Emphysema and Pneumothorax After Percutaneous Tracheostomy*
Case Reports and an Anatomic Study

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Study objective: Part 1: To describe cases of emphysema (subcutaneous and/or mediastinal) and pneumothorax after percutaneous dilational tracheostomy (PDT) in a series of 326 patients, and to review the existing literature describing the incidence and possible mechanisms. Part 2: To analyze the potential mechanisms for the development of emphysema and pneumothorax in human cadaver models.

Design: A retrospective analysis of PDTs, in combination with an anatomic study in human cadavers.

Materials and methods: Part 1: All ICU patients who underwent PDT between 1997 and 2002 were enrolled in the study. We analyzed the cases of emphysema and pneumothorax. Similar cases were retrieved from the literature and underwent a systematic review. Part 2: The relevant anatomic structures were studied. We simulated the clinical situation after PDT in a human pathologic study in order to induce subcutaneous emphysema and pneumothorax.

Measurements and results: Part 1: Five cases of subcutaneous emphysema (1.5%) and two cases of pneumothorax (0.6%) are described. In the literature search, we found 41 cases of emphysema (1.4%) and 25 cases of pneumothorax (0.8%) in a total of 3,012 patients. Part 2: Subcutaneous emphysema could easily be induced in a human cadaver model by inflating air in the pretracheal tissues and after posterior tracheal wall laceration. Air leakage was also possible through a fenestrated cannula via the space between the inner nonfenestrated cannula and outer cannula and then through the fenestration.

Conclusions: We conclude that one mechanism for the development of emphysema is an imperfect positioning of the fenestrated cannula, whereby the fenestration is extraluminal. For this reason, fenestrated cannulas should not be used immediately after placement of a PDT. Posterior tracheal wall laceration is another mechanism responsible for emphysema after PDT. After perforation of the posterior tracheal wall, the pleural space can be reached easily. This may result in a pneumothorax.

Key words: complications; dilational; emphysema; subcutaneous pneumothorax; tracheostomy, percutaneous

Abbreviations: CDT = conic dilational tracheostomy; GWDF = guidewire dilational forceps; LPC = low pressure cuffed; PC = pressure control; PDT = percutaneous dilational tracheostomy; PEEP = positive end-expiratory pressure

For long-term ventilation, two techniques to control the airway are available: tracheostomy and endotracheal intubation. Percutaneous tracheostomy was first described in 1955.1 In 1985, Ciaglia et al2 described percutaneous dilational tracheostomy (PDT). In 1990, an alternative technique was described by Griggs et al3: the guidewire dilating forceps (GWDF) tracheostomy. In 1998, Ciaglia developed the conic dilational tracheostomy (CDT), better known as the Blue Rhino technique; it combined the advantages of PDT and GWDF, ie, fast and smooth concentric dilatation.4

Endotracheal intubation and tracheostomy both have clear advantages and disadvantages.5 6 The

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choice of technique needs to be individualized for the patient in question.7 Percutaneous tracheostomy has been advocated as a safe and efficient bedside alternative for open tracheostomy.8–10 Clearly, it is important to analyze the specific complications associated with percutaneous tracheostomy using different techniques. Most of these complications are mild and easy to overcome, but some major, life-threatening complications have been reported as well.11–13 Several cases of emphysema (ie, subcutaneous and/or mediastinal) and pneumothorax are reported. Often, these complications are attributed to posterior tracheal wall laceration.13–19 Although the pathophysiology of “malignant emphysema” was elucidated by the classic laboratory studies of the Macklins in 1944, the different mechanisms responsible for emphysema and pneumothorax after PDT are often not clear.20 The aims of this study are as follows: (1) to describe the incidence of emphysema and pneumothorax in our own series, (2) to review the literature and to postulate possible mechanisms for the observed complications, and (3) to test these possible mechanisms in a human cadaver model.

