# A Bench Study of 2 Ventilator Circuits During Helmet Noninvasive Ventilation

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**OBJECTIVE: To compare helmet noninvasive ventilation (NIV), in terms of patient-ventilator interaction and performance, using 2 different circuits for connection: a double tube circuit (with one inspiratory and one expiratory line) and a standard circuit (a Y-piece connected only to one side of the helmet, closing the other side). METHODS: A manikin, connected to a test lung set at 2 breathing frequencies (20 and 30 breaths/min), was ventilated in pressure support ventilation (PSV) mode with 2 different settings, randomly applied, of the ratio of pressurization time to expiratory trigger time ($T_{press}/T_{exp\text{-}trigger}$) 50%/25%, default setting, and $T_{press}/T_{exp\text{-}trigger}$ 80%/60%, fast setting, through a helmet. The helmet was connected to the ventilator randomly with the double and the standard circuit. We measured inspiratory trigger delay ($T_{insp\text{-}delay}$), expiratory trigger delay ($T_{exp\text{-}delay}$), $T_{press}$), time of synchrony ($T_{synch}$), trigger pressure drop, inspiratory pressure-time product (PTP), PTP at 300 ms and 500 ms, and PTP at 500 ms expressed as percentage of an ideal PTP500 (PTP500 index). RESULTS: At both breathing frequencies and ventilator settings, helmet NIV with the double tube circuit showed better patient-ventilator interaction, with shorter $T_{insp\text{-}delay}$, $T_{exp\text{-}delay}$, and $T_{press}$; longer $T_{synch}$; and higher PTP300, PTP500, and PTP500 index (all $P < .01$). CONCLUSIONS: The double tube circuit had significantly better patient-ventilator interaction and a lower rate of wasted effort at 30 breaths/min.** *Key words: noninvasive ventilation; patient-ventilator interaction; helmet; ventilator circuit.* [Respir Care 2013;58(9):1474–1481. © 2013 Daedalus Enterprises]

## Introduction

Noninvasive ventilation (NIV) is an effective technique to treat patients with acute respiratory failure. Although many factors can influence NIV success,[1] tolerance is a crucial determinant of NIV outcome,[2,3] depending on both patient-ventilator interaction and the interface used.[4,5]

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The authors have disclosed no conflicts of interest.

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The helmet is a relatively new interface, proposed as alternative to the face mask to deliver NIV, since it reduces the incidence of some of the most common face mask side effects (ie, pain at the nasal bridge, skin ulceration and necrosis, conjunctive inflammation, interface intolerance); therefore, it is more tolerated than the face mask and requires fewer discontinuations, allowing a prolonged application.[6,7] However, several studies have clearly demonstrated that the helmet is less efficient than the face mask in terms of gas exchange improvement,[6,7] patient-ventilator interaction,[8,9] and inspiratory effort reduction.[9-11] These drawbacks are directly related to the helmet's physical characteristics such as the large inner volume and the highly compliant material, determining an initial pressure dissipation, and prolonging the time needed to reach the preset level of pressure support.[12]

In the last years, many efforts have been made to improve helmet NIV, and several models of helmet with different designs and materials are now available for clin-

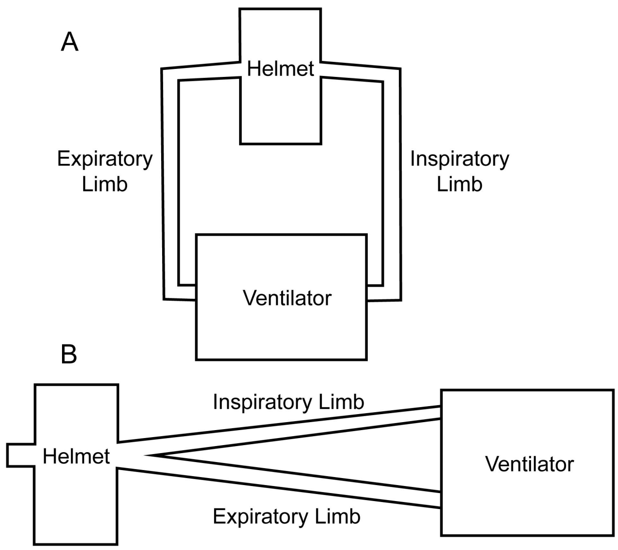


Fig. 1. A: Schematic representation of a helmet connected to a ventilator with a double tube circuit. B: Helmet connected to the ventilator with a standard circuit: the Y-piece is connected only to one side of the helmet: the other side is occluded.

ical use.[12] Moreover, ventilator technological improvements, such as specific softwares for NIV, new ventilator modes such as neurally adjusted ventilatory assist,[13] and various levels of inspiratory and expiratory triggers,[14] have also been proposed to minimize the impact of both air leaks and the helmet's intrinsic characteristics on patient-ventilator interaction.

