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Hypercarbia during tracheostomy: a comparison of percutaneous endoscopic, percutaneous Doppler, and standard surgical tracheostomy

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Abstract *Objective:* Tracheostomy is one of the most commonly performed surgical procedures in the critical care setting. The early use of tracheostomy as a method of primary airway management has been proposed as a means to decrease pulmonary morbidity and to shorten the number of ventilator, intensive care unit, and hospital days. We set out to (1) determine whether hypercarbia occurs during tracheostomy of the critically ill patient and (2) determine the extent to which the partial pressure of carbon dioxide in arterial blood ($PaCO_2$) rises during percutaneous endoscopic, percutaneous Doppler, and standard surgical tracheostomy.
Design: Prospective, open clinical trial.
Setting: Surgical intensive care unit and operating room in teaching hospitals.
Patients: During mechanical ventilation, patients underwent either percutaneous endoscopic (PET), percutaneous Doppler (PDT), or standard surgical tracheostomy (ST), based on surgeon preference. Arterial blood gas readings were obtained approximately every 4 min throughout each procedure.
Measurements and results: All tracheostomies were successfully performed. No serious complications (including hypoxia) occurred during the study. Significant ($p < 0.05$ vs PDT and ST) hypercarbia (maximum $\Delta PaCO_2$ 24 ± 3 mmHg) and acidosis (maximum ΔpH – 0.16 ± 0.02) developed during PET. The changes in $PaCO_2$ and pH during PDT (maximum $\Delta PaCO_2$ 8 ± 2 mmHg; maximum ΔpH – 0.07 ± 0.02) and ST (maximum $\Delta PaCO_2$ 3 ± 1 mmHg; maximum ΔpH – 0.04 ± 0.01) were markedly less pronounced.
Conclusions: Continuous bronchoscopy during percutaneous tracheostomy contributes significantly to early hypoventilation, hypercarbia, and respiratory acidosis during the procedure. Percutaneous tracheostomy, when performed using the Doppler ultrasound method to position the endotracheal tube, significantly reduces CO_2 retention when compared to PET. Because of a possible rise in intracranial pressure, the potential for hypercarbia should be considered when choosing the method of tracheostomy in the critically ill and/or head-injured patient, where hypercarbia may be detrimental. If PET is to be performed, steps to minimize occult hypercarbia, such as using the smallest bronchoscope available, minimizing suctioning during bronchoscopy, and minimizing the length of time the bronchoscope is in the endotracheal tube, should be undertaken.

Key words Complications · Hypercarbia · Tracheostomy · Percutaneous endoscopic tracheostomy · Percutaneous Doppler tracheostomy · Acidosis · Bronchoscopy

Introduction

Tracheostomy is one of the most commonly performed surgical procedures in the critical care setting. The early use of tracheostomy as a method of primary airway management has been proposed as a means to decrease pulmonary morbidity and to shorten the number of days on a ventilator, in the intensive care unit, and in hospital on line [1]. Percutaneous dilatational tracheostomy, with the positioning of the endotracheal tube performed blindly or by the Doppler method, has been introduced as an alternative to standard operative tracheostomy [2–6]. The percutaneous technique has been shown to be safe, with intraprocedural complication rates similar to those seen with standard surgical tracheostomy [7, 8]. The addition of endoscopic guidance (fiberoptic bronchoscopy) has further increased the safety of this procedure and may prevent such complications as pneumothorax, subcutaneous emphysema, and paratracheal false passage previously reported with percutaneous tracheostomy when performed without endoscopic guidance [9–12]. However, the use of bronchoscopy to confirm guidewire placement, coupled with the use of intraluminal dilators to enlarge the tracheotomy, may lead to hypercarbia due to hypoventilation and to subsequent respiratory acidosis. In an earlier report, we demonstrated hypercarbia during percutaneous endoscopic tracheostomy in a brain-injured patient which led to increased intracranial pressure and a significant decrease in cerebral perfusion pressure [13]. The purpose of this report is to characterize and quantify the occurrence of hypercarbia and respiratory acidosis during standard surgical tracheostomy and percutaneous tracheostomy using bronchoscopy or Doppler guidance in critically ill patients in a surgical intensive care unit.

