

Pneumatic performance

A comparison of turbine-driven mechanical ventilators and conventional ventilators

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Turbine-driven mechanical ventilators have some important advantages over conventional ventilators. The most obvious of these is independence of compressed air supply during patient transport, but higher NIV performance due to higher peak flow is also often mentioned. However, there is still a widespread belief that conventional ventilators using compressed air supplies outperform turbine-driven mechanical ventilators in their pneumatic performance. This assumption is, in many cases, based on the inability of the early-generation turbine-driven devices to achieve high peak pressures and to deliver accurate tidal volumes (Mehta S. 2001). In this article we will argue that the pneumatic performance of current turbine-driven ventilators, represented by the HAMILTON-C1, is at least equal to that of conventional ventilators.

Bench studies

The pneumatic performance of ventilators can only be tested with patient simulators. So-called bench studies examine trigger performance when connected to an active test lung. Data gained in bench studies reflects operation in a respiratory laboratory. ICU patients, however, have individual sensations: clinicians regularly report that a ventilator that interacts satisfactorily with one particular patient does not do so with another, even when both have similar pathologies.

The results of bench tests should be assessed with care for two more reasons. First, these tests often measure the ventilator trigger delay, T_d , which is the time a ventilator needs before it reacts to a patient's breath demand. Research has shown that a T_d below

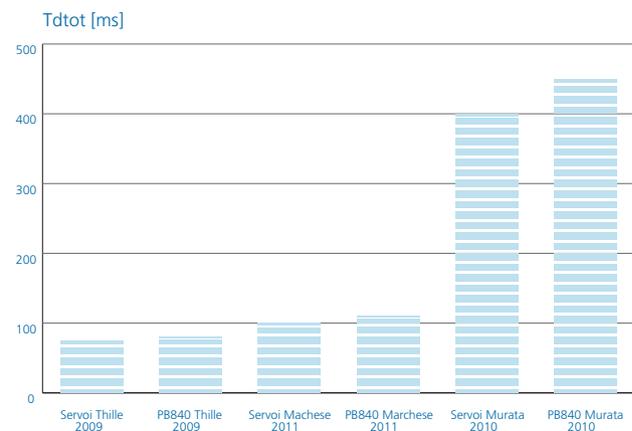


Figure 1: Comparison of measured total trigger delay (T_{dtot}) in different bench studies for Maquet Servo-i and Puritan Bennet PB 840. (From (Thille 2009), (Murata S. 2010), (Marchese A.D. 2011)).

150 ms cannot be felt by the patient (Whitelaw 1975). As all currently available ventilators have trigger delays that are below this 150-ms threshold, the impact of these test results on patient outcomes is questionable. Second, Olivieri et al. found that the results of bench tests vary considerably. Figure 1 shows total trigger delay measurements for the same two ventilators in three different bench-testing publications from different groups.

This wide variation is due to the absence of a standard for the setup, test materials used, and measurements recorded (Olivieri 2012). In bench tests, the placement of the flow and pressure analyzer, the method for simulating the patient and leakage, and the nomenclature for the time and effort measurements used are not standardized. As most bench tests do not include all available ventilators, the data presented in different publications has to be compared, but cannot be compared for the reasons discussed here. However, since bench tests are currently the only method available for comparing pneumatic performance across ventilators, Hamilton Medical carried out a test series in 2012. In this test, four conventional ICU ventilators were compared with the turbine-driven HAMILTON-C1, in both invasive and noninvasive modes.

Method

The objective of this bench test, carried out at Hamilton Medical in Bonaduz, Switzerland, was to prove that the pneumatic performance of the turbine-driven ventilator HAMILTON-C1 is equal to that of conventional ventilators. In this test, the trigger performance was also examined, using the setup suggested by Richard et al. (Richard 2002) and Thille (Thille 2009).