A poorly investigated aspect during helmet NIV is the role played by the circuit connecting the helmet to the ventilator. In several studies[6-9] the helmet has been connected to the ventilator through a double tube circuit (one inspiratory and one expiratory line, connected to the 2 specific inspiratory and expiratory ports of the helmet) (Fig. 1A). However, in clinical practice the interface is often connected to the ventilator through a standard circuit, connecting the Y-piece only to one side of the helmet and occluding the other side, thereby realizing a single port circuit (see Fig. 1B). Even if the helmet was originally designed to be connected to the ventilator through a double circuit, there are no published preclinical tests of this circuit, nor a formal contraindication to the use of a standard circuit, We have personally observed the use of a single circuit, probably for the sake of simplicity, in several ICUs across Europe. Knowing that the supposed improper use of these clinical devices is unfortunately widespread, we think it useful to formally investigate if the kind of circuit used really plays a role in patient-ventilator interaction during helmet NIV.

The aim of this bench study was to compare the helmet NIV with the double circuit to the helmet NIV with the standard circuit in terms of ventilator performance and patient-ventilator interaction (assuming the simulator as a patient).

**QUICK LOOK**

**Current knowledge**

During noninvasive ventilation (NIV) the type of ventilator and interface impact patient-ventilator interaction. Auto-triggering due to leaks is the most common asynchrony during NIV.

**What this paper contributes to our knowledge**

In a model of helmet NIV, a double-limb ventilator circuit with a Y-piece significantly improved synchrony and decreased missed triggers, compared to the traditional circuit.

## Methods

This study was performed at the Respiratory Mechanics Laboratory of the Catholic University in Campobasso, Italy, between November 2010 and March 2011.

NIV was applied to a manikin (Laerdal Medical, Stavanger, Norway), connected to an active test lung (ASL 5000, IngMar Medical, Pittsburgh, Pennsylvania) set to breathe at 2 breathing frequencies (20 and 30 breaths/min) through a helmet (CaStar, StarMed, Mirandola, Italy). The manikin was connected to the test lung through the trachea with a 5 cm plastic tube having the same diameter of a 70 kg adult male trachea (about 2 cm).

The following simulator settings remained unchanged throughout the study: single-compartment model; resistance 4 cm $H_2O$/L/s; compliance 60 mL/cm $H_2O$; simulator inspiratory time 640 ms at 20 breaths/min, or 430 ms at 30 breaths/min; inspiratory muscle pressure ($P_{mus}$) 6 cm $H_2O$, semi-sinusoidal waveform, rise time 15%, inspiratory hold 5%, and release time 25%.

Helmet NIV was delivered in pressure support ventilation (PSV) (pressure support 12 cm $H_2O$ and PEEP 8 cm $H_2O$), with an ICU ventilator (Puritan Bennett 840, Covidien, Mansfield, Massachusetts), at 2 ventilator settings, randomly applied: default ($T_{press}$/$T_{exp\text{-}trigger}$ 50%/25%) and fast ($T_{press}$/$T_{exp\text{-}trigger}$ 80%/60%), where $T_{press}$ is the rise time to reach the preset level of pressure support and $T_{exp\text{-}trigger}$ is the flow percentage threshold at which the expiratory valve opens, the inspiratory phase ends, and expiration starts.

The helmet was placed on the manikin and connected to the ventilator with the double tube circuit or the standard circuit, randomly applied. The presence of air leaks was eliminated by tightening the soft helmet collar to the manikin neck.

The air flow delivered by the ventilator to the helmet during the inspiratory phase was measured with a pneumotachograph (Fleisch 2, Metabo, Epalinges, Switzerland) positioned at the distal end of the inspiratory limb of the double circuit and at the Y-piece with the standard circuit. The air flow signal integrated on time was used to obtain the inspiratory tidal volume ($V_T$) and to measure the mechanical inspiratory and expiratory time. The airway pressure ($P_{aw}$) was measured by a pressure transducer with a differential pressure of $\pm 10$ cm $H_2O$ (Digima Clic-1, ICU-Lab System, KleisTEK, Bari, Italy), placed distally to the pneumotachograph. All these signals were acquired, amplified, filtered, digitized at 100 Hz, recorded on a dedicated computer, and analyzed with a specific software (ICU-Lab 2.3, KleisTEK, Bari, Italy). The air flow, $V_T$, $P_{aw}$, and $P_{mus}$ signals were processed with a specific software (LabView, IngMar Medical, Pittsburgh, Pennsylvania). The amount of $V_T$ delivered to the simulator during its active inspiration (ie, while $P_{mus}$ was negative) was the "neural $V_T$," calculated as the volume generated from the onset of $P_{mus}$ negative deflection to its return to baseline.