Materials and methods

This study was approved by the University of Pennsylvania Institutional Review Board Committee on Studies Involving Human Beings. Informed consent was obtained from patients and/or family members before each procedure.

Patients in the Surgical Intensive Care Unit (SICU) requiring tracheostomy underwent either percutaneous endoscopic tracheostomy ($n = 10$), percutaneous Doppler tracheostomy ($n = 10$), or surgical tracheostomy ($n = 5$). The choice of the method of tracheostomy performed was left to the surgeon (nonrandomized). All procedures were performed in the SICU, except in cases where additional procedures (e.g., jejunostomy tube placement) were simultaneously being performed. All patients had in place an indwelling radial artery pressure monitor. Arterial blood was drawn before the start of the tracheostomy and serially (approximately every 4 min) throughout the procedure for blood gas determination. The person obtaining the blood gas specimen was blinded to the procedure as it progressed and drew specimens and recorded times without directly observing the procedure. The time recorded on each specimen (and not that time when they were scheduled to be drawn) was used to determine the exact time from the beginning of the procedure for result purposes. In all cases, the procedure (tracheostomy and/or bronchoscopy) was performed by surgeons or surgical residents experienced with the procedure.

Percutaneous endoscopic tracheostomy with bronchoscopy was performed as previously described [9]. All patients had in place an 8.0 endotracheal tube. Briefly, patients were maintained on volume-cycled ventilation with a fractional inspired oxygen of 1.0 throughout the procedure. Minute volume was set at previous ventilator settings using an assist-control mode of ventilation and maintained throughout the procedure. Ventilator alarms and settings were not adjusted during the procedure. Intravenous narcotics (morphine) and benzodiazepines (midazolam) were used for sedation and confirmed neuromuscular blockade (vecuronium) achieved before initiation of the procedure. Patients were positioned with the neck extended. A flexible fiberoptic adult bronchoscope (5.8 mm O.D.) was introduced via a side arm adapter of the endotracheal tube. The endotracheal tube was then withdrawn such that the tip remained below the level of the vocal cords. After transillumination and palpation of the cricothyroid membrane and trachea, a small incision was made in the skin over the second tracheal ring. The platysma muscle was bluntly divided and a needle catheter (Ciaglia Percutaneous Introducer Set, Cook Critical Care, Bloomington, Ind., USA) was inserted below the second tracheal ring, into the tracheal lumen. Placement was confirmed both endoscopically and by the aspiration of air through the needle catheter. A guidewire was then passed through the catheter into the tracheal lumen. A Teflon guiding catheter was placed over the guidewire, and successive dilators were then used progressively to dilate the tracheotomy up to 36 Fr. Each dilator was passed three times prior to progression to the next larger size. The 36-F size allowed placement of a No. 8 tracheostomy tube in the trachea. Throughout the procedure, the bronchoscope was intermittently used to confirm guidewire, dilator, and, ultimately, tracheostomy position. After successful placement of the tracheostomy, the guidewire, Teflon guiding catheter, and dilator were removed and placement was confirmed by visualization of the tracheal carina during bronchoscopy via the new tracheostomy. The tracheostomy was then sutured into place. A chest X-ray was then performed to confirm tracheostomy tube placement and to exclude pneumothorax.

Percutaneous Doppler tracheostomy was performed in a manner similar to that described above. However, the bronchoscope was not used. Rather, the endotracheal tube was positioned just below the level of the vocal cords with the aid of a sterile Doppler device [6]. Briefly, a small incision was made in the skin over the second tracheal ring and the Doppler probe placed over the trachea. The endotracheal tube was then slowly withdrawn. As the tip of the tube reached the second tracheal ring, the intensity of the Doppler signal increased greatly due to an increased signal from unencumbered, turbulent air. The endotracheal tube was then resecured, and the trachea entered with the needle catheter, as confirmed by the aspiration of air through the needle. The percutaneous tracheostomy was then performed as described above. The size of dilators and length of time each dilator was in the trachea did not differ between the percutaneous endoscopic and percutaneous Doppler groups.