**Materials and Methods**

**Part 1: Case Description and Review of the Literature**

From March 1997 to December 2002, 326 critically ill adult patients underwent PDT in our ICU. One hundred seventy-one consecutive PDTs were performed using the GWDF technique.21 As of February 2000, the CDT procedure became our method of choice; since then, 155 PDTs have been performed using this technique.22 Six patients underwent PDT using the PercuTwist technique.23 The GWDF technique was carried out at the bedside in the ICU according to a standard protocol.21 In short, after local infiltration, a transverse incision was made through the skin and subcutaneous tissues. The trachea was punctured with a cannulated needle below the level of the cricoid cartilage, aiming for the interspace between first and second or second and third tracheal rings. The guidewire was inserted through this cannula. The position and depth of the tracheal puncture as well as the position of the guidewire were routinely checked with a fiberscope in all patients. The forceps were advanced along the guidewire and used to dilate the tracheal wall in two steps, the first to dilate the pretracheal tissues, the second to dilate the tracheal wall. Finally, the tracheostomy tube was introduced and connected to the ventilator; the correct position was confirmed by capnography.

The CDT procedure is basically the same as the GWDF procedure except for the final stages.22 A curved Crite forceps was used for careful blunt dissection of the cervical fascia anterior to the trachea. Subsequently, the trachea was punctured with an introducer needle, and the guidewire was threaded through the catheter. A small dilator was used to predilate the puncture canal. The conic dilator was mounted on a guiding catheter and advanced into the trachea. A Shiley tracheostomy tube was fitted over the 28F loading dilator and advanced into position.

Patient demographics were recorded at the time of the procedure using a standard form. Cases of emphysema and pneumothorax were analyzed for perioperative difficulties that may have resulted in these complications. Emphysema was defined as perioperative or postoperative presence of a palpable or radiologically visible amount of air in the subcutaneous tissues or the soft tissues of the mediastinum. Pneumothorax was defined as perioperative or postoperative presence of air in the pleural space.

A PubMed search was performed in the literature from 1986 to 2003 using the following key words: “percutaneous,” “tracheostomy,” “complications,” “pneumothorax,” and “emphysema.” Sometimes, several consecutive reports by one group were published.24–26 In such instances, only the most recent study was taken into account. Citations were limited to human studies. We formulated a number of hypotheses concerning the mechanisms responsible for the development of emphysema and pneumothorax as complications of PDT.

**Part 2: Analysis of Mechanisms Causing Emphysema and Pneumothorax**

The way in which air might spread through the paratracheal tissues was investigated. First, the anatomy of this region of the neck and its fascial planes were reviewed. The neck region in human cadavers was then dissected to examine the most important anatomic structures and cervical compartments. In a human cadaver model, we simulated air leakage into the pretracheal space. For this purpose, we used a cannulated 14-gauge needle connected to an oxygen cylinder. The same experiment was repeated to examine whether air leakage into the retrotracheal space occurred when an incision was made through the mucosa of the posterior tracheal wall.

We suspected that with an insufflated cuff, the only way that air might leak proximally to the cuff was via the space between the inner and outer cannula of a fenestrated tracheostomy tube. The fenestrated cannula was photographed at a magnitude of 40× (Panasonic Digital Camera, model WV-CD-110; Panasonic; Matsushita Electric; Osaka, Japan) mounted on an Olympus microscope (TNO; Eindhoven, the Netherlands), and the outer diameter of the internal cannula and the inner diameter of the external cannula were measured using a coordinate measuring apparatus (Zeiss UMG 5508; Zeiss; Oberkochen, Germany). This machine contains a sensor that measures the spatial coordinates of a given object. Each 0.1 mm, it measures a coordinate of the circumference of a round object. Its accuracy is ±1.3 μm.

We measured air leakage through the fenestration of a fenestrated tracheostomy tube, containing a nonfenestrated inner cannula, at different pressure control (PC) and positive end-expiratory pressure (PEEP) levels. The cannula was directly connected and sealed with petroleum jelly to the artificial lung. The air leakage through the fenestration was confirmed by the observation of bubbles after application of a soap solution. We used a Siemens 300 ventilator (Siemen-Elema AB; Solna, Sweden) connected to an artificial lung; the difference between inspiratory and expiratory volume was registered during 10 respiratory cycles for each level of PC and PEEP. Data are presented as mean ± SD.

