Effect of Percutaneous Tracheostomy on Gas Exchange in Hypoxemic and Non-hypoxemic Mechanically Ventilated Patients

Giacomo Bellani MD PhD, Salua Abd El Aziz El Sayed Deab MD, Andrea Pradella MD, Tommaso Mauri MD, Giuseppe Citerio MD, Giuseppe Foti MD, and Antonio Pesenti MD

BACKGROUND: The influence of percutaneous tracheostomy on ventilator-dependence and clinical outcomes has been investigated in a number of studies. However, except for the variations during the procedure, the impact of tracheostomy on gas exchange has been scarcely explored. We investigated the effect of tracheostomy on respiratory function in a cohort of ICU patients. METHODS: In this retrospective study, clinical records of 107 patients from a general ICU and neurosurgical ICU who underwent percutaneous tracheostomy were reviewed to compare ventilator setting, gas exchange, and hemodynamic parameters on the day before and on the day after the procedure. Further, a pre-established subgroup analysis on hypoxemic patients (Pa_{O_2}/F_{IO_2} < 300 mm Hg) was performed. RESULTS: Among all patients analyzed, a marginal decrease in Pa_{CO_2} (43 ± 9 mm Hg vs 42 ± 7 mm Hg, before vs after *P* = .004) and an increase in pH (7.43 ± 0.04 vs 7.44 ± 0.03, before vs after *P* = .03) were observed after tracheostomy. In the subgroup of hypoxemic patients (*n* = 38), after the tracheostomy an increase in Pa_{O_2}/F_{IO_2} (222 ± 60 mm Hg vs 256 ± 84 mm Hg, before vs after *P* = .001) and a decrease in Pa_{CO_2} (46 ± 11 mm Hg vs 43 ± 9 mm Hg, before vs after *P* = .001) were found. CONCLUSIONS: Percutaneous tracheostomy did not worsen gas exchange in a cohort of ICU patients. In hypoxemic patients, tracheostomy appeared to improve oxygenation and ventilation. *Key words: percutaneous tracheostomy; gas exchange; carbon dioxide; respiratory failure; tracheotomy; airway management.* [Respir Care 2013; 58(3):482–486. © 2013 Daedalus Enterprises]

Introduction

Percutaneous tracheostomy is a procedure commonly performed by intensivists on mechanically ventilated patients in the ICU.[1] Even though a consensus conference recommended performing tracheostomy after 3 weeks of translaryngeal intubation, debate exists on the proper timing for performing a tracheostomy,[2] for its relevant advantages in terms of avoidance of laryngeal and vocal cords injury from prolonged intubation, more effective airway suctioning, possibility of oral feeding, improvement of the patient's comfort, and reduction of respiratory resistance and anatomical dead space. Particularly because of these latter aspects, tracheostomy might have an impact also on patients' gas exchange.

Although tracheostomy has been shown to improve mechanics of breathing,[3] there has been no improvement in survival, the need for prolonged mechanical ventilation, or the incidence of hospital associated pneumonia.[4,5] There have been several reports in the literature on ventilatory parameters, gas exchange, and hemodynamics during the percutaneous tracheostomy procedure.[6,7] Quite surprisingly, however, little information is provided concerning the effects of tracheostomy (in comparison with the endotracheal tube) on these parameters during regular tidal ventilation. The aim of this retrospective study was thus to assess the effects of tracheostomy on gas exchange and

The authors are affiliated with the Department of Emergency, San Gerardo Hospital, and with the Department of Health Science, University of Milano-Bicocca, Monza, Italy, with the exception of Dr Citerio and Dr Foti, who are affiliated with the Department of Department of Emergency Medicine, San Gerardo Hospital, Monza, Italy.

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Correspondence: Giacomo Bellani MD PhD, Department of Health Science, University of Milano-Bicocca, Via Cadore 48, 20052 Monza, Italy. E-mail: giacomo.bellani1@unimib.it.

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respiratory variables in a mixed ICU population of mechanically ventilated patients, to verify if tracheostomy is associated with an improvement in gas exchange.