Standard surgical tracheostomy was performed as previously described [14]. Intravenous sedation, narcotics, and neuromuscular blockade were used for standard surgical tracheostomy in a fashion identical to the anesthesia provided to those patients undergoing percutaneous tracheostomy. Of note, ventilation proceeded throughout the procedure until the endotracheal tube was withdrawn under direct vision through the tracheotomy, and the tracheostomy tube was placed.

The results of the blood gas measurements were presented as changes in the partial pressure of carbon dioxide in arterial blood ($PaCO_2$) and arterial pH from the baseline measurements recorded before the procedure began. Maximal change in $PaCO_2$ and arterial pH each represent the single value of maximal change from the baseline for each procedure. These values were expressed as the mean ± 1 SEM. These measurements were compared suing Student's *t*-test with corrections made for multiple comparisons when appropriate. To evaluate the overall impact of each tracheostomy technique on $PaCO_2$, a time-averaged change in $PaCO_2$ (area under the curve) was determined. The following formula was used:

$$\frac{\dfrac{(m_1+m_0)}{2}\times(t_1-t_0)+\dfrac{(m_2+m_1)}{2}\times(t_2-t_1)+\ldots\;\dfrac{(m_f+m_{f-1})}{2}\times(t_1-t_{f-1})}{t_f}$$

where m_0 = measured value at baseline, m_1 = measured value at time 1, m_f = measured value at completion, t_0 = time =, t_1 = time 1, t_f = time of completion. Values for time-averaged $PaCO_2$ (mmHg) were expressed as the mean ± 1 SEM and compared using Student's *t*-test with corrections made for multiple comparisons when appropriate.

To further assess the overall impact on hypercarbia, we plotted the change in $PaCO_2$ against time. For each plot, the line best fitting all of the points was calculated by linear regression analysis through the origin. The slope of each line was thus determined and expressed as the mean ± 1 SEM. The slopes of the lines constructed through the actual data points were compared with one another using a modification of the *t*-test. For all statistical comparisons with the null hypothesis, values of $p < 0.05$ were considered to indicate significant differences.

Table 1 The duration of each procedure, the maximum increase in $PaCO_2$ and pH, and the time-averaqed change in $PaCO_2$. Values are mean ± SEM (*PET* percutaneous endoscopic tracheostomy, *PDT* percutaneous Doppler tracheostomy, *ST* surgical tracheostomy)

Method	*n*	Procedure time (min)	Max $\Delta PaCO_2$ (mmHg)	Max Δ pH	Time-averaged $\Delta PaCO_2$ (mmHg)
PET	10	13 ± 6	24 ± 3*	– 0.16 ± 0.02*	13 ± 2*
PDT	10	16 ± 2	8 ± 2	– 0.07 ± 0.02	3 ± 1
ST	5	24 ± 12	3 ± 1	– 0.04 ± 0.01	0 ± 0.3

* $p < 0.05$ versus PDT and ST

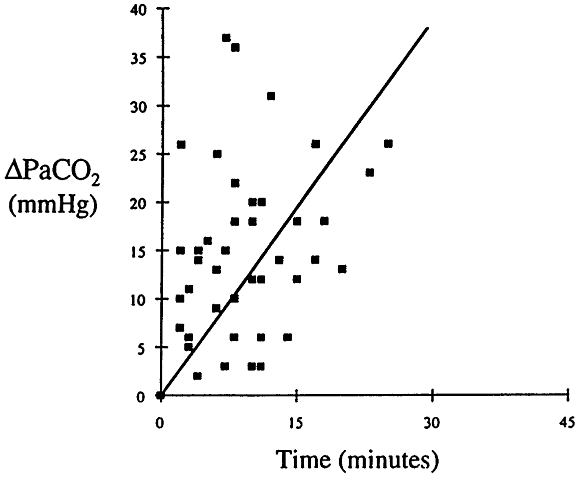

Fig. 1 Scatter plot of changes in $PaCO_2$ versus time for percutaneous endoscopic tracheostomy. The solid line represents the regression line through the origin for these 54 points ($m = 1.3 \pm 0.1$, $r^2 = 0.10$, $p < 0.05$)

Results

No significant intraprocedural complications (e.g., hypoxia, bleeding, or hypotension) were noted in these 25 patients. The length of each procedure is listed in Table 1. There was no significant difference in procedure times between percutaneous endoscopic, percutaneous Doppler, and standard surgical tracheostomy. An average of 5.3 ± 0.3 arterial blood specimens for blood gas measurements (min 4; max 7) was obtained from each patient. There was no significant difference between groups in the number of specimens obtained. No postprocedural complications (e.g., subcutaneous emphysema or pneumothorax) were evident on subsequent chest X-rays.