The anatomic relations between the trachea and the pleural cavities were investigated in human cadavers. We simulated a situation in which a cannulated needle passes in the midline through the trachea, perforates the posterior tracheal wall, and ends into the pleural cavity. Next, the neck region was dissected to inspect the anatomic structures that had been passed or damaged. Subsequently, a human cadaver was frozen, cut into 0.5-cm-thick slices and photographed to establish the topographic relations between the trachea, the para-tracheal structures, and pleural cavities.
RESULTS

Part 1: Case Descriptions and Review of the Literature

**Patient 1:** A percutaneous tracheostomy was performed in a 73-year-old patient 15 days after cardiac surgery, using the GWDF technique. Dilatation of the trachea was performed with difficulty; after three attempts, the tracheostomy tube could finally be inserted. Several hours postoperatively, extensive subcutaneous emphysema developed, as seen in Figure 1. Chest radiographs showed air around the arch of the aorta, indicating mediastinal emphysema. The subcutaneous emphysema resolved spontaneously within 5 days, and no other problems related to the procedure occurred.

**Patient 2:** A 74-year-old woman was admitted to the ICU after extensive abdominal surgery. Percutaneous tracheostomy was performed after 11 days using the GWDF technique. The guidewire dislocated out of the trachea during forceps dilatation. Subsequent insertion of the tracheostomy tube was not possible. We repeated the procedure, and it was completed without further complications. A fenestrated Shiley size 6.0 low-pressure cuffed (LPC) tracheostomy tube was inserted. Immediately after the procedure, chest radiographs showed signs of subcutaneous emphysema and an unclearly defined mediastinum, compatible with mediastinal emphysema. As there was no progression of the emphysema, no further intervention was indicated. The subcutaneous emphysema resolved spontaneously within 3 days, and no other procedure-related complications occurred.

**Patient 3:** A 67-year-old man had cardiac tamponade after placement of a pacemaker. He was admitted to the ICU. Three weeks later, a percutaneous tracheostomy was performed using the CDT technique. After dilatation of the trachea, a fenestrated Shiley size 8.0 LPC tracheostomy tube was inserted. The procedure was performed without difficulty. After 2 h, massive subcutaneous emphysema of the head, neck, and thorax developed. The tracheostomy tube was replaced by a nonfenestrated cannula without difficulties. The patient died 2 days later after a cardiac arrest, not likely related to the PDT procedure. Permission for autopsy could not be obtained.

**Patient 4:** A 56-year-old woman was admitted to the ICU after subarachnoid hemorrhage. Percutaneous tracheostomy was performed after 13 days using the GWDF technique. The trachea was punctured twice to achieve optimal intratracheal localization. Dilatation of the trachea was performed without difficulty, and the tracheostomy tube was inserted. The patient was weaned from mechanical ventilation, and 9 days later the tracheostomy tube was replaced by a fenestrated cannula. Insertion of the new tracheostomy tube proved difficult. A fenestrated Shiley size 6.0 LPC tracheostomy tube was inserted. In the middle of the night, suction through the tracheostomy tube suddenly appeared impossible. The next day bronchoscopy was performed, but it was not possible to pass the tracheostomy tube because of obstruction. A CT scan was made, which showed a pretracheal localization of the tracheostomy tube and subcutaneous emphysema of the neck. The tracheostomy tube was put into place again, and intratracheal localization was verified. The subcutaneous emphysema resolved shortly after. Apparently, the patient was able to breathe past the malpositioned tracheostomy tube.