Methods

Patient Population and Study Design

In this retrospective study, after approval of the local ethics committee, we reviewed the records of all patients admitted in the general and in the neurosurgical ICUs (with 8 and 5 beds, respectively) from January 2006 to December 2008. Patients in whom percutaneous tracheostomy had been performed during their ICU stay were included in the analysis. Exclusion criteria were age < 18 years, presence of extracorporeal membrane oxygenation at the time of tracheostomy, and data availability for < 24 hours before and/or after the procedure (eg, in patients transferred from or to other institutions), surgical tracheostomy. The tracheostomies were performed according to the published techniques,[8,9] during general anesthesia and paralysis, which were maintained only for the duration of the procedure.

Data were extracted from the patient data management system available in the ICUs (Innovian Solution Suite, Dräger, Lübeck, Germany). This system hourly collects numeric data from the monitors and mechanical ventilators. Nurses assess that data are correctly stored and manually correct artifacts. Moreover, laboratory data, including each arterial blood gas analysis performed, are stored in the system. Data of interest were manually extracted from the data management system and recorded in a spreadsheet (Excel, Microsoft, Redmond, Washington) for analysis.

In detail we focused on the following parameters:

- Ventilatory variables: F_{IO_2}, breathing frequency, tidal volume, minute ventilation, PEEP, pressure support level (if patient was undergoing pressure support ventilation), and end-tidal CO_2
- Gas exchange: pH, P_{aO_2}, P_{aCO_2}, S_{pO_2}
- Hemodynamic parameters: heart rate, mean arterial blood pressure, central venous pressure

For each parameter we recorded the mean of 3 measurements (taken approximately at 7 AM, 3 PM, and 11 PM, at which times patients are usually not undergoing any nursing procedure) on the day preceding and the day following the procedure of tracheostomy; the day of the procedure itself was not considered. If one parameter was not available on the day before or after the tracheostomy (eg, patient without arterial cannula and thus no arterial blood gases), this variable was excluded from the analysis. For this reason the sample sizes differ among variables in the analysis.

Since we hypothesized that in patients with an impairment of gas exchange the effect of tracheostomy might have been different than in the general patient population, we planned a priori to separate patients into 2 subgroups: hypoxic ($P_{aO_2}/F_{IO_2} < 300$ mm Hg on the day before tracheostomy) and non-hypoxic patients.

QUICK LOOK

Current knowledge

Percutaneous tracheostomy has advantages for the mechanically ventilated ICU patient, and the safety of percutaneous tracheostomy is comparable to that of open tracheostomy. The impact of percutaneous tracheostomy on gas exchange and lung mechanics suggests transient changes associated with the procedure.

What this paper contributes to our knowledge

Data from one day before and one day after percutaneous tracheostomy indicated a slight decrease in P_{aCO_2} and increase in pH. In a subgroup of hypoxemic subjects, oxygenation and carbon dioxide elimination were improved the day after percutaneous tracheostomy.

Statistical Analysis

Data were analyzed with statistics software (SPSS 19.0, SPSS, Chicago, Illinois). Each parameter was compared before and after tracheostomy by means of a paired *t* test in the general population and in the 2 subgroups separately. Linear regression was used to assess the correlation between 2 variables. Categorical variables before and after tracheostomy were compared using the chi-square test. A P value $< .05$ was considered as statistically significant.

Results

A total of 107 tracheostomized patients (68 Fantoni technique, 39 PercuTwist technique), age 65 ± 16 years, were included in data analysis. The mean intubation time before tracheostomy was 12 ± 9 days. Table 1 reports the causes of respiratory failure at ICU admission of the patients.

Table 2 summarizes the results for the general population. The day after tracheostomy, heart rate and S_{pO_2} both marginally increased; P_{aCO_2} decreased with a simultaneous pH increase, although the clinical relevance of the entity of the variation is probably modest.

