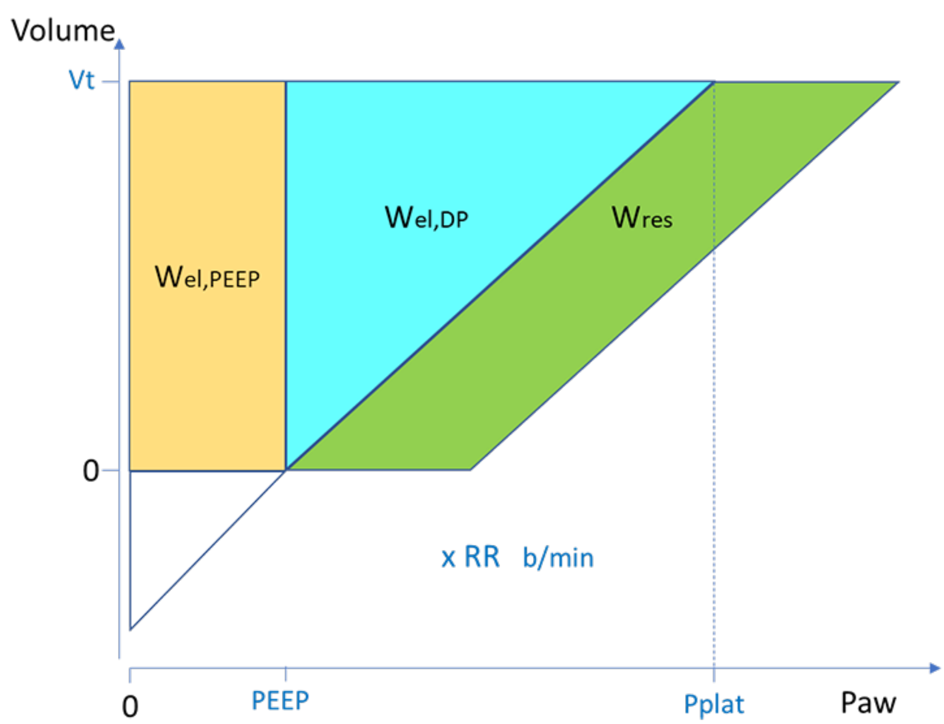


Figure 1: Pressure-volume diagram depicting the various components of mechanical power (see text for explanation)

Mechanical power during PCV

A similar approach can be applied during Pressure Controlled Ventilation (PCV) for the calculation of Wel,PEEP and Wel,DP from Vt, PEEP and DP. Wres can be **approximated** by calculating the area of the rectangle with Ppeak minus

PEEP as base and Vt as height, and then subtracting the triangle corresponding to Wel,DP. This calculation for Wres can be applied in the same way where Ppeak is equal to Pplat (Figure 2) or higher than it (Figure 3), i.e., where the end-inspiratory flow is zero or still positive, respectively. In both cases the **approximation** results in a slight overestimate of Wres, and hence of the true total ventilator work (3).