The HAMILTON-C1 was compared with:

- Servo-i, Maquet, Solna, Sweden
- Evita V500, Dräger, Lübeck, Germany
- Engström Carestation, General Electric Healthcare, Fairfield, Conn, USA

The smaller compartment of a two-compartment test lung (Model 1601, Michigan Instruments, Grand Rapids, MI, USA) was connected to a driving ventilator (HAMILTON-C2), which was set in APRV mode with an inspiratory trigger set at its maximal value, to mimic patient inspiratory effort, Plow 5 mbar, phigh-plow= effort, rate 10, I:E 1:5. The ventilator being tested was connected to the larger lung compartment. The two compartments were linked with a metal strip, so that inflation of the first compartment automatically inflated the second. Compliance was adjusted by variable spring positions

on the test lung; resistance was adjusted by variable airway restrictions. The low compliance of the smaller compartment, together with the loose-link connection between the compartments, prevented the inflation of the smaller compartment from influencing the cycling time and inflation speed of the larger compartment. At the proximal end of the breathing circuit (Y-piece), a Fleisch pneumotachograph (PT-180, Erich Jäger GmbH & CO. KG, Höchberg, Germany) measured real-time air flow and pressure of the test ventilator, and transmitted this data via a recording system (BIOPAC Systems, Goleta, CA, USA) to a PC for analysis (AcqKnowledge 3.9.1 software, BIOPAC Systems, Goleta, CA, USA). Pressure and volume measurements taken by the pneumotachograph were calibrated before performing the tests using a digital manometer (halstrup-walcher GmbH, Kirchzarten, Germany) and precision syringes (S1500, Hamilton Company, Reno, Nevada, USA).

We tested ventilator performance:

- During pressure support ventilation: support level 10 mbar, PEEP 5 mbar, 10 breaths/minute, cycling 25%
- Under normal lung conditions: compliance 60 ml/mbar, resistance 5 mbar/l/s
- Under obstructive lung conditions: compliance 60 ml/mbar, resistance 20 mbar/l/s
- Under normal lung conditions: NIV with medium (8 mbar) effort

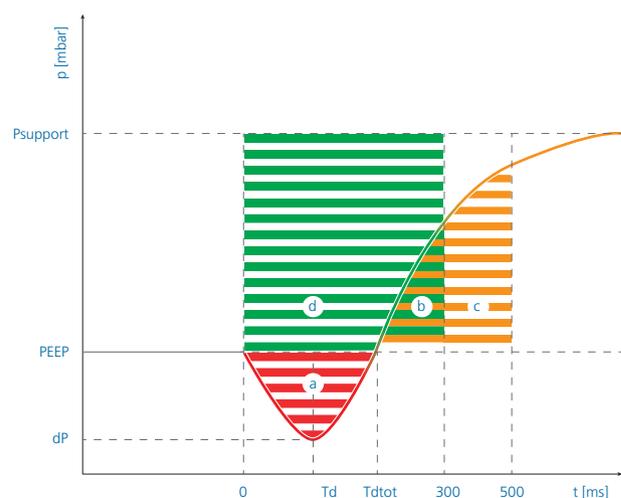


Figure 2: Defined values in Hamilton Medical bench testing, according to Olivieri et al 2012. PTPt corresponds to area **d**, PTP300 to area **b** minus area **a**, PTP500 to areas **c** and **b** minus area **a**. The ideal PTP300 would have the size of **d**.

- Under normal lung conditions: NIV with high effort (20 mbar) in the above-described normal conditions

For noninvasive measurement, the appropriate mode was selected in the test ventilator, and a leakage (flow 15 l/min at pressure support level of 10 mbar, resulting in a total leak of up to 1000 ml per cycle) was built into the circuit. Ventilation was provided using a face mask (Vygon Schweiz GmbH, Niederwangen BE, Schweiz) to the face model Bill I (VBM Medizintechnik GmbH, Sulz a. N, Germany).

The measured values are presented in Figure 2 and correspond to the method suggested by Olivieri et al. (Olivieri 2012). PTPt is pressure-time-product trigger. PTP is pressure-time-product. PTP300 and PTP500 refer to PTP at 300 and 500 ms, respectively. Time zero is defined as the start of the inspiration on the driving ventilator side, displaying the start of the patient's inspiration.