Patient-ventilator interaction was evaluated by determining:

- Inspiratory trigger delay ($T_{insp\text{-}delay}$), calculated as the time lag between the onset of $P_{mus}$ negative swing and the start of the ventilator support (ie, $P_{aw}$ positive deflection)
- Expiratory trigger delay ($T_{exp\text{-}delay}$), assessed as the delay between the offset of the inspiratory effort and the offset of the mechanical insufflation (ie, flow deflection)
- Pressurization time ($T_{press}$), defined as the time necessary to achieve the preset level of pressure support
- Time of synchrony ($T_{synch}$), defined as the time during which $P_{mus}$ and $P_{aw}$ were in phase (ideally 100%)
- Wasted efforts, defined as ineffective inspiratory efforts not assisted by the ventilator

The ventilator performance with the 2 helmet circuits was evaluated in terms of:

- Trigger pressure drop, defined as the pressure drop generated by triggering the ventilator
- Inspiratory pressure-time product (inspiratory PTP), defined as the area under the $P_{aw}$ curve relative to time between the onset of inspiratory effort and mechanical assistance (Fig. 2)
- PTP at 300 and 500 ms (PTP300 and PTP500), defined as the speediness of pressurization and the ventilator's capacity to maintain the preset pressure within the first 300 ms and 500 ms, respectively (see Fig. 2)
- PTP500 index, expressed as percentage of the ideal PTP, which is unattainable since it would imply a trigger pressure drop of zero and an instantaneous pressurization of the machine.

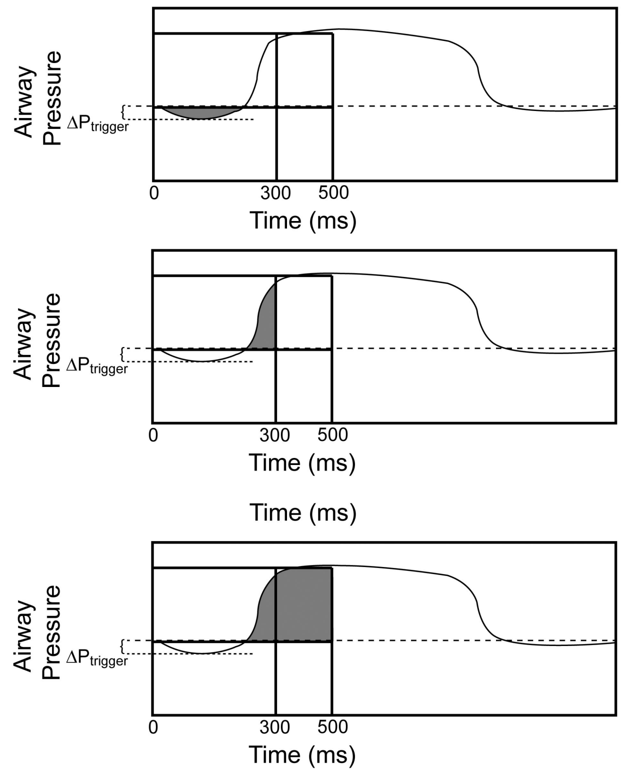


Fig. 2. Inspiratory pressure-time product (PTP), PTP at 300 ms, and PTP at 500 ms on the pressure/time trace.

### Statistical Analysis

All data are expressed as mean $\pm$ SD. Analysis of variance for repeated measures was used to detect significant differences between the different experimental conditions. When significant differences were detected, post-hoc analysis was performed using the Bonferroni test. *P* values $< 0.05$ were considered statistically significant.

## Results

As shown in Figure 3, at both breathing frequencies and ventilator settings tested, $T_{insp\text{-}delay}$ and $T_{exp\text{-}delay}$ were significantly shorter with the double tube than with the standard circuit ($P < .01$). With the default setting and a breathing frequency of 30 breaths/min, the $T_{insp\text{-}delay}$ did not show statistically significant differences.