**Patient 5:** A 67-year-old man was admitted to the ICU after cardiac surgery. Percutaneous tracheos-
tomy was performed after 24 days using the CDT technique. Because of obstruction due to excessive mucus production, the tracheostomy tube had to be replaced frequently. On day 20 following the first procedure, the tracheostomy tube was replaced by a fenestrated Shiley size 8.0 LPC tracheostomy tube. We experienced some difficulty placing the new tube. It was successfully inserted at the third attempt. When the patient was connected to the respirator, ventilation proved impossible. Because the patient was breathing spontaneously, he was administered oxygen via the tracheostomy cannula, but he desaturated gradually. Subsequently, he was ventilated with a Waters set. Subcutaneous emphysema of the neck developed instantaneously. The fenestrated tube was replaced by a nonfenestrated one (size 6.0). The emphysema subsided after 2 days. No other procedure-related complications occurred.

**Patient 6:** A 26-year-old woman had been involved in a high-energy accident and was admitted to the ICU. A percutaneous tracheostomy was performed after 7 days, using the CDT technique. A Shiley size 8.0 LPC tracheostomy tube was inserted. A chest radiograph obtained immediately after the procedure showed a right-sided pneumothorax. Bronchoscopy showed no lesions of the posterior tracheal wall, and there was no significant bleeding. A chest tube was inserted. No other procedure-related problems occurred.

**Patient 7:** A 74-year-old man who had undergone extensive abdominal surgery was admitted to the ICU. Complications developed resulting in prolonged ventilatory dependency. A percutaneous tracheostomy using the CDT technique was performed after 20 days without any difficulty or significant bleeding. A fenestrated Shiley size 8.0 LPC tracheostomy tube was inserted. After a couple of hours, increasing respiratory failure and an asystole due to a left-sided tension pneumothorax developed. After insertion of a thoracic drain, the patient stabilized. Bronchoscopy showed a blood clot in the left mainstem bronchus, although there were no signs of active bleeding. Possibly, the blood clot functioned as a one-way valve resulting in high airway pressures and subsequent pneumothorax. There were no signs of tracheal damage. Because the tracheostomy caused persisting blood loss, the next day it was decided to examine the tracheostomy site in the operating room. This examination revealed that the percutaneous tracheostomy had actually penetrated the cricothyroid membrane. Therefore, a surgical tracheostomy was performed.

![Graph](https://publication.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/22008/)

**Figure 2.** Incidence of emphysema and pneumothorax. The x-axis depicts the first author of the publication. The y-axis depicts the incidence of emphysema (black) and pneumothorax (gray).
**Review of the Literature:** Our review of the literature showed a total of 21 series, including 3,012 patients. The incidence of subcutaneous emphysema was 1.4% (41 cases) and of pneumothorax 0.8% was (25 cases). Furthermore, 9 case reports were reviewed, including 10 patients with subcutaneous emphysema and 6 patients with pneumothorax. The incidences of subcutaneous emphysema and pneumothorax are presented in Figure 2. In the series of Trottier et al., the incidence of pneumothorax with accompanying emphysema was unexpectedly high, leading to a quality improvement program. Proposed mechanisms for emphysema and pneumothorax after PDT are presented in Figure 3. All these mechanisms lead to air leaking from the trachea into the subcutaneous tissues. Air then will track along the path of least resistance. In 16 cases, the exact mechanisms for the development of emphysema and pneumothorax were not described or unclear. Three publications, including six patients, mentioned damage to the anterior tracheal wall as a possible mechanism for the development of subcutaneous emphysema. Ambesh et al. described three cases in which the tracheal circumference was split after PDT using the GWDF technique, resulting in subcutaneous emphysema. Van Heurn et al. related subcutaneous emphysema to multiple punctures of the trachea and tearing of the intercartilagenous tissue adjacent to the cannula. Excessive dilatation of the anterior tracheal wall also increases the risk of emphysema. Seven publications, dealing with 15 patients, attributed emphysema to posterior tracheal wall laceration. Four publications, dealing with seven patients, mentioned posterior tracheal wall laceration resulting in pneumothorax. Injury to the posterior tracheal wall might be caused by improper stabilization of the guidewire and guiding catheter, allowing them to move along the posterior tracheal wall. Another mechanism of damage to the posterior tracheal wall is laceration by the tip of the tracheostomy tube introducer. Dislocation of the tracheostomy tube, false passage, or paratracheal placement resulting in emphysema and pneumothorax are described in seven publications, concerning 22 patients. Only two cases have been described in which emphysema was related to a fenestrated tube, due to extraluminal localization of the fenestration. Four publications, concerning five patients, explained the development of pneumothorax as a result of barotrauma.