When the subgroups of non-hypoxic patients ($n = 69$) and hypoxic patients ($n = 38$) were considered separately,

Table 1. Causes of Respiratory Failure at ICU Admission

	no. (%)
Neurosurgical disease	36 (34)
Acute lung injury	20 (19)
Trauma	13 (12)
Emergency abdominal surgery	10 (9)
Cardiac arrest	11 (10)
Status epilepticus	7 (7)
Other	10 (9)

no significant differences were observed in the former group, except for a mild increase in heart rate (see Table 2). On the contrary, the group of hypoxic patients showed, despite unchanged ventilatory parameters and modalities, a mild improvement in gas exchange, with an increase in Pa_{O_2}/F_{IO_2} and a decrease in Pa_{CO_2} (see Table 2). Although Pa_{CO_2} decreased on average by 3 mm Hg only, the decrease in Pa_{CO_2} was more pronounced in patients being hypercapnic before tracheostomy, as shown by Figure 1. Moreover, in hypoxic patient under pressure support ventilation ($n = 28$), Pa_{CO_2} decrease was correlated with the level of assistance before the procedure, as shown in Figure 2. No significant correlations were found between changes in Pa_{O_2}/F_{IO_2} or Pa_{CO_2}, and variables such as the duration of mechanical ventilation before tracheostomy, the level of PEEP, and the patient's age.

Discussion

In recent years, percutaneous tracheostomy is becoming the first choice technique to perform a tracheostomy in the critically ill patient requiring prolonged mechanical ventilation.[10] However, its effects on gas exchange are still not well established. The main finding of this study is that percutaneous tracheostomy determines a mild decrease in Pa_{CO_2} (with a doubtful clinical relevance). In the hypoxemic patients we observed a mild increase in oxygenation and a decrease in Pa_{CO_2} linearly correlated with the baseline Pa_{CO_2}. The reasons for this improvement in gas

Table 2. Respiratory Function, Ventilator Settings, and Hemodynamic Parameters on the Day Before and on the Day After Percutaneous Tracheostomy

	All Patients ($n = 107$)			Non-hypoxemic Patients ($n = 69$)			Hypoxemic Patients ($n = 38$)		
	Before Tracheostomy	After Tracheostomy	*P*	Before Tracheostomy	After Tracheostomy	*P*	Before Tracheostomy	After Tracheostomy	*P*
F_{IO_2}	0.39 ± 0.09	0.40 ± 0.08	.42	0.35 ± 0.07	0.37 ± 0.05	.09	0.46 ± 0.10	0.44 ± 0.11	.33
pH	7.43 ± 0.04	7.44 ± 0.03	.03	7.44 ± 0,04	7.45 ± 0.03	.32	7.42 ± 0.05	7.43 ± 0.03	.16
Pa_{O_2}, mm Hg	113 ± 22	117 ± 23	.08	120 ± 18	123 ± 20	.22	100 ± 22	106 ± 23	.07
Pa_{O_2}/F_{IO_2}, mm Hg	304 ± 85	305 ± 81	.88	348 ± 60	333 ± 63	.10	222 ± 60	256 ± 84	.001
Pa_{CO_2}, mm Hg	43 ± 9	42 ± 7	.004	42 ± 7	41 ± 7	.91	46 ± 11	43 ± 9	.001
Sp_{O_2}, %	97.6 ± 2.3	98.3 ± 1.1	.003	97.9 ± 2.6	98.6 ± 0.7	.35	97.3 ± 1.5	97.7 ± 1.3	.91
P_{ETCO_2}, mm Hg	36 ± 7	35 ± 8	.06	38 ± 7	36 ± 8	.42	34 ± 5	33 ± 6	.35
Ventilation Mode, no. (%)			.04			.04			.91
PRVC-CMV	29 (28)	28 (27)		20 (29)	19 (28)		9 (24)	9 (24)	
PC-CMV	2 (2)	2 (2)		2 (3)	2 (3)		0 (0)	0 (0)	
PSV	62 (58)	59 (55)		34 (49)	31 (45)		28 (74)	28 (74)	
CPAP	14 (12)	12 (11)		13 (19)	11 (15)		1 (2)	1 (2)	
Tracheostomy tube	0 (0)	6 (5)		0 (0)	6 (9)		0 (0)	0 (0)	
Pressure support level, cm H_2O	16 ± 5	15 ± 5	.20	15 ± 5	14 ± 5	.73	17 ± 5	16 ± 6	.17
Breathing frequency, breaths/min	22 ± 6	22 ± 5	.59	22 ± 6	21 ± 5	.34	21 ± 5	23 ± 6	.10
Tidal volume, mL	440 ± 20	437 ± 38	.74	431 ± 135	429 ± 145	.75	459 ± 95	450 ± 123	.42
Minute ventilation, L/min	9.1 ± 2.6	9.2 ± 2.3	.66	8.9 ± 2.4	8.7 ± 2.0	.56	9.7 ± 2.9	10.1 ± 2.6	.28
PEEP, cm H_2O	7 ± 2	7 ± 2	.11	6 ± 2	6 ± 2	.89	7 ± 2	8 ± 2	.91
Heart rate, beats/min	86 ± 17	88 ± 16	.02	85 ± 16	88 ± 16	.04	88 ± 19	88 ± 18	.73
Mean arterial pressure, mm Hg	81 ± 15	81 ± 12	.73	83 ± 15	83 ± 13	.78	77 ± 13	77 ± 10	.91
Central venous pressure, mm Hg	9 ± 3	8 ± 3	.07	8 ± 3	8 ± 4	.21	10 ± 3	9 ± 3	.23