The average baseline $PaCO_2$ did not differ among the three groups of patients. The maximum increases in $PaCO_2$ and arterial pH are also presented in Table 1. The maximum increase in $PaCO_2$ during percutaneous endoscopic tracheostomy was significantly greater than that during either percutaneous Doppler or standard surgical tracheostomy. There was no significant difference between the maximum increase in $PaCO_2$ during percutaneous Doppler tracheostomy and that during standard tracheostomy. The maximal decrease in arterial pH during percutaneous endoscopic tracheostomy mirrored the reciprocal increase in $PaCO_2$ during these procedures. The maximal respiratory acidosis noted was significantly greater during percutaneous endoscopic tracheostomy than during either percutaneous Doppler or standard surgical tracheostomy.

The time-averaged change in $PaCO_2$ was calculated for each technique and is presented in Table 1. $PaCO_2$ was elevated an average of 13 ± 2 mmHg over the entire duration of percutaneous endoscopic tracheostomy. This increase was significantly greater than that during percutaneous Doppler tracheostomy or standard surgical tracheostomy. The time-averaged increase in $PaCO_2$ during standard tracheostomy was only 0 ± 0.3 mmHg; however, there was no statistically significant difference between this increase and that seen during percutaneous Doppler tracheostomy.

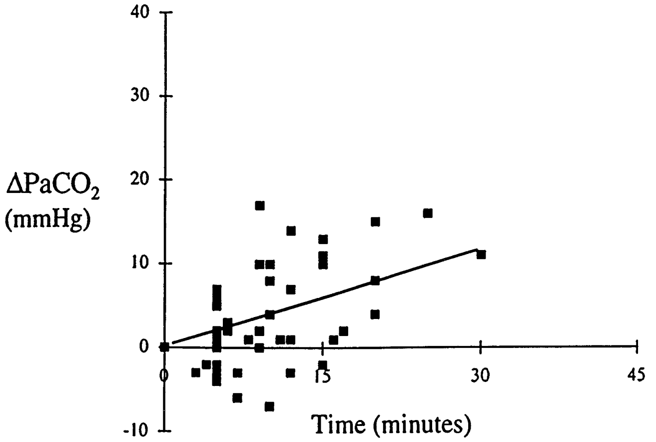

Fig. 2 Scatter plot of changes in PaCO$_2$ versus time for percutaneous Doppler tracheostomy. The solid line represents the regression line through the origin for these 52 points ($m = 0.4 \pm 0.1$, $r^2 = 0.30$, $p < 0.001$)

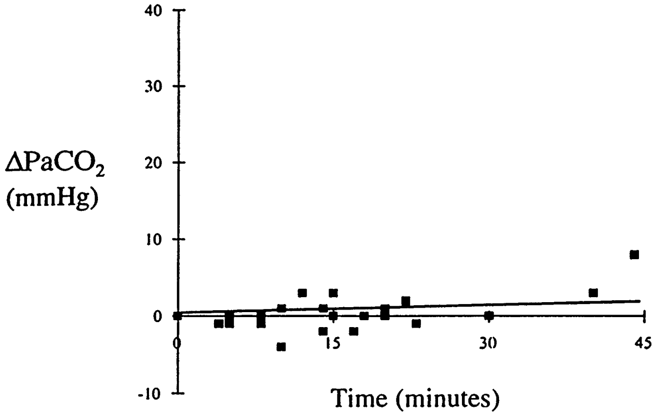

Fig. 3 Scatter plot of changes in PaCO$_2$ versus time for standard surgical tracheostomy. The solid line represents the regression line through the origin for these 28 points ($m = 0.05 \pm 0.1$, $r^2 = 0.21$, $p < 0.05$)