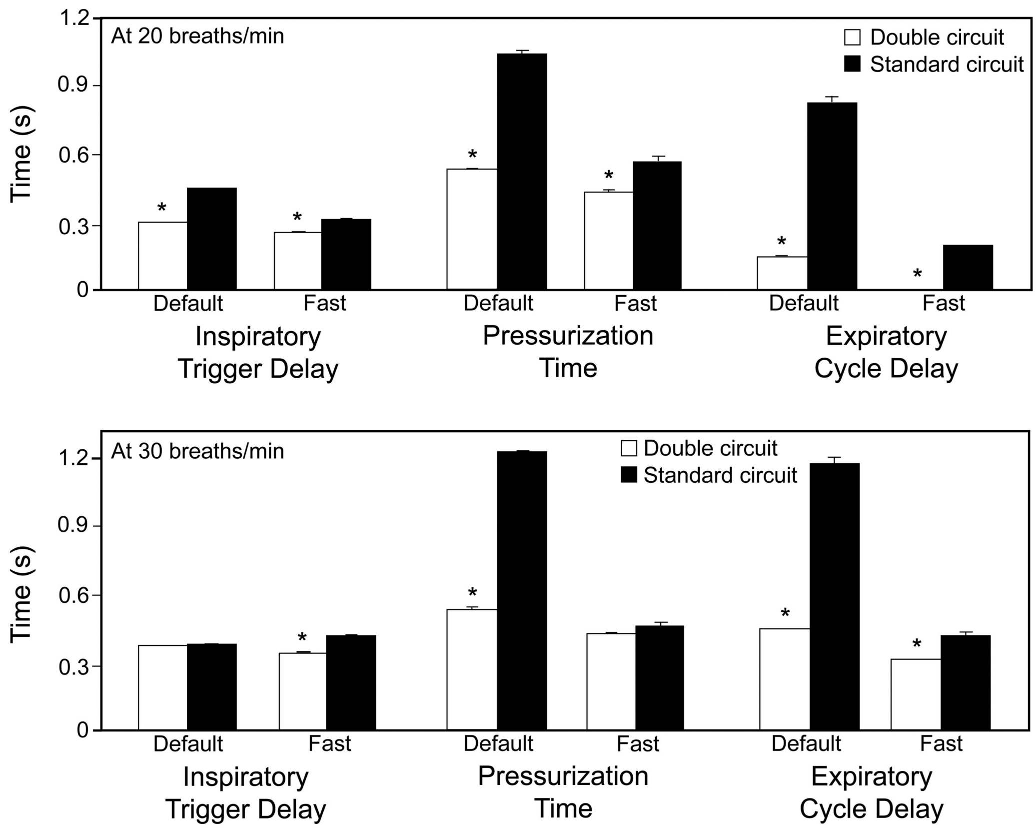


Fig. 3. Inspiratory trigger delay, pressurization time, and expiratory trigger delay at 20 and 30 breaths/min, with 2 ventilator settings: default and fast (see text). * For double circuit versus standard circuit: $P < .01$.

The $T_{press}$ with the double tube circuit was always shorter than with the standard circuit ($P < .01$), except at the fast setting and 30 breaths/min ($P = .10$). A shorter $T_{press}$ indicates a better pressurization.

The $T_{synch}$ with the double tube circuit was longer than with the standard circuit in all the tested conditions ($P < .01$). The difference was not statistically significant with the default setting at 30 breaths/min (Fig. 4).

In the matter of ventilator performance, at 20 breaths/min, with the double circuit we observed shorter trigger pressure drop and inspiratory PTP, compared to the standard circuit. At 30 breaths/min the situation was opposite (Table). Of note, at 30 breaths/min and the default setting, with the standard circuit there was a wasted effort/cycled effort ratio of 1 to 1: this means we observed a wasted effort after each successfully triggered inspiratory effort, so about the 50% of cycles were wasted. At 30 breaths/min with the fast setting the standard circuit allowed a statistically better performance in terms of trigger pressure drop and inspiratory PTP than did the double circuit.

Figure 5 depicts the PTP300 and PTP500 values, which were always significantly higher with the double tube than with the standard circuit ($P < .01$). Accordingly, the calculated PTP500 index was higher with the double then with the standard circuit, although this difference was statistically significant only with the default setting, at both 20 and 30 breaths/min (59% vs 51% at 20 breaths/min and 57% vs 54% at 30 breaths/min, $P < .05$).

The $V_T$ and neural $V_T$ values were significantly higher with the double tube circuit, compared to the standard circuit ($P < .001$, see the Table). With the default setting and 30 breaths/min these values were higher with the standard circuit.