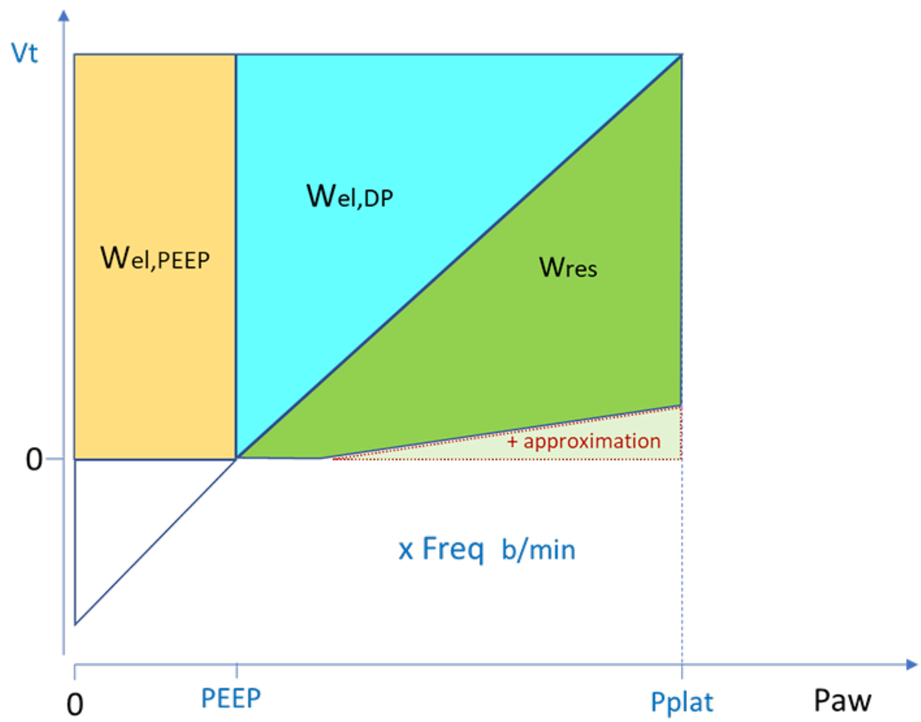


Figure 2: Approximation of Wres in PCV where Ppeak is equal to Pplat

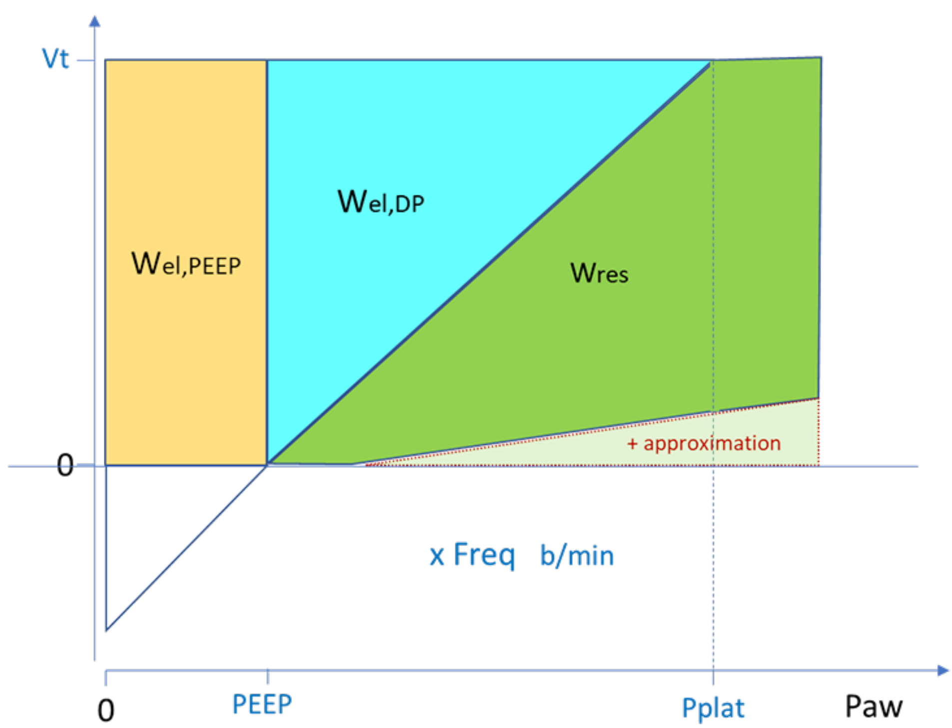


Figure 3: Approximation of Wres in PCV where Ppeak is higher than Pplat

Is mechanical power clinically relevant?

Quite a few investigators have computed the MP from the data of ventilatory studies in ICU patients with (2, 4, 5) or without ARDS (6, 7, 8).
In these analyses:

- Non-survivors received significantly larger MP than survivors
- Increasing MP was statistically correlated with ICU and hospital mortality, fewer ventilator-free days, and increased ICU and hospital length of stay

Overall, these retrospective studies suggest that excessive MP should preferably be avoided, assuming that a worse clinical outcome was related in part to VILI.

Is there a safe MP value for all patients?

The methods used to calculate MP in published studies must be read carefully to interpret them properly. Depending on the data available, the authors may have included or excluded some of the components of MP. There is also an ongoing debate regarding the most appropriate procedure for comparing different patients. Normalization for the patient's size (predicted weight), compliance or end-expiratory lung volume have been proposed.

Generally speaking, however, there is not yet a standardized approach for the calculation of MP, nor is there any widely accepted safe value for the estimated MP.

Is mechanical power ready for continuous monitoring?

Individual changes of ventilator settings have complex effects on other variables of the ventilation mechanics. The MP concept relies on the implicit assumption that all ventilatory variables have a linear relationship and the same contribution to VILI. However, this is obviously not the case, as PEEP for instance has a curvilinear (J-shape) relationship to VILI (2). During inspiration, there is probably a safe volume, a threshold value and an injurious zone that should not be reached (9). The inspiratory flow pattern, which is not accounted for in MP, may play a significant role in VILI (10).

Although a series of open issues remains, monitoring total MP and its components may prove useful for assessing the individual patient's evolution or their response to ventilatory setting changes. MP may become a new consideration along with several others in clinical judgement and decision making. Moreover, MP monitoring would greatly help the collection of high-quality data for any prospective study on the relationship between MP and VILI.

So how do we reduce the risk for VILI with ventilatory settings?

Different researchers have tried to identify the most detrimental components of ventilation. A retrospective study compiling the ventilatory data of 4500 ARDS patients enrolled in controlled studies assessed the relationships of MP, Vt, RR and DP to 28-day mortality using multivariable models (2). DP represents Vt normalized for compliance and is considered by many as a key component of VILI (11).

Not surprisingly, the authors found that global MP was correlated with mortality. When assessing the various components of MP, only the elastic dynamic component (MPel,DP, i.e, the MP that depends on Wel,DP) was statistically significant, while the components that depend on PEEP or resistance were not. MPel,DP is particularly simple to calculate at the bedside, in both CMV and PCV.

- **MPel,DP = Vt x DP x RR / 2**

Moreover, the authors found a similar predictivity of mortality just by combining DP and RR in the following index:

- **4DP+RR Index = (4 x DP) + RR**

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The authors concluded that “although mechanical power was associated with mortality in patients with ARDS, the ΔP and RR were as informative and easier to assess at the beside [sic]. Whether a ventilatory strategy based on these variables improves outcomes needs to be tested in randomized controlled studies” (2).

Footnotes

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