Values are mean ± SD unless otherwise indicated.
P_{ETCO_2} = end-tidal CO_2
PRVC-CMV = pressure regulated volume control, continuous mandatory ventilation
PC-CMV = pressure control, continuous mandatory ventilation
PSV = pressure support ventilation

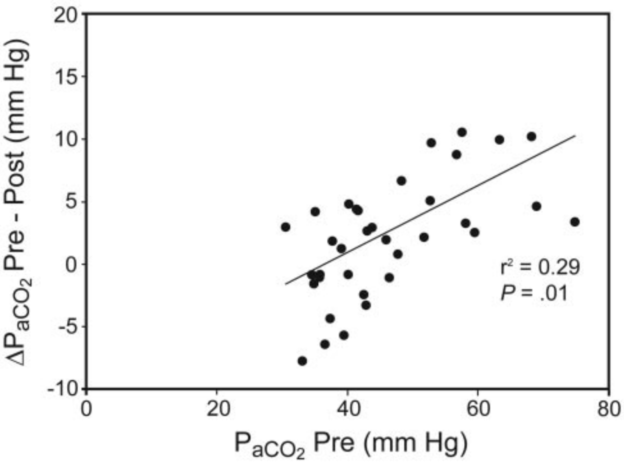

Fig. 1. In the subgroup of hypoxemic patients (n = 38) the plot of $Paco_2$ on the day before tracheostomy ($Paco_2$ Pre) versus the difference between $Paco_2$ on the day before tracheostomy and $Paco_2$ on the day after tracheostomy ($\Delta Paco_2$ Pre - Post) shows a statistically significant correlation between the variables ($r^2 = 0.29$, $P = .01$).

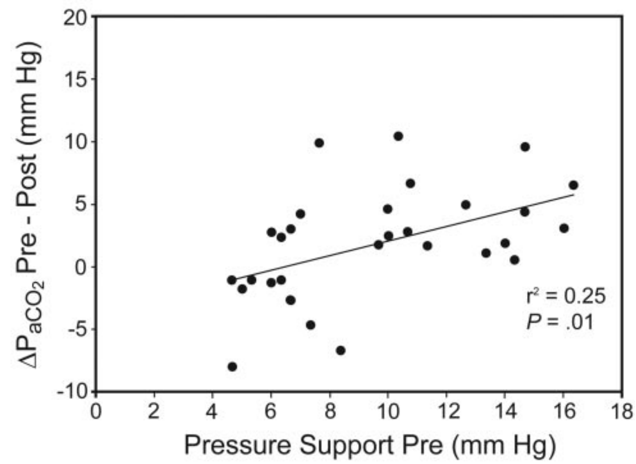

Fig. 2. The pressure support level on the day before tracheostomy (pre) was significantly, albeit weakly, correlated ($r^2 = 0.25$, $P = .01$) with the difference between $Paco_2$ on the day before tracheostomy and $Paco_2$ on the day after tracheostomy ($\Delta Paco_2$ pre - post) in the subgroup of hypoxemic patients under pressure support ventilation (n = 28).