Wasted effort never occurred with the double circuit, irrespective of the breathing frequency and ventilator settings. With the standard circuit, with the default setting and 30 breaths/min, wasted effort accounted for 50% of the overall breaths.

## Discussion

The results of the present study suggest that during helmet NIV, beyond the kind of helmet and the applied ventilator settings, the optimal choice of the circuit plays a major role in improving patient-ventilator interaction. Compared to the standard circuit with a Y-piece, a double tube circuit showed both a significantly better patient-ventilator

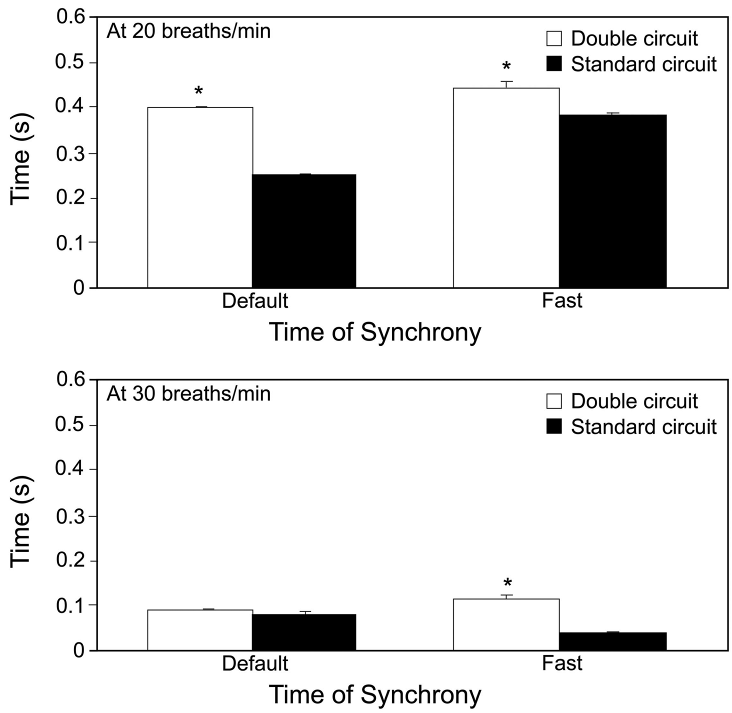


Fig. 4. Time of synchrony at 20 and 30 breaths/min, with 2 ventilator settings: default and fast (see text). * For double circuit versus standard circuit: $P < .01$.

Table. Double Tube Circuit Versus Standard Circuit During Helmet Noninvasive Ventilation

| | At 20 Breaths/Min | | At 30 Breaths/Min | |
|---|---|---|---|---|
| | Double Circuit | Standard Circuit | Double Circuit | Standard Circuit |
| Trigger Pressure Drop, cm $H_2O$ | | | | |
| Default setting | 0.79 ± 0.04* | 1.29 ± 0.01 | 1.76 ± 0.02† | 0.99 ± 0.03 |
| Fast setting | 0.57 ± 0.01† | 0.78 ± 0.02 | 1.52 ± 0.06† | 1.4 ± 0.07 |
| Inspiratory PTP, cm $H_2O$•s | | | | |
| Default setting | 0.1 ± 0.01* | 0.3 ± 0.01 | 0.36 ± 0.01* | 0.14 ± 0.01 |
| Fast setting | 0.06 ± 0.01† | 0.1 ± 0.01 | 0.25 ± 0.02 | 0.29 ± 0.01 |
| Percent of ideal PTP at 500 ms | | | | |
| Default setting | 59* | 51 | 57* | 54 |
| Fast setting | 67 | 66 | 64 | 63 |
| Tidal volume, mL | | | | |
| Default setting | 768 ± 7† | 556 ± 2 | 566 ± 5† | 581 ± 5 |
| Fast setting | 691 ± 8† | 570 ± 6 | 568 ± 3† | 368 ± 4 |
| Neural tidal volume, mL | | | | |
| Default setting | 552 ± 9† | 258 ± 7 | 145 ± 1† | 201 ± 5 |
| Fast setting | 625 ± 14† | 392 ± 2 | 170 ± 9 | 151 ± 3 |

± Values are mean ± SD.
For double circuit vs standard circuit: * $P < .05$, † $P < .01$.
PTP = pressure-time product

interaction (shorter inspiratory and expiratory delays and longer time of synchrony) and a significantly higher ventilator performance.