**Part 2: Analysis of Mechanisms for the Development of Subcutaneous Emphysema and Pneumothorax**

**Cadaver Model 1, Air Leakage Through the Anterior Tracheal Wall:** We performed a percutaneous tracheostomy in a human cadaver, using the CDT technique. The cannula was withdrawn and small-
sized oxygen tubing was placed in the pretracheal subcutaneous tissues. Air was able to spread along the cervical planes without difficulty. In a matter of minutes, subcutaneous emphysema developed, extending from the cervical area to the head and thorax. This resembled the presentation as described in the case of the first patient.

**Cadaver Model 2, Air Leakage Through the Posterior Tracheal Wall:** We performed a percutaneous tracheostomy in a human cadaver, using the CDT technique. The cannula was withdrawn and a 2-cm, vertical transmucosal incision was made in the posterior tracheal wall. The tracheostomy tube was re-introduced with the insufflated cuff occluding the tracheostomy opening. Finally, a cuffed endotracheal tube was placed in order to secure the proximal airway. In this way, we ensured that the mucosal incision was distal to the cuff and air leakage through the anterior defect was prevented. When the tracheostomy tube was connected to a Waters set, subcutaneous emphysema suddenly appeared after an interval of several minutes, much in the same way as in cadaver model 1. After this experiment, the trachea was further opened. The incision in the posterior wall had widened as if it had been dissected by the positive ventilation pressure.

**Measurement of Cannula Diameters:** The outer diameter of the internal cannula was 9.22 mm with a variation of 0.056 mm, and the inner diameter of the external cannula was 9.35 mm with a variation of 0.07 mm. The average distance between the internal and external cannula was 0.13 mm (Fig 4).

**Air Leakage Through the Fenestration:** The results of our measurements in a model of air leakage through the fenestration of a tracheostomy tube at different PC and PEEP levels were impressive. Air loss was more pronounced at higher levels of PC and PEEP. At PC of 30 and a PEEP of 20 cm H₂O, the air loss was 2780 ± 85 mL/min (Fig 5).

**Cadaver Model 3, Pneumothorax:** In a human cadaver with the lungs removed, we performed a midline puncture with a cannulated needle as in a standard PDT procedure. We perforated the posterior tracheal wall and, although the introduction of the needle was almost vertical, it was fairly easy to reach the pleural cavity. During subsequent dissection of the pretracheal space, we confirmed that the needle passed through the anterior tracheal wall into the tracheal lumen and through the posterior tracheal wall, finally ending in the pleural cavity. This model shows that, even when puncturing the trachea in the midline, the tip of the needle can still punc-

**Figure 4.** Photograph (40×) of outer and inner cannula. Arrow indicates space between outer and inner cannula.
ture the pleural cavity. This also shows that the pleural dome may extend in the neck posterolaterally to the tracheal wall (Fig 6).

We believe that this is also the area where posterior tracheal wall puncture or laceration is most likely to occur, especially when the puncture site is lower than usual. The distance between the dorsal tracheal wall and the pleural cavity also decreases in the distal slices. In our cadaver model, this distance was approximately 5 mm.

![Figure 5. Air leakage through a fenestrated outer cannula with a nonfenestrated inner cannula measured as the difference of inspiratory and expiratory volume at different PEEP and PC levels at a respiratory rate of 15 breaths/min. Mean ± SD of 10 observations.](image)

**Figure 5.** Air leakage through a fenestrated outer cannula with a nonfenestrated inner cannula measured as the difference of inspiratory and expiratory volume at different PEEP and PC levels at a respiratory rate of 15 breaths/min. Mean ± SD of 10 observations.