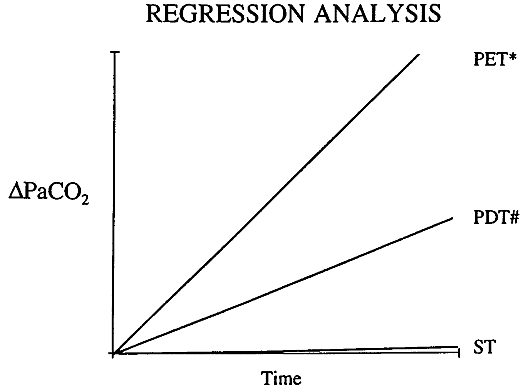

Fig. 4 Regression analysis of percutaneous endoscopic tracheostomy *PET*, percutaneous Doppler tracheostomy *PDT*, and standard surgical tracheostomy *ST*. *$p < 0.05$ vs PDT and ST; $p < 0.05$ vs ST

The plot of changes in PaCO$_2$ versus time for percutaneous endoscopic tracheostomy is presented in Fig. 1. Fifty-four total data points are represented on the graph. A similar plot of changes in PaCO$_2$ versus time for percutaneous Doppler tracheostomy is presented in Fig. 2. Fifty-two total data points are represented on the graph. The plot of changes in PaCO$_2$ versus time for standard surgical tracheostomy is presented in Fig. 3. Twenty-eight total data points (some of which fall below the x axis) are represented on the graph.

Figure 4 presents the three regression analyses. The slope of the regression line for percutaneous endoscopic tracheostomy was found to be statistically significantly greater than the slopes of the regression lines for both percutaneous Doppler tracheostomy and standard surgical tracheostomy. In addition, the slope of the regression line for percutaneous Doppler tracheostomy was found to be significantly greater than that for standard surgical tracheostomy.

Discussion

Percutaneous dilatational tracheostomy has been introduced as an alternative to standard operative tracheostomy [2–5]. This procedure has been found to have a safety profile comparable to that of operative tracheostomy [4, 7, 11]. The addition of endoscopic guidance to percutaneous tracheostomy has further increased the safety of this procedure [9–12]. Complications such as pneumothorax, paratracheal false passage of dilators or the tracheostomy tube, and perforation of the posterior wall of the trachea, all previously reported with blind percutaneous methods, are largely prevented with bronchoscopic visualization of the tracheal cannulation [9–12]. However, the insertion of a bronchoscope into an airway already compromised by intraluminal dilators results in further obstruction of the ventilatory path, worsening the hypoventilation. This iatrogenic hypoventilation results in occult hypercarbia.

The use of a Doppler probe is another option to facilitate percutaneous tracheostomy [6]. The Doppler probe is used to guide endotracheal tube positioning to decrease the incidence of inadvertent extubation during the procedure and also to verify that the endotracheal tube has been sufficiently withdrawn prior to dilator placement. To date, no studies evaluating the safety of percutaneous Doppler tracheostomy in comparison to that of standard percutaneous tracheostomy or percutaneous endoscopic tracheostomy have been reported.

The patients described in this report all underwent uneventful tracheostomy. No intraprocedural complications occurred. While a minimal decrease in arterial oxygen tension was noted in association with the hypercarbia which developed, significant hypoxia (arterial oxygen saturation < 91 %) did not develop, in part because the fractional inspired oxygen was maintained at 1.0 throughout the procedure. Procedure times for all three techniques were not significantly different. Post-tracheostomy chest X-rays demonstrated proper placement of each tracheostomy tube. However, patients undergoing percutaneous endoscopic tracheostomy became profoundly and significantly hypercarbic during the procedure. As a result, these patients also developed significant respiratory acidosis. The hypercarbia and respiratory acidosis persisted throughout the duration of the procedure and only began to resolve slowly with the resumption of normal ventilation at the conclusion of the procedure. $PaCO_2$ also rose during percutaneous Doppler tracheostomy and standard surgical tracheostomy. However, both the maximum change and the time-averaged change in $PaCO_2$ were significantly less than during percutaneous endoscopic tracheostomy. In addition, regression analysis demonstrated that the increase in $PaCO_2$ versus time was significantly greater during percutaneous endoscopic tracheostomy when compared to the other two techniques.