As reported in the introduction, the helmet is not an easy interface, compared to the face mask; therefore, clinicians must apply various strategies to minimize its drawbacks

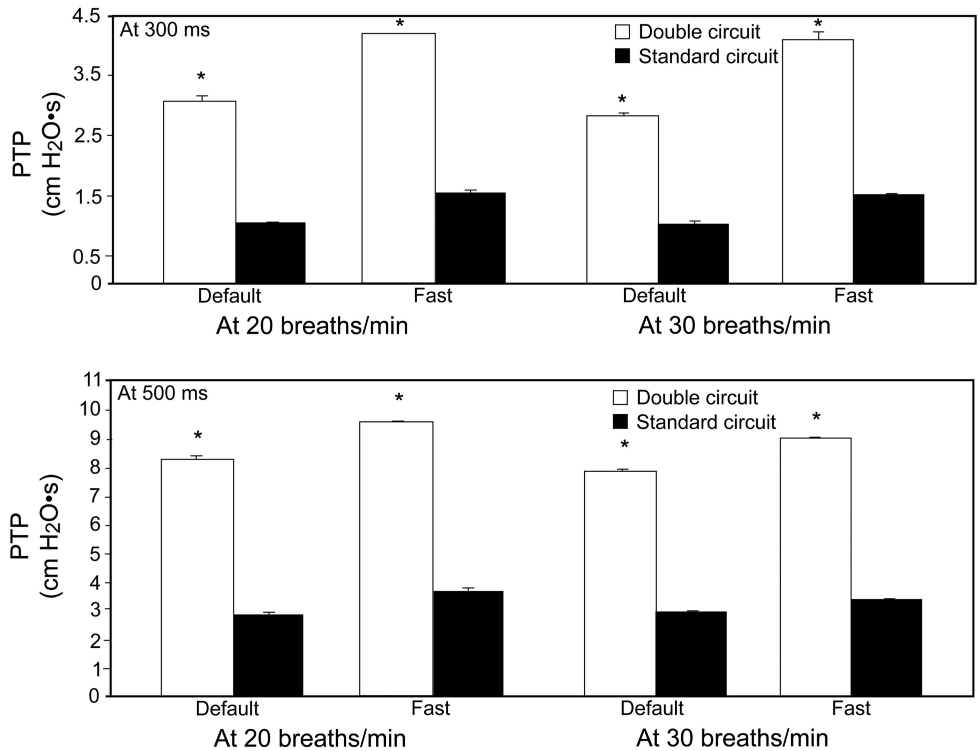


Fig. 5. Pressure-time product (PTP) at 300 ms and 500 ms, at 20 breaths/min and 30 breaths/min with 2 ventilator settings: default and fast (see text). * For double circuit versus standard circuit: $P < .01$.

and optimize its potentiality. The goal is to improve NIV tolerance: to ameliorate patient's comfort and prolong the time of continuous NIV application.[6,7] Thus, it is possible to improve gas-exchange and reduce the work of breathing and the risk of infections related to invasive mechanical ventilation.[12,15,16]

The first strategy to apply is the use of an optimized ventilator setting. In this study the choice of specific pressure support and PEEP values as well as $T_{press}$ and $T_{exp\text{-}trigger}$ was based on the results of studies investigating the use of specific ventilator settings to enhance ventilator performance with the helmet, thus improving patient-ventilator interaction. Vargas and colleagues[14] showed that increasing by 50% both pressure support and PEEP levels and using the highest pressurization rate can significantly improve patient-ventilator interaction during helmet NIV. In a bench study, Costa and colleagues[17] evaluated patient-ventilator interaction during PSV delivered with 3 different interfaces (endotracheal tube, face mask, and helmet). The authors concluded that an appropriate choice of ventilator settings can improve patient-ventilator interaction during helmet NIV, especially at high breathing frequencies. In particular, the use of a fast setting can significantly reduce some of the helmet limitations in terms of patient-ventilator interaction.

Moreover, new NIV-dedicated ventilator software systems have been introduced into clinical use: they propose to improve ventilator performance and so patient-ventilator interaction, thanks to a specific algorithm designed to compensate for air leaks. New ventilation modes have also been investigated, such as neurally adjusted ventilatory assist, in order to improve patient-ventilator interaction during NIV, as recently demonstrated by Cammarota and colleagues.[13]

The success of NIV depends also on the kind of helmet. In recent years, many technological efforts have been made to improve helmet features in terms of design, material, and application systems, since it has been demonstrated[13] that the helmet's specific physical characteristics may significantly affect patient-ventilator interaction, suggesting that different helmets determine different ventilator performance, even if specific ventilator settings are applied.