To better compare the ventilator responses, we show the PTP values as a percentage of the ideal value. For example,

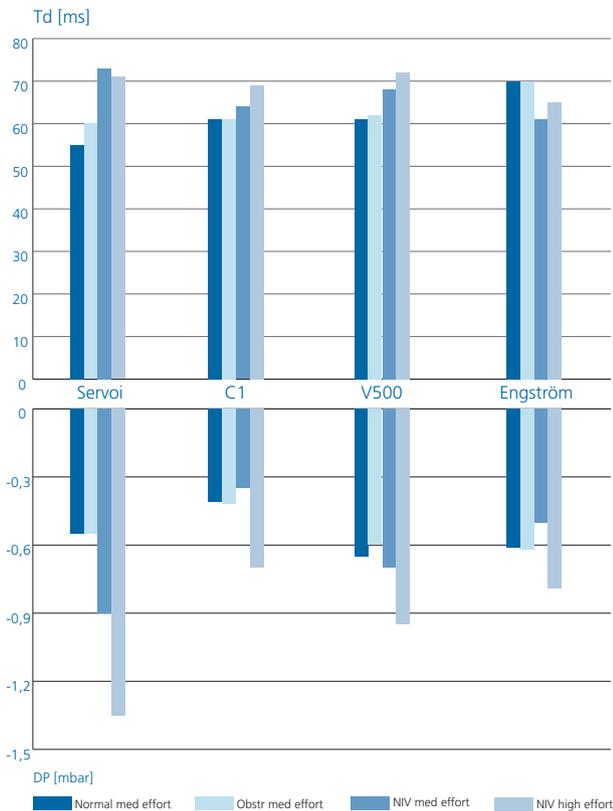


Figure 3: Trigger delay (Td) and drop pressure (DP) during active inspiration with normal and obstructive lung function, and noninvasive ventilation (NIV) with normal lung conditions and medium and high inspiration effort.

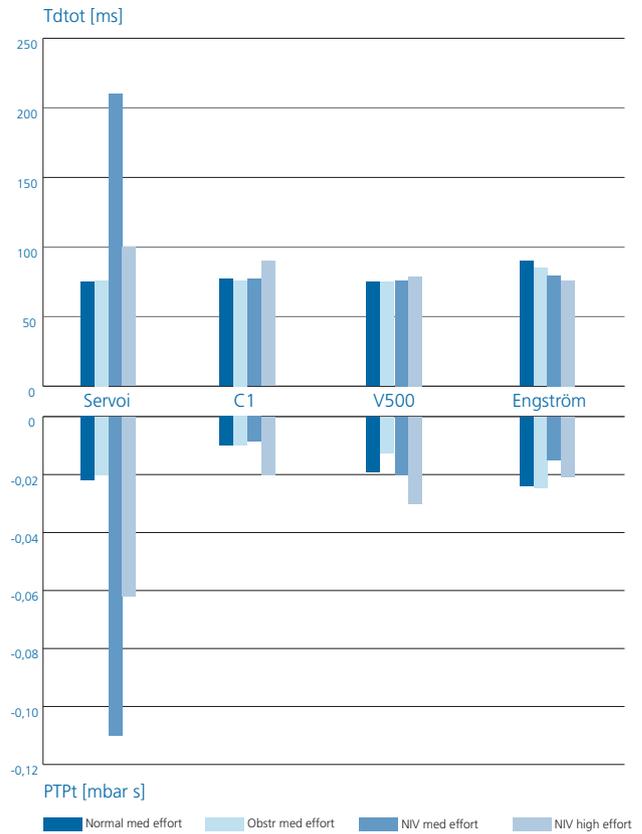


Figure 4: Pressure-time-product (PTP) during active inspiration with normal and obstructive lung function, and noninvasive ventilation (NIV) with normal lung conditions and medium and high inspiration effort.

the ideal PTP300 would be 3 mbar s for 300 ms and a pressure support of 10 mbar.