exchange may be related to the beneficial effect of tracheostomy (when compared to orotracheal tube) on respiratory mechanics, need for patient sedation, and clearance of tracheal secretions.[3]

Improvement in CO_2 elimination after percutaneous tracheostomy observed in this retrospective study is a relatively new finding, though compatible with one of the positive effects on respiratory mechanics linked to tracheostomy: a reduction in anatomic dead space.[11] Despite this reasonable physiological background, a previous prospective study on mechanically ventilated patients, which investigated the influence of tracheostomy on dead space fraction, failed to show any positive effect on CO_2 elimination.[12] However, in comparison to that study, our population presents a slightly higher $Paco_2$ on the day before tracheostomy, especially the subgroup of hypoxemic patient. Baseline $Paco_2$ may have some influence on the improvement of carbon dioxide elimination associated with percutaneous tracheostomy, as we were able to establish in our subgroup of hypoxemic patients (see Fig. 1). In another study, tracheostomy was also associated with a decrease of resistive and elastic work of breathing in patient undergoing pressure support ventilation,[13] and this improvement in ventilation efficacy may explain a higher $Paco_2$ reduction in hypoxemic patients ventilated with an elevated pressure support level (see Fig. 2), although these results should be interpreted cautiously, due to the small sample size.

This study also demonstrates an improvement in oxygenation after percutaneous tracheostomy in the subgroup of hypoxemic patients. An improvement in oxygenation after tracheostomy was previously described in 3 recent studies. In the first one, feasibility of bronchoscopically guided percutaneous tracheostomy was evaluated in patients ventilated with severe respiratory failure, ventilated with a PEEP $>$ 10 cm H_2O (n = 88), in comparison to those ventilated with a PEEP $\leq$ 10 cm H_2O (n = 115).[14] Interestingly, in the severely hypoxemic patients (lowest quartile of Pao_2/Fio_2) in both groups (n = 23 and n = 27, respectively), an improvement in oxygenation was seen after 24 hours from tracheostomy. Similarly, an improvement in oxygenation after surgical tracheostomy was seen at 8 hours in a retrospective study on a small cohort (n = 20) of patients with major burns,[15] and at 24 hours in a prospective study on brain injured patients (n = 20).[16]

A physiological explanation for this improvement in oxygenation is not well defined. Some authors attribute it to a lower peak inspiratory pressure after tracheostomy, possibly connected to a reduction of ventilator associated lung injury.[15] However, it has to be recalled that the determinant of alveolar injury is plateau pressure, since peak airway pressure includes the resistive components such that peak inspiratory pressure does not reach the alveoli.

Our study has some limitations. Being a retrospective study we could only rely on data systematically collected in all patients, or at least in a vast majority. As a consequence, for example, it was impossible to evaluate the effect of percutaneous tracheostomy on plateau pressure (which, albeit measured in some patients, was not systematically recorded by the data management system). This would have been a useful parameter in order to define the role of percutaneous tracheostomy in a "lung-protective" ventilation strategy. These data may be especially interesting for our subgroup of hypoxemic patient, in whom improvement of gas exchange that we described was even more pronounced.

Another limitation of our study is that we do not have any information about rescue therapies, like recruitment maneuvers, which might have been instituted during or immediately after the tracheostomy to correct gas exchange impairment, due to intraprocedural alveolar derecruitment. However, even if performed, this procedure would have little influence on gas exchange on the day after the procedure, if not followed by a change in ventilation parameters, such as observed in our study population. Finally, the follow-up period of the patients was relatively short, being limited to 24 hours.

Conclusions

In conclusion, our retrospective data demonstrate that percutaneous tracheostomy does not worsen short-term gas exchange parameters in a mixed group of critically-ill patients. Indeed, in the subgroup of hypoxemic patients we observed an increased CO_2 elimination associated with an improvement of oxygenation, albeit of limited clinical relevance. Since the ventilator settings were unmodified between before and after the procedure, the improvement might be attributed, at least in part, to the tracheostomy itself.

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