In real-life clinical practice, the method of connecting the helmet and the ventilator can be different in various ICUs. To our knowledge, this is the first study investigating this practical aspect related to helmet NIV: the optimal circuit connecting the helmet to the ventilator and its influence on ventilator performance and patient-ventilator interaction during NIV. This element can play an important role in determining failure or success of NIV.

We decided to perform a physiologic bench study, mimicking a normal subject (with normal compliance and normal resistances) in order to define only the limitations of the interface and the ventilator setting, including the circuit, thus eliminating all the other possible variables altering the results.

In our study, during helmet NIV the use of a double tube circuit showed a better patient-ventilator interaction, compared to the standard circuit, as demonstrated by shorter $T_{insp\text{-}delay}$ and $T_{exp\text{-}delay}$, faster $T_{press}$, and higher $T_{synch}$, an important parameter to evaluate patient-ventilator interaction. The observed differences between the 2 circuits did not reach statistical significance with the default setting; however, it is noteworthy that the default setting is not the optimal ventilator setting for NIV, especially at high breathing frequencies, which dramatically reduce $T_{synch}$ during helmet NIV.

Using the double tube circuit we observed higher PTP300, PTP500, and PTP500 index, indicating a faster speediness of pressurization and a better capacity of the ventilator to maintain the preset pressure within the first 300 and 500 ms, respectively.

During helmet NIV with the double tube circuit, both patient-ventilator interaction and ventilator performance parameters were better, suggesting that interaction and performance are strongly linked and are critical for NIV success.

In further analyzing performance, at 20 breaths/min, we observed shorter trigger pressure drop and inspiratory PTP values with the double tube circuit; the situation was opposite at 30 breaths/min, due to the fact that at this frequency the wasted effort/cycled effort ratio of 1 to 1 was observed.

Despite the helmet's now being considered a suitable alternative to the face mask for delivering NIV, it is well known from the literature that during helmet NIV asynchronous phenomena are more likely to be produced, compared to NIV with face mask, with a significant worsening of patient-ventilator interaction,[8-11] especially at elevated breathing frequencies.[17] This suggests that the helmet should not be used in patients with COPD exacerbation, at high risk of patient-ventilator asynchrony, and should be used only with specific settings in patients with restrictive disease.[14-17] Wasted effort is a common asynchronous phenomena during mechanical ventilation, and in the present study, at 30 breaths/min with the default setting, we observed a wasted effort/cycled effort ratio of 1 to 1. Moreover, the absence of wasted effort with the double tube circuit demonstrates the positive influence of the optimal circuit on patient-ventilator interaction and ventilator performance, as wasted effort generates patient discomfort, gas exchange deterioration, work of breathing increase, and rise in risk of NIV failure.[12-17]

It is noteworthy that better interaction and performance determined significantly higher $V_T$ and neural $V_T$ values with the double tube circuit, compared to the standard circuit, at both breathing frequencies and ventilator settings, except at 30 breaths/min with the default setting; however, this condition was altered by the presence of wasted effort, which make the analysis unreliable. On the basis of our results, we suggest the use of a double tube circuit to connect the helmet to the ventilator during helmet NIV.

A possible explanation is that, using a standard circuit, both the inspiratory and the expiratory flows are forced to pass through the Y-piece of the circuit, probably generating turbulence that may increase resistances inside the passage, thus inducing alterations in patient-ventilator interaction. These drawbacks can be reduced with the application of a double tube circuit, since in this case the inspiratory and expiratory flows pass through different limbs, probably avoiding turbulence and its negative consequences.

Finally, several important limitations of the study must be addressed. First, we tested only one kind of helmet and one ventilator, so our results cannot be generalized to all the devices on the market, although major differences are unlikely, because of similar design of the inspiratory and expiratory ports in the various devices clinically used. Another limitation is that we performed a bench physiological study, not a clinical study on critically ill patients, nor a bench study testing different respiratory system mechanics conditions to simulate clinical scenarios. Finally, the design of our study did not allow us to investigate $CO_2$ elimination, although it would be interesting to investigate whether or not the 2 different circuits have an impact on $CO_2$ rebreathing because of the increased expiratory resistance with the standard circuit.

## Conclusions

In order to correctly apply helmet NIV it is important to consider that, beyond the kind of helmet and the ventilator settings, the optimal choice of circuit also plays a major role in improving patient-ventilator interaction. Compared to the standard circuit with a Y-piece, with a double tube circuit we observed both a significantly better patient-ventilator interaction, with shorter inspiratory and expiratory delays, a longer time of synchrony, the absence of wasted effort, and a better ventilator performance, suggesting that this kind of circuit should be preferred in clinical practice.