**Figure 6.** Cross-sections at the level of Th1 and Th2 (the cricoid cartilage is located at the level of C6).
1 = pleural cavity, 2 = trachea, 3 = esophagus, 4 = clavicle, 5 = brachiocephalic trunc.

**Discussion**

In our own experience and according to the existing literature, the incidence of emphysema and pneumothorax after PDT is rather low. We demonstrated that it is possible to induce subcutaneous emphysema via an anterior or a posterior tracheal lesion in a cadaver model. It is also possible to reach the pleural cavity after a midline dorsal puncture, possibly resulting in pneumothorax. Finally, in our series, complications were associated with a difficult PDT procedure and the use of a fenestrated cannula.

A literature search (Table 1) showed that 1.4% of patients with a PDT acquired emphysema, and 0.8% of patients with a PDT had a pneumothorax. Although several mechanisms may explain the development of emphysema, it can only develop after an air leak occurring somewhere in the respiratory tract. Air then will track along the path of least resistance. As long as there exists a tracheal defect without a route for air to escape via the skin, air will track along subcutaneous tissue and fascial planes into the neck, face, pharynx, chest wall, mediastinum, and pleural cavity. By this mechanism, anterior tracheal wall lesions may cause subcutaneous emphysema. This may happen when positive pressure ventilation via the endotracheal tube is continued after PDT (and after the cuff of the tracheostomy cannula is insufflated) or by dislocation of the tracheostomy tube. Multiple punctures and excessive dilatation of the trachea during the proce-
Ciaglia and Graniero 1992 170 Subcutaneous emphysema (1.2%, n

Noden and Kirkpatrick 1995 Case report Pneumothorax (n

Friedman and Mayer 1993 100 Subcutaneous emphysema (4.0%, n

Fish 1996 Case report Tension pneumothorax (n

Hazard et al 1998 55 Subcutaneous emphysema (2.5%, n

Hinerman et al 2000 50 Pneumothorax (2%, n

Sun 1996 Case report Subcutaneous emphysema (n

Cole 1994 55 Subcutaneous emphysema (3.6%, n

Massick et al 2000 97 Pneumothorax (2.1%, n

Lin et al 2000 134 Pneumomediastinum (2.2%, n

Velmahos et al 2000 100 Cervical emphysema (4.0%, n

Ambesh et al 2002 60 Subcutaneous emphysema (5.0%, n

Byhahn et al 1996 Case report Subcutaneous emphysema (n

Escarment et al 2000 162 Subcutaneous emphysema (0.6%, n

Van Heurn et al 1996 150 Subcutaneous emphysema (1.3%, n

Cole 1994 55 Subcutaneous emphysema (3.6%, n

Friedman and Mayer 1993 100 Subcutaneous emphysema (4.0%, n

Ciaglia et al 1995 130 Subcutaneous emphysema (0.7%, n

Ivatury et al 1992 55 Subcutaneous emphysema (2.0%, n

Schachner et al 1989 80 Subcutaneous emphysema (2.5%, n

Hazard et al 1988 55 Subcutaneous emphysema (3.6%, n

Kaylie and Wax 2002 Case report Subcutaneous emphysema (n

Mostert and Stuart 2001 Case report Subcutaneous emphysema (n

Douglas and Flabouris 1999 Case report Cervical emphysema (n

Fraipont et al 1999 Case report Pneumoperitoneum (n

Malhander et al 1998 Case report Pneumothorax (n

Sun 1996 Case report Subcutaneous emphysema (n

Fish 1996 Case report Tension pneumothorax (n

Noden and Kirkpatrick 1995 Case report Pneumothorax (n

Wang et al 1992 Case report Pneumothorax (n

Table 1—Review of the Literature: Incidence of Emphysema and Pneumothorax After PDT and Causative Mechanisms