The regression analysis of changes in $PaCO_2$ versus time also demonstrated that the increase in $PaCO_2$ observed during standard surgical tracheostomy was significantly less than the increases seen during both percutaneous Doppler and percutaneous endoscopic tracheostomy. Little change in $PaCO_2$ was noted during standard surgical tracheostomy, except for a slight increase in $PaCO_2$ when the endotracheal tube was withdrawn, the tracheostomy tube placed, and ventilation switched to the tracheostomy tube. As a result, the slope of this regression line is essentially flat, and the time-averaged change in $PaCO_2$ is minimal.

The regression analysis does not demonstrate a tight linear relationship between changes in $PaCO_2$ and time. $PaCO_2$ did not increase progressively throughout each procedure. In addition, the length of time required to complete each procedure (as well as the time spent using bronchoscopy, dilators, etc.) varied from patient to patient. As a result, there is a fair amount of scatter among the points plotted on each graph (Fig. 1–3). The regression analysis (Fig. 4), however, does give equal weight to each point, and thus minimizes the effect of a single “bump” in $PaCO_2$ during an individual procedure. Therefore, we felt it useful to employ regression analysis in the statistical evaluation of this data.

The specific etiology of hypercarbia during percutaneous tracheostomy may be multifactorial. Ventilator/patient asynchrony may result in hypoventilation. However, the use of neuromuscular blockade eliminates ventilator/patient asynchrony. The presence of dilators in the tracheal lumen may also contribute to the development of hypercarbia. The temporary occlusion (partial or complete) by the dilators (often manifest by the pressure-limit alarm on the ventilator during percutaneous endoscopic and Doppler tracheostomy) may explain the small (but not statistically significant) increase in both maximum change and time-averaged change in $PaCO_2$ noted during percutaneous Doppler tracheostomy.

The presence of an open, uncontrolled tracheotomy during the procedure may also contribute to hypoventilation and hypercarbia. Air may escape through this stoma while dilators are exchanged between successive passages. This may result in the loss of tidal volumes, essentially a tracheocutaneous fistula. In addition, the loss of exhaled volumes through this stoma may make the analysis and tracking of minute ventilation meaningless.

Since significant hypercarbia developed, even during procedures lasting only nine minutes, the length of time needed to perform percutaneous tracheostomy safely does not appear to be responsible for the hypercarbia which was noted. Minimizing the length of the procedure may be beneficial in these critically ill patients and, conversely, taking time to ventilate patients between dilators, with the stoma controlled, may also help to prevent hypercarbia.

Although the exact duration of “bronchoscopic time” for each procedure was not recorded, the use of bronchoscopic guidance during percutaneous endoscopic tracheostomy appears to be the single most important factor responsible for the hypercarbia which develops during the procedure. When the bronchoscope is omitted from the procedure (i. e., percutaneous Doppler tracheostomy), hypercarbia is minimized and the resultant respiratory acidosis significantly attenuated. While the introduction of a bronchoscope into the airway may well limit ventilation, again often manifest by the pressure-limit alarm on the ventilator, this complication of bronchoscopy in the intensive care unit is not well recognized [15], though hypercarbia during bronchoscopy has been reported [16]. The potential benefits of endoscopic guidance during percutaneous tracheostomy (increased safety of the procedure) must be weighed against the hypercarbia and subsequent respiratory acidosis which develop. We currently minimize bronchoscopic time (when possible) during the performance of this procedure. Furthermore, with increased experience and confidence with this procedure we feel this technique can be safely performed without bronchoscopic assistance.

Monitoring end-tidal CO_2 or expired minute volumes may be warranted during the procedure, but the loss of exhaled gases through the tracheotomy or via suctioning through the bronchoscope may invalidate this technique [17]. Continuous in-line arterial blood gas monitoring would be optimal but is not routinely available and may also not be cost effective. Steps to minimize occult hypercarbia, such as using the smallest bronchoscope available, minimizing suctioning during bronchoscopy, and minimizing the length of time the bronchoscope is present in the endotracheal tube, should all be taken when performing percutaneous endoscopic tracheostomy. Other techniques of tracheostomy may be appropriate in the critically ill and/or head-injured patient where hypercarbia and respiratory acidosis may be deleterious.

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