Results

Figures 3 through 5 show our results. The graphs show the mean values over five consecutive breath cycles with normal compliance (60 ml/mbar), normal ("Normal") and high ("Obstr") resistance, and medium demand (8 mbar) for the four tested ventilators. NIV indicates measurements that include leakage, as well as measurements in noninvasive mode with leakage compensation enabled, where possible. The response to a medium demand (8 mbar) was compared to the

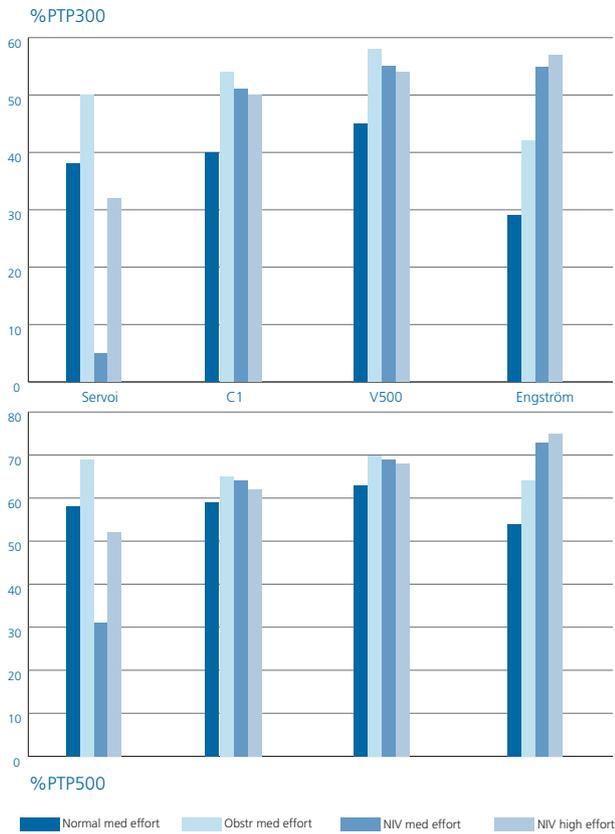


Figure 5: PTP in 300 and 500 ms during active inspiration with normal and obstructive lung function, noninvasive ventilation (NIV) with normal lung conditions and medium and high inspiration effort. The graphs show the percentage of the ideal value at pressure support level (10 mbar) times elapsed time.

response to a high demand (20 mbar). For both NIV tests, we used “normal” lung conditions. The outcomes prove that the performance of the HAMILTON-C1 is either equal to that of conventional high-end ICU ventilators such as Maquet Servo-i and Dräger V500, or exceeds their performance, with shorter Td, and smaller DP and PTPt.

Further research

Our data is supported by additional research results. Richard et al. found that turbine-driven ventilators achieve the same level of performance in pressurization and trigger response as conventional ventilators (J. C. Richard 2002).

In two other research projects, the HAMILTON-C1

and HAMILTON-T1 were compared to conventional ventilators.

First, Cartaux et al. show that turbine-driven devices (among them HAMILTON-T1, CareFusion Vela, ResMed Elisee250, Philips Respironics BiPAP vision, Philips Respironics V60, and Dräger Carina) outperform conventional ICU ventilators using a compressed air supply (including CareFusion Avea, GE Engström, and Dräger Evita XL) with shorter trigger delay times and better synchronization in the presence of large leakages (exceptions: Covidien PB840 and Dräger Evita V500 (Carteaux G. 2012)).

Second, Bousset et al. tested different transport ventilators and concluded that “Clearly, for triggering and pressurization capabilities, the latest generation of turbine-powered transport ventilators outperformed the gas-compressed powered model.” (Bousset S. 2013)

Conclusion

The results of the Hamilton Medical 2012 bench test show that turbine-driven ICU ventilators are comparable to compressed-air-driven ventilators in terms of pneumatic performance. Our findings are supported by three additional recent publications, as mentioned above. We, therefore, conclude that the pneumatic performance of the HAMILTON-C1 compact turbine-driven ventilator is at least equal to, or better than, that of conventional, compressed-air-driven ICU ventilators.

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