<table>
<thead>
<tr>
<th>Source</th>
<th>Patients, No.</th>
<th>Conditions Proposed Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambesh et al 2002</td>
<td>60</td>
<td>Subcutaneous emphysema (5.0%, n = 3) Transverse mucosal lacerations</td>
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<tr>
<td>Cantais et al 2002</td>
<td>53</td>
<td>Subcutaneous emphysema (1.9%, n = 1) Rupture of emphysematous bulla</td>
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<tr>
<td>Fikkers et al 2002</td>
<td>100 (55)</td>
<td>Subcutaneous emphysema (1.3%, n = 2) Lesion posterior tracheal wall</td>
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<tr>
<td>Fikkers et al 2002</td>
<td>171</td>
<td>Subcutaneous emphysema (1.8%, n = 3) See present article</td>
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<td>Byhahn et al 2000</td>
<td>50</td>
<td>Pneumothorax (2%, n = 1) Perforation of the posterior tracheal wall</td>
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<tr>
<td>Escarment et al 2000</td>
<td>162</td>
<td>Subcutaneous emphysema (0.6%, n = 1) Fartracheal placement of the tracheostomy tube</td>
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<tr>
<td>Hinerman et al 2000</td>
<td>50</td>
<td>Pneumothorax (2%, n = 1) Unclear; no signs of tracheal wall laceration</td>
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<td>Kearney et al 2000</td>
<td>824</td>
<td>Subcutaneous emphysema (0.2%, n = 2) Dislocation of tracheostomy tube</td>
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<tr>
<td>Lin et al 2000</td>
<td>134</td>
<td>Pneumomediastinum (2.2%, n = 3) Tear in posterolateral tracheal wall</td>
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<tr>
<td>Massick et al 2000</td>
<td>97</td>
<td>Pneumothorax (2.1%, n = 2) No explanation</td>
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<tr>
<td>Velmahos et al 2000</td>
<td>100</td>
<td>Cervical emphysema (4.0%, n = 4) Posterior tracheal wall damage and dislocation of cannula</td>
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<td>Moe et al 1999</td>
<td>130</td>
<td>Subcutaneous emphysema (0.7%, n = 1) No explanation</td>
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<td>Trottier et al 1999</td>
<td>24</td>
<td>Subcutaneous emphysema (12.5%, n = 3) Barotrauma due to high-frequency jet ventilation</td>
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<td>Walz et al 1998</td>
<td>337</td>
<td>Subcutaneous emphysema (0.9%, n = 3) Tear in posterior tracheal wall (same patients)</td>
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<td>van Heurn et al 1996</td>
<td>150</td>
<td>Subcutaneous emphysema (1.3%, n = 2) Mediastinal placement of the tracheostomy tube; reintubation not possible because of cervical emphysema; patient died</td>
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<tr>
<td>Cole 1994</td>
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<td>Subcutaneous emphysema (3.6%, n = 2) Multiple punctures of the trachea; tearing of the intercartilaginous tissue next to the cannula</td>
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<td>Friedman and Mayer 1993</td>
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<td>Subcutaneous emphysema (4.0%, n = 4) No explanation</td>
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<td>Subcutaneous emphysema (1.2%, n = 2) Difficulties in changing the tracheostomy tube</td>
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<td>Ivatury et al 1992</td>
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<td>Subcutaneous emphysema (2.0%, n = 1) High ventilatory pressures</td>
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<td>Schachner et al 1989</td>
<td>80</td>
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<td>Subcutaneous emphysema (3.6%, n = 2) Possibly perforation or tear in posterior tracheal wall</td>
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<td>Kaylie and Wax 2002</td>
<td>Case report</td>
<td>Subcutaneous emphysema (n = 1) Tear in posterior tracheal wall caused by tracheostomy tube introducer</td>
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<td>Mostert and Stuart 2001</td>
<td>Case report</td>
<td>Subcutaneous emphysema (n = 1) Fenestrated tube, extraluminal localization of the fenestration</td>
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<td>Douglas and Flabouris 1999</td>
<td>Case report</td>
<td>Cervical emphysema (n = 2) Laceration of posterior tracheal wall; damage by the tip of the tracheostomy tube introducer</td>
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<td>Fraipont et al 1999</td>
<td>Case report</td>
<td>Pneumoperitoneum (n = 1) Tear in posterior tracheal wall</td>
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<td>Malhander et al 1998</td>
<td>Case report</td>
<td>Pneumothorax (n = 2) Tear in posterior tracheal wall</td>
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<td>Sun 1996</td>
<td>Case report</td>
<td>Subcutaneous emphysema (n = 4) Air leaks into the cervical tissues during cannulation procedure</td>
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<tr>
<td>Fish 1996</td>
<td>Case report</td>
<td>Tension pneumothorax (n = 1) Tear in posterior tracheal wall</td>
</tr>
<tr>
<td>Noden and Kirkpatrick 1995</td>
<td>Case report</td>
<td>Pneumothorax (n = 1) Direct placement of tracheostomy tube in pleural cavity</td>
</tr>
<tr>
<td>Wang et al 1992</td>
<td>Case report</td>
<td>Pneumothorax (n = 2) Direct placement of tracheostomy tube in anterior mediastinum; perforation of posterolateral tracheal wall; placement of tube tip in tracheoesophageal groove</td>
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Dure will also increase the risk of peristomal air leakage through the anterior tracheal wall. Even in seemingly uncomplicated cases, extensive mucosal and cartilaginous damage may be present, with bidirectional mucosal tears beyond one tracheal ring flanking the stoma.43 Tears in the posterior tracheal wall can be caused by the tip of the loading catheter, if the guidewire and guiding catheter are not properly stabilized, allowing them to move along the posterior tracheal wall.17,18 During PDT using the
GWDF technique, the tip of the dilating forceps could damage the posterior tracheal wall. Finally, the use of a fenestrated cannula can cause subcutaneous emphysema, when the fenestration is wholly or partially located outside of the tracheal lumen, allowing air to leak through the fenestration into the pretracheal space.