### REFERENCES

1. Nava S, Hill N. Non-invasive ventilation in acute respiratory failure. Lancet 2009;374(9685):250-259.
2. Squadrone E, Frigerio P, Fogliati C, Gregoretti C, Conti G, Antonelli M, et al. Non invasive versus invasive ventilation in COPD patients with severe acute respiratory failure deemed to require ventilatory assistance. Intensive Care Med 2004;30(7):1303-1310.
3. Carlucci A, Richard JC, Wysocki M, Lepage E, Brochard L. Non invasive versus conventional mechanical ventilation. An epidemiologic survey. Am J Respir Crit Care Med 2001;163(4):874-880.

4. Navalesi P, Fanfulla F, Frigerio P, Gregoretti C, Nava S. Physiologic evaluation of non invasive mechanical ventilation delivered with three types of masks in patients with chronic hypercapnic respiratory failure. Crit Care Med 2000;28(6):1785-1790.
5. Vignaux L, Vargas F, Roeseler J, Tassaux D, Thille AW, Kossowsky MP, et al. Patient-ventilator asynchrony during non-invasive ventilation for acute respiratory failure: a multicenter study. Intensive Care Med 2009;35(5):840-846.
6. Antonelli M, Conti G, Pelosi P, Gregoretti C, Pennisi MA, Costa R, et al. New treatment of acute hypoxemic respiratory failure: noninvasive pressure support ventilation delivered by helmet: a pilot controlled trial. Crit Care Med 2002;30(3):602-608.
7. Antonelli M, Pennisi MA, Pelosi P, Gregoretti C, Squadrone V, Rocco M, et al. Noninvasive positive pressure ventilation using a helmet in patients with acute exacerbation of chronic obstructive pulmonary disease: a feasibility study. Anesthesiology 2004;100(1): 16-24.
8. Racca F, Appendini L, Gregoretti C, Stra E, Patessio A, Donner CF, Ranieri VM. Effectiveness of mask and helmet interface to deliver non invasive ventilation in a human model of resistive breathing. J Appl Physiol 2005;99(4):1262-1271.
9. Navalesi P, Costa R, Ceriana P, Carlucci A, Prinianakis G, Antonelli M, et al. Noninvasive ventilation in chronic abstructive pulmonary disease patients: helmet versus facial mask. Intensive Care Med 2007;33(1):74-81.
10. Chiumello D, Pelosi P, Carlesso E, Severgnini P, Aspesi M, Gamberoni C, et al. Non invasive positive pressure ventilation delivered by helmet vs standard face mask. Intensive Care Med 2003;29(10): 1671-1679.
11. Pelosi P, Severgnini P, Aspesi M, Gamberoni C, Chiumello D, Fachinetti C, et al. Non invasive ventilation delivered by conventional interfaces and helmet in emergency department. Eur J Emerg Med 2003;10(2):79-86.
12. Costa R, Navalesi P, Spinazzola G, Rossi M, Cavaliere F, Antonelli M, et al. Comparative evaluation of different helmets on patient-ventilator interaction during non invasive ventilation. Intensive Care Med 2008;34(6):1102-1108.
13. Cammarota G, Olivieri C, Costa R, Vaschetto R, Colombo D, Turucz E, et al. Noninvasive ventilation through a helmet in postextubation hypoxemic patients: physiologic comparison between neurally adjusted ventilatory assist and pressure support ventilation. Intensive Care Med 2011;37(12):1943-1950.
14. Vargas F, Thille A, Lyazidi A, Campo FR, Brochard L. Helmet with specific settings versus facemask for noninvasive ventilation. Crit Care Med 2009;37(6):1921-1928.
15. Conti G, Costa R, Antonelli M. Non invasive ventilation in immunocompromised patients. Minerva Anestesiol 2011;77(3):342-348.
16. Rocco M, Dell'Utri D, Morelli A, Spadetta G, Conti G, Antonelli M, Pietropaoli P. Noninvasive ventilation by helmet or face mask in immunocompromised patients: a case-control study. Chest 2004; 126(5):1508-1515.
17. Costa R, Navalesi P, Spinazzola G, Ferrone G, Pellegrini A, Cavaliere F, et al. Influence of ventilator settings on patient-ventilator synchrony during pressure support ventilation with different interfaces. Intensive Care Med 2010;36(8):1363-1370.