Our findings suggest that the most important location of air leakage after PDT is through the anterior tracheal wall, although air leakage through a posterior tracheal wall perforation is also possible. We hypothesized that air leakage through a fenestrated cannula could be responsible for the development of subcutaneous emphysema. To test this hypothesis, we measured the air leak of the space between the nonfenestrated inner cannula and fenestrated outer cannula and found impressive and progressive air leakage with increasing ventilatory pressures. This narrow slit (0.13 mm) was enough to allow air to pass between the internal and external cannulas, and finally pass through the fenestration. Subcutaneous emphysema developed in a matter of minutes. We believe that, in patients who have a fenestrated cannula, the most important mechanism for development of emphysema is air leakage between the inner and outer cannula. Therefore, these cannulas should not be used primarily after PDT. It is clear from our experiments and from the literature that subcutaneous emphysema can also be caused by posterior tracheal wall laceration. Air finds its way along the trachea ventrally and thus causes subcutaneous emphysema in the neck and facial region, although a delay in the occurrence of subcutaneous emphysema was noted in our experiments.

Concerning the mechanism of pneumothorax after PDT, we found that even when puncturing the trachea in the midline, the tip of the needle can still puncture the lung. This can be explained by the fact that the pleural cavity is not limited to the lateral regions of the trachea, but extends around the lateral tracheal wall to the posterior tracheal wall. Because of the short distance between the dorsal tracheal wall and the pleural cavity, the lungs can easily be punctured during the PDT procedure, when the posterior tracheal wall is lacerated or punctured. The risk of puncturing the lung increases when the puncture site is lower. Moreover, in patients with COPD, the risk of puncturing a lung is higher because of a higher pleural dome. Another possible mechanism of pneumothorax after tracheal air leak might be the occurrence of pneumomediastinum followed by air leak through the mediastinal pleura.

In conclusion, emphysema and pneumothorax are relevant, but infrequent complications of PDT. Understanding the causative mechanisms will help in preventing these complications. Fenestrated cannulas should not be used immediately, but, if required, only after a week, when the tracheostomy wound has healed sufficiently. Avoiding perforation of the posterior tracheal wall can prevent pneumothorax. Bronchoscoppy is invaluable in this respect, as it may help to avoid puncture of the posterior tracheal